Analysis of volcanic facies at the Chatree gold mine and in the Loei-Petchabun Volcanic belt, central Thailand

Grace V. Cumming BSc. University of Tasmania

University of Tasmania

Centre for Ore Deposit Research

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Chapter 1: Introduction

1.1 Significance and Aims

This thesis presents a detailed volcanological study of the Permo-Triassic rocks that host the low-sulphidation epithermal gold deposit at the Chatree mine in the Loei-Petchabun Volcanic belt, central Thailand. Rocks of similar age that lack appreciable mineralisation have also been studied in the surrounding Petchabun region and in the south of the belt (on Koh Chang Island). Using volcanic facies analysis combined with whole-rock geochemistry, this study seeks to better constrain the depositional setting, origin and style of the volcanism, and volcanic facies architecture at the Chatree epithermal deposit.

The aims of this project are:

1. to describe the lithologies in and around the Chatree mine, in the Petchabun Province, and Koh Chang Island and to group them into facies using observations made from drillcore, mine exposures, field outcrops and field samples,
2. to use geochemical and petrological data together with volcanic facies analysis to determine the tectonic setting and source characteristics,
3. to constrain the depositional environment and volcanic setting of the volcanic succession at the Chatree mine and to identify the sequence of eruptive events, and
4. to determine the position of hydrothermal alteration and mineralisation within the stratigraphy that host the Chatree deposit. In doing so, the relative timing of deposition of the volcanic units with respect to mineralisation is defined.

This study has significant importance to understanding the host volcanic rocks of the Chatree epithermal deposit. and elsewhere in the Loei–Petchabun Volcanic belt (LVb). To date, there has been no detailed volcanological investigation in the region.

1.2 Location and Access

Very little rock is exposed in southern and central Thailand. Thailand has low lying topography and a deeply weathered land surface. The area at the Chatree mine occurs along a drainage divide between the Pitchit and Phitsanoluk/Petchabun Provinces and is characterised by a thick layer of (average 5m) laterite. The climate of the area is characterised by a seasonal tropical monsoon from March to May and a dry season from

November to February. The sparse rock outcrop means that assessment of the volcanic facies is best done the aid of through drill core.

Location and access to the Chatree mine

The Chatree gold mine is located approximately 27 km north of the small town of Khao Sai (situated at the intersection of highways 11 and 113), in the Petchabun Province of central Thailand, 280 km north-north east of Bangkok (Figure 1.1). The Chatree mine lease covers a 3 km by 5 km area. Current mining activity is focused on several mineralised veins, referred to as the C and H and D lenses. Two prospects are also covered by the mining lease; i.e., Prospect A covers the western side of Khao Mo, a small hill rising 100m above the neighbouring agricultural land. Prospect K, which is also not being mined, occurs on the flanks of Khao Mo. The open cut mines provided good exposures of the lithological units, however this study is based predominantly on the analysis of drill core (which was assessed from all mined ore lenses and established prospects).

Location and access to outcrop in the Petchabun region

Outcrop was also assessed in the Petchabun area (Figure 1.1). These outcrops were located on road cuttings, small mine workings, on hill tops and in agricultural areas. Access to outcrop was via sealed and unsealed roads using a four wheel drive vehicle. A Thai and English speaking government geologist (Somboon Koshitanont) helped to enable entrance onto private land. Access to outcrops was improved by burn-offs carried out by the local farmers, field site locations are included in Chapter 5. Outcrop was also briefly visited in other regions of the LVb in the vicinity of Sara Buri, Wichian Buri and Khao Sap Noi (Figure 1.2). At these locations, outcrop was assessed at road cuttings along major roads.

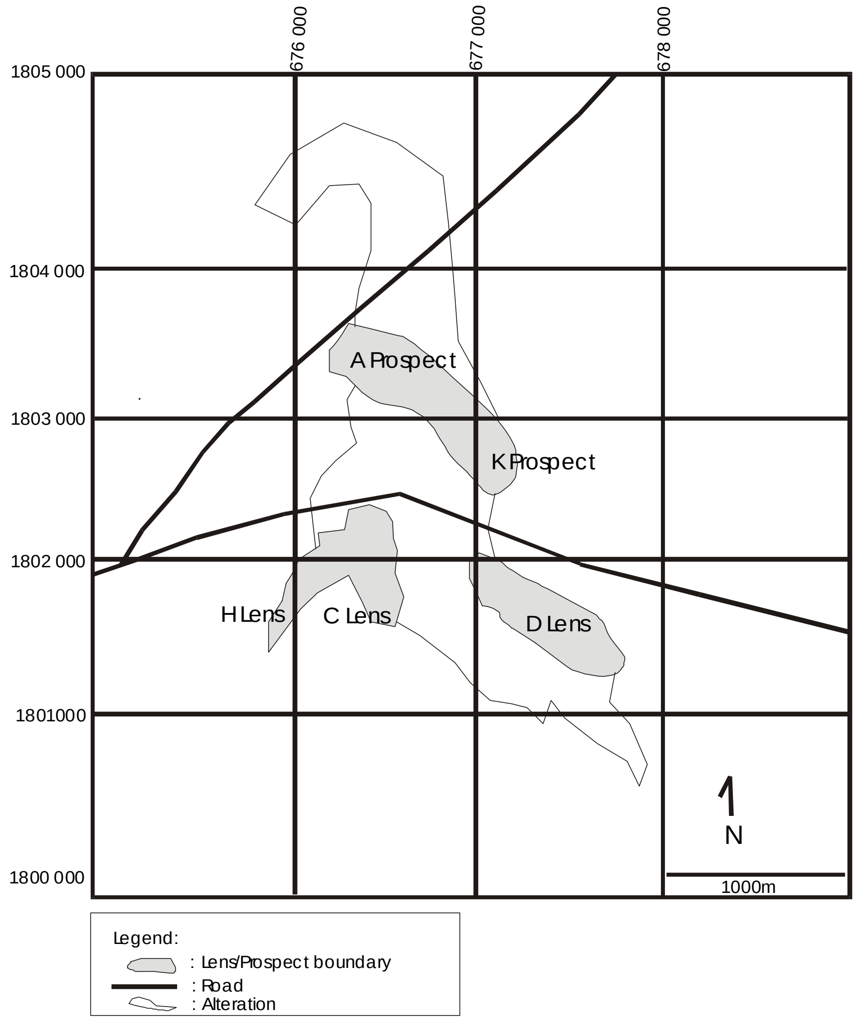

Figure 1.1 *Layout of the Chatree mine site (modified from Diemar & Diemar, 1999)*

Koh Chang Island

Koh Chang Island is a national park located 260 km southeast of Bangkok and 40 km west of the Cambodian border. Access to the island is by a 30 minute ferry ride. Outcrop is obscured by thick vegetation, and outcrop exposures were limited to and assessed at road cuttings, land-fill sites, water falls and along the coast.

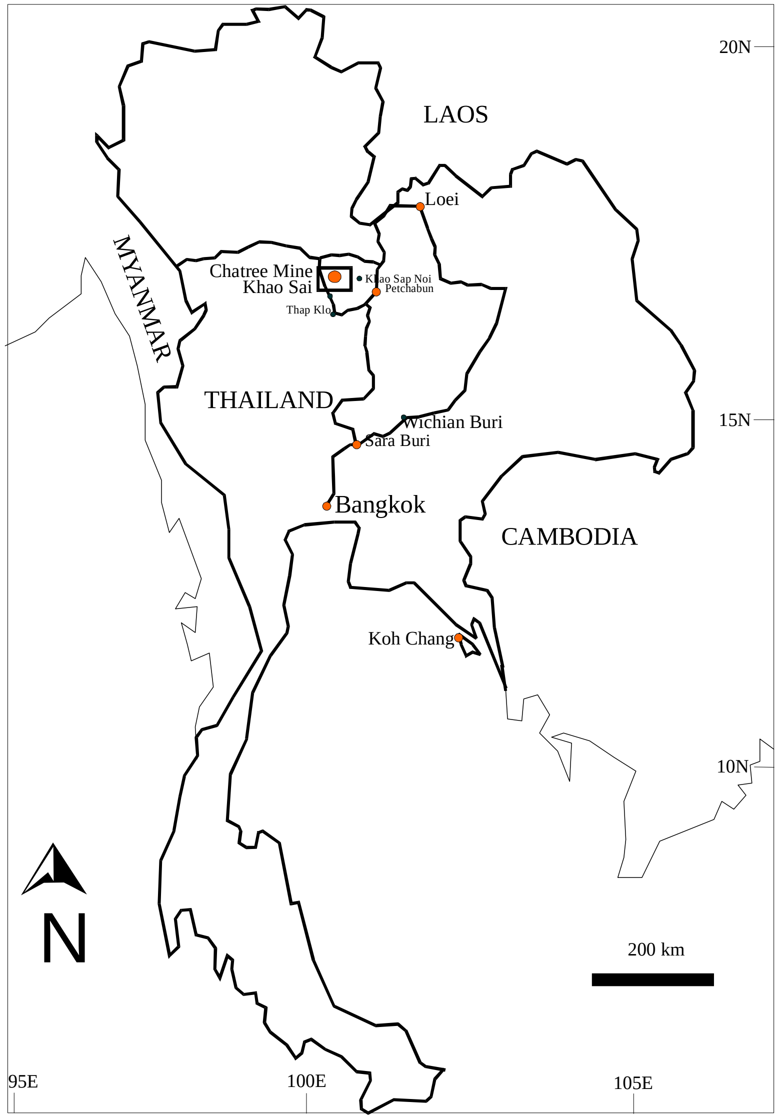

Figure 1.2 *Map of Thailand showing the location of study areas and locations mentioned in the text (Dedenczuk, 1998)*

1.3 Methods

Core from 18 drill holes sampled and logged. In order to obtain the best possible understanding of the volcanic facies architecture at the Chatree mine, the least altered cores were chosen from each prospect. This enured that the original volcanic textures were preserved. The main methods for assessment include;

1. Logging of drill core selected from all available prospects (the widest area possible) within the mine site.

2. The collection of 180 samples from drill core and outcrop at the Chatree mine, Petchabun region and Koh Chang Island. These were assessed for components, textures and petrography using thin sections and slabs
3. Using the geochemical technique know as X-ray Fluorescence (XRF) to determine trace and major element characteristics.

1.4 Previous Work

The character of mineralisation and alteration of the Loei Volcanic belt, tectonic setting of Thailand and geochemical characteristics have been studied by Gatinsky (1978), Bunopas (1991), Bunopas & Vella (1983), Hutchinson (1989), Barr & McDonald (1991), Jungyasuk and Khoshitanont (1992), and Intasopa (1993).

Gatinsky (1978), Bunopas (1991) and Bunopas and Vella (1983) clarified the geologic history of Thailand using plate tectonic models. They concluded that Thailand consists of two separate micro-continents; the Shan-Thai and the Indochina Terranes, which were cratonic fragments of Gondwana in the Precambrian to Lower Palaeozoic. During the Middle Palaeozoic to Lower Triassic, Shan-Thai and Indochina rifted into the Palaeo-Tethys Ocean. These terranes then moved closer together until later suturing occurred. Barr and McDonald (1991) used the idea of tectonostratigraphic terranes to determine an early Mesozoic tectonic model for Thailand. They proposed the existence of a fold belt; the so-called Sukhothai fold belt, separating the Shan-Thai and the Indosinian (Indochina) terranes. These blocks have sutured together along the Nan-Uttaradit-Sa Kaeo suture (Nan suture).

More detailed analysis of available geology & the tectonic evolution of Thailand were given by Mitchell (1981), Stauffer (1983), Audrey-Charles (1983, 1988), Sengor (1984, 1988), Chausiri (1989), Burrett (1990), and Metcalfe (1996). Metcalfe (1996) proposed that the Indochina and Shan-Thai Terranes rifted and separated from Gondwana during three episodes; the Devonian, the Late-Early Permian and the Late Triassic- Late Jurassic. During this rifting, the Tethyan ocean basins opened. Metcalfe (1997) proposed that the various terranes of Southeast Asia are bounded by suture zones that represent the remnants of various Tethyan basins or by strike slip faults. The Shan-Thai and Indochina are believed to have been separated by the Palaeo-Tethys Ocean, which opened in the Mid-Late Devonian and closed during the Triassic.

Aspects of the geochemical affinities of volcanic rocks in the LVb through time were addressed by Intasopa (1993). Her study confirmed that parts of the belt formed at a convergent margin, and related volcanism is linked to multiple subduction events. Geochemical work reveals that parts of the belt are related to continent-oceanic crust collision and some parts are linked to an oceanic volcanic arc type setting.

Dedenczuk (1998) undertook an honours project on the geology, mineralogy, geochemistry of the mineralised rocks at prospects A and D at the Chatree mine. Greener (1999) also undertook an honours thesis documenting the alteration and mineralisation at prospects C and H at the Chatree gold mine. Numerous industry consultants have also worked at Chatree. Barron (1998) undertook detailed petrographic investigations, paying particular attention to the mineralogy of the rocks.

A limited volcanological study has been undertaken at Chatree by an industry consultant, Chris Stevens (2003). His work found that the palaeo-environment is consistent with two settings; an intermediate volcanic terrane, possibly within the ring plain of an active strato-volcano, and an area of low sediment input containing abundant vegetal matter such as a swamp or lacustrine environment marginal to an andesite complex. He also suggested a marginal marine environment based on the presence of marine fossils found in A Prospect.

No volcaonological assessment of Koh Chang Island has been undertaken and the setting, nature of volcanism and relationship to the Loei-Petchabun Volcanic belt has not been determined.

Chapter 2: Regional Geology

2.1 Introduction

This chapter summarises the regional geology of Thailand (Figure 2.1) paying particular attention to the tectonic evolution and timing of volcanism in the Loei-Petchabun Volcanic belt (LVb).

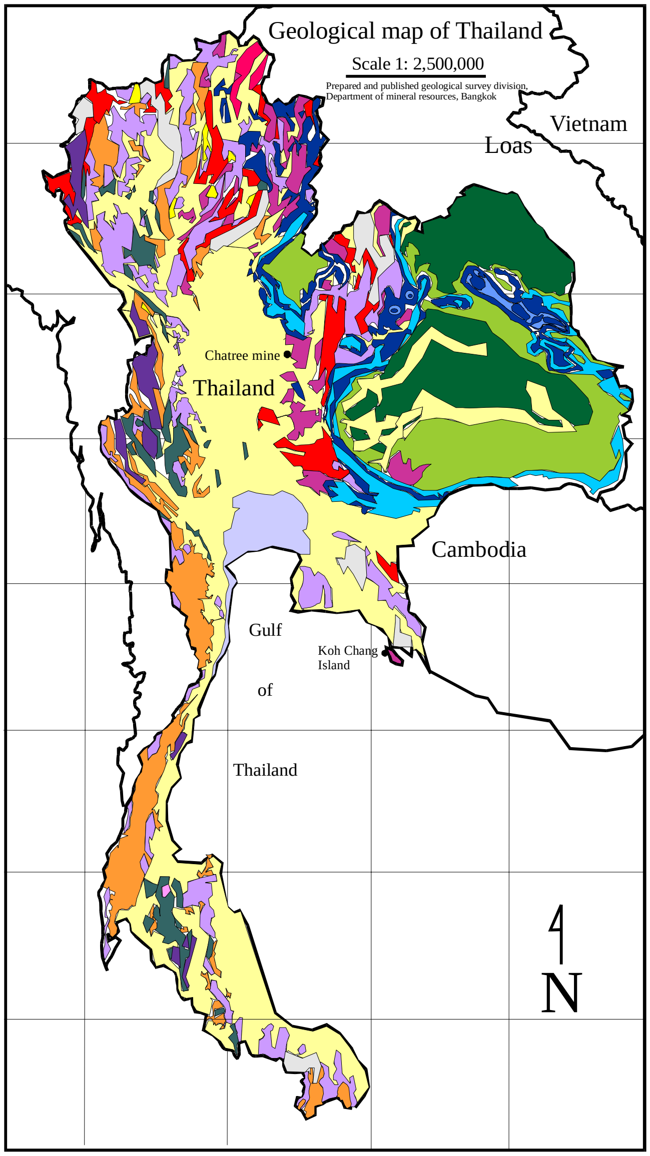

Figure 2.1 *Summary Geological Map of Thailand (after DMR, 1999). The Loei-Petchabun volcanic belt extends from central north Thailand to the Gulf of Thailand (refer to legend in figure 2.2)*

AGE	Legend Sedimenatry and metamorphic rocks
QUARTERNARY	Fluvial deposits: Flood plain, alluvium, terrace and colluvium
TERTIARY	Mae Moh Group and Krabi group: semiconsolidated, consolidated rocks and coal beds
CRETACEOUS	Sandstone and mudstone
	Arkosic sandstone, conglomerate and shale
JURASSIC	Conglomerate,sandstone, shale and mudstone
TRIASSIC	Umpang Group: mudstone, siltstone, sandstone and limestone
	Lampang Group: mudstone, limestone, sandstone, siltstone and conglomerate
PERMIAN	Ratburi Group: limestone, dolomitic limestone, chert and dolomite
	Saraburi group; limestone, chert, basalt, ultramafic and serpentinite
CARBONIFEROUS	Conglomerate, sandstone, shale, slate, chert and limestone
DEVONIAN	
SILURIAN	
ORDOVICIAN	Thung Song Group: Argillaceous limestone, limestone, dolomitic limetsone, marble and shale
CAMBRIAN	Tarutao Group: sandstone, quartzite, shale, and conglomerate
PRE-CAMBRIAN	

IGNEOUS ROCKS	AGE
Rhyolite, andesite and tuff	Createaceous to Permian
Granite	

Figure 2.2 *Legend for geological map of Thailand from figure 2.1 (DMR, 1999)*

2.2 Tectonic evolution of Thailand

Thailand covers two micro-continents, referred to as the Indochina and Shan-Thai terranes (figure 2.3). The Indochina Terrane consists of Eastern Thailand, Laos, Cambodia and parts of Vietnam (Bunopas, 1983). The Shan-Thai Terrane comprises eastern Myanmar, western Thailand, the western Malaysian peninsula and northern Sumatra. Both terranes had their origins along the northern margin of Gondwana (i.e., north-western Australia) during the lower Palaeozoic (Sengor, 1984; Burrett and Stait, 1986; 1990).

Rocks of the Shan-Thai Terrane principally consist of Precambrian granitoids, ortho- and para-gneisses overlain by Palaeozoic and Mesozoic sedimentary rocks. Carboniferous to Cretaceous granitoids intrude these rocks. The Indochina Terrane comprises Middle Palaeozoic rocks and Permian platform carbonate and deep water clastic sedimentary rocks, and volcanic and volcaniclastics of Permo-Triassic age. This terrane was intruded by Triassic to Cretaceous granitoids. Covering most of the Indochina Terrane are Mesozoic are the red-beds of the Khorat Group.

These terranes were sutured together after the closure of the Palaeo-Tethys sometime during the Triassic (Metcalfe, 1996) and are joined together along the Nan Suture (Bunopas, 1981).

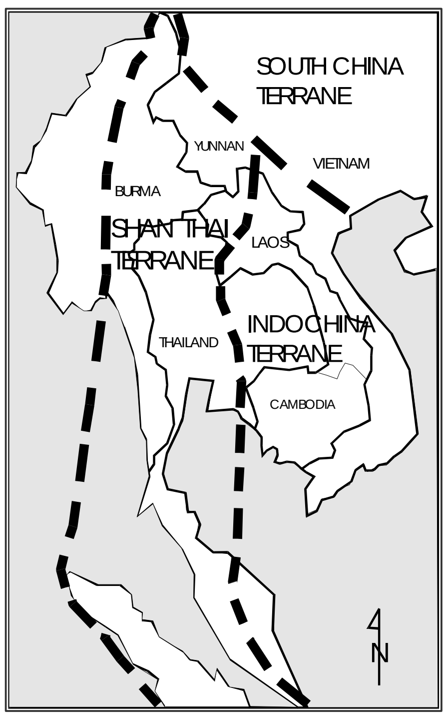

Figure 2.3 *Positions of the Shan-Thai, Indochina and South China Terranes. (modified from Bunopas, 1993)*

The Precambrian basement of the Shan-Thai Terrane is composed of metamorphic basement rocks derived from north western Australia. In the Carboniferous, the terrane rifted off from the Australian Craton and migrated northwards into the Palaeo-Tethys (Bunopas, 1981). In the Permian, Shan-Thai moved towards lower latitudes where carbonate platform sediments were deposited. In the Triassic there was westward subduction of oceanic floor beneath the Shan Thai Terrane followed by flysch and arc type sedimentation (Figure 2.4).

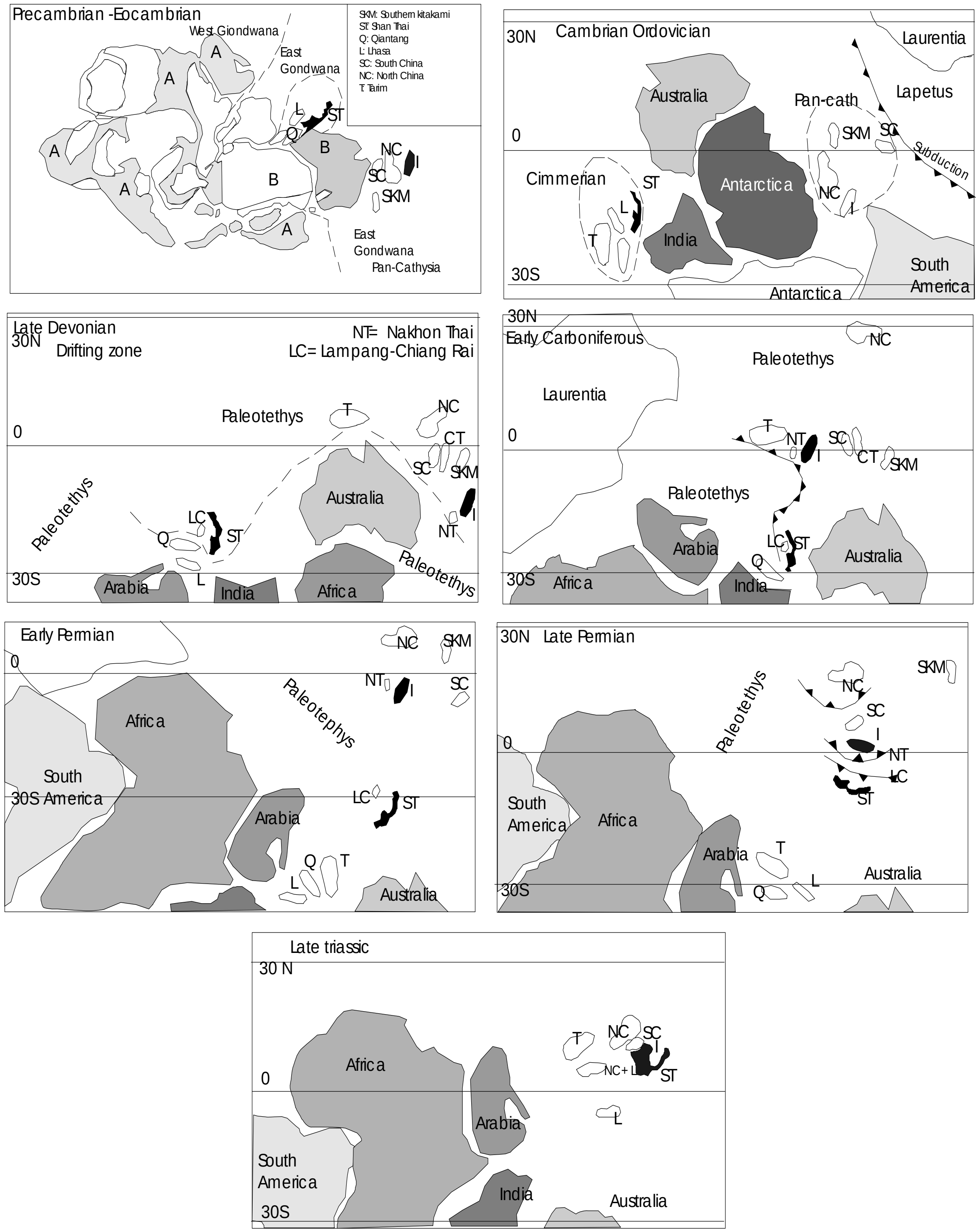

__Figure 2.4__ Paleo-geographical distribution of Shan-Thai (ST), Indochina (I), Lampang-Chiang Rai(LC) and Nakhon Thai (NT) plates in comparison with other tectonic plates (Chausiri et al., 2002)

Several researchers consider this event to have occurred prior to its collision with Indochina (Bunopas and Vella; 1978; Chantaramee; 1978, Asnachinda; 1978, Bunopas; 1981, Sengor; 1984, Barr and Macdonald; 1987, and Hayashi; 1989) due to the distribution of Silurian–Devonian and Permian–Early Triassic volcanics (LVb) in central north Thailand.

The timing of their collision and the way these terranes amalgamated is contentious (Bunopas 1981; Helmcke, 1986, Chaodumrong, 1992). It is largely believed the closure of the Palaeo-Tethys and suturing between the two terranes was completed by the Late Triassic (Bunopas, 1981 and Chaodumrong, 1992). Some authors, namely Bunopas, (1981), Chaodumrong, (1992) suggest that the Shan-Thai Terranes began to collide with the Indochina Terrane during the late Permian (figure 2.3). Voluminous granites were emplaced along eastern and central belts within the LVb after the collision.

The LVb belt is thought to form through subduction of oceanic crust beneath the Indochina crust between the Silurian and Triassic. However, recent studies by Chausiri (2001) have proposed that an oceanic volcanic arc developed in the Early Cambrian to Early Triassic between the Shan-Thai and Indochina Terranes. These arc complexes are termed the Nakhon-Thai Volcanic Arc and Lampang-Chaing Rai Volcanic Arc and are thought to have formed before the collision between the Shan-Thai and Indochina Terranes (Chausiri, 2001),(figure 3).

During the Cainozoic, after the collision of the Shan -Thai and Indochina Terranes, most of the tectonic features of Thailand were caused from the India–Eurasia collision. The consequent rotation & uplift of the Southeast Asian crustal block resulted in a series of extensional basins extending from the Gulf of Thailand to the South China Sea (Harder, 1991). Evidence for this Cainozoic collision in Thailand is preserved as N-S normal faults and NW-SE trending fault zones and NNE-SSW strike slip faults (Diemar and Diemar, 1999).

2.3 Age, Geochemistry and Petrogenesis of the Loei volcanic belt

There has been four main periods of magmatic activity and tectonic growth during the geological evolution of Thailand. These major events will be considered in relation to their age, geochemical affinities and petrogenesis. These events preluded and are associated with the generation of the Loei-Petchabun-Volcanic belt. The major tectonic/magmatic events include:

1. Precambrian to Early Cambrian: Cratonisation of the Shan-Thai and Indochina Terrane.
2. Early Cambrian to Early Triassic: Island Arc magmatism at the margin of Shan-Thai and/or possible development of the Nakhon-Thai Volcanic Arc (OIA) and Lampang- Chaing Rai Volcanic Arc between Shan Thai and Indochina Terranes, rifting between these Terranes and concurrent oceanic subduction possibly generating the Loei volcanics in the LVb (Chausiri, 2001).
3. Middle Triassic to Miocene: underthrusting of the Indochina Terrane under the Shan-Thai Terrane followed by generation and emplacement of S-and I-types granites and consecutive uplift (Intasopa, 1993).
4. Miocene to Recent: Collision of India with Asia, uplift and erosion followed by the eruption of basalts and rhyolites.

During the Precambrian to Early Cambrian cratonisation of the Shan-Thai and Indochina Terranes occurred. The Indochina Terrane has been isotopically dated by Hutchison (1989) as 2,300 Ma. U-Pb dating of zircons from granites from NE Thailand has yielded a lower intercept age of 200-240 Ma and an upper intercept age of 1,400-2000 Ma indicating that granites may have intruded these Precambrian terranes in the Triassic (Intasopa, 1993).

The Nakhon-Thai Volcanic Arc developed between the Early Cambrian to Early Triassic. Correlation with Palaeomagnetic data indicates that the Nakhon Thai arc was close to the palaeo-equator during the Carboniferous to Early Triassic (Chausiri et al., 2001). The Lampang- Chiang Rai Volcanic Arc is associated with the Shan-Thai Terrane and occurred at lower palaeo-latitudes during the Carboniferous. Bunopas (1981) and Intasopa (1993) and have proposed that rifting between these terranes and Late Palaeozoic subduction generated and the volcanics preserved in the LVb during several magmatic episodes (between the Middle Devonian to the Late Tertiary).

Intasopa (1993) concluded that the volcanic rocks in the LVb were not formed contemporaneously as a single magmatic cycle but were a consequence of three periods of volcanic activity, this was based on Rb-Sr isochron ages and $^{40}Ar/^{39}Ar$ ages. These magmatic events occurred during the Late Devonian to Early Carboniferous, Middle Triassic and Tertiary.

The earliest (Late Devonian to Early Carboniferous) volcanic rocks were produced in two episodes. The first involved the eruption of ocean floor tholeiitic basalts and spilites, the second involved the eruption of rhyolites derived through partial melting of a less evolved continental crust east of the LVb (Intasopa, 1993). The generation of andesite, basaltic andesite and basalts in the Petchabun area (central LVb) occurred in the Triassic (Intasopa, 1993). Absolute $^{40}Ar/^{39}Ar$ ages of hornblende indicate that eruption occurred between 238 ± 4 and 237 ± 12 Ma. These magmas are LILE enriched and HFSE depleted. Intasopa (1993) suggests that the Sr, Nd and Pb isotopic signatures indicate derivation from an enriched mantle source. Furthermore, isotopic studies of the Petchabun magmas suggest interaction with slab-derived fluids/melts generated by dehydration of the subducted components (oceanic basalt and sediment). The available geochronology (including Rb/Sr $^{40}Ar/^{39}Ar$ geochronologic data) across the belt are shown in Figure 2.5.

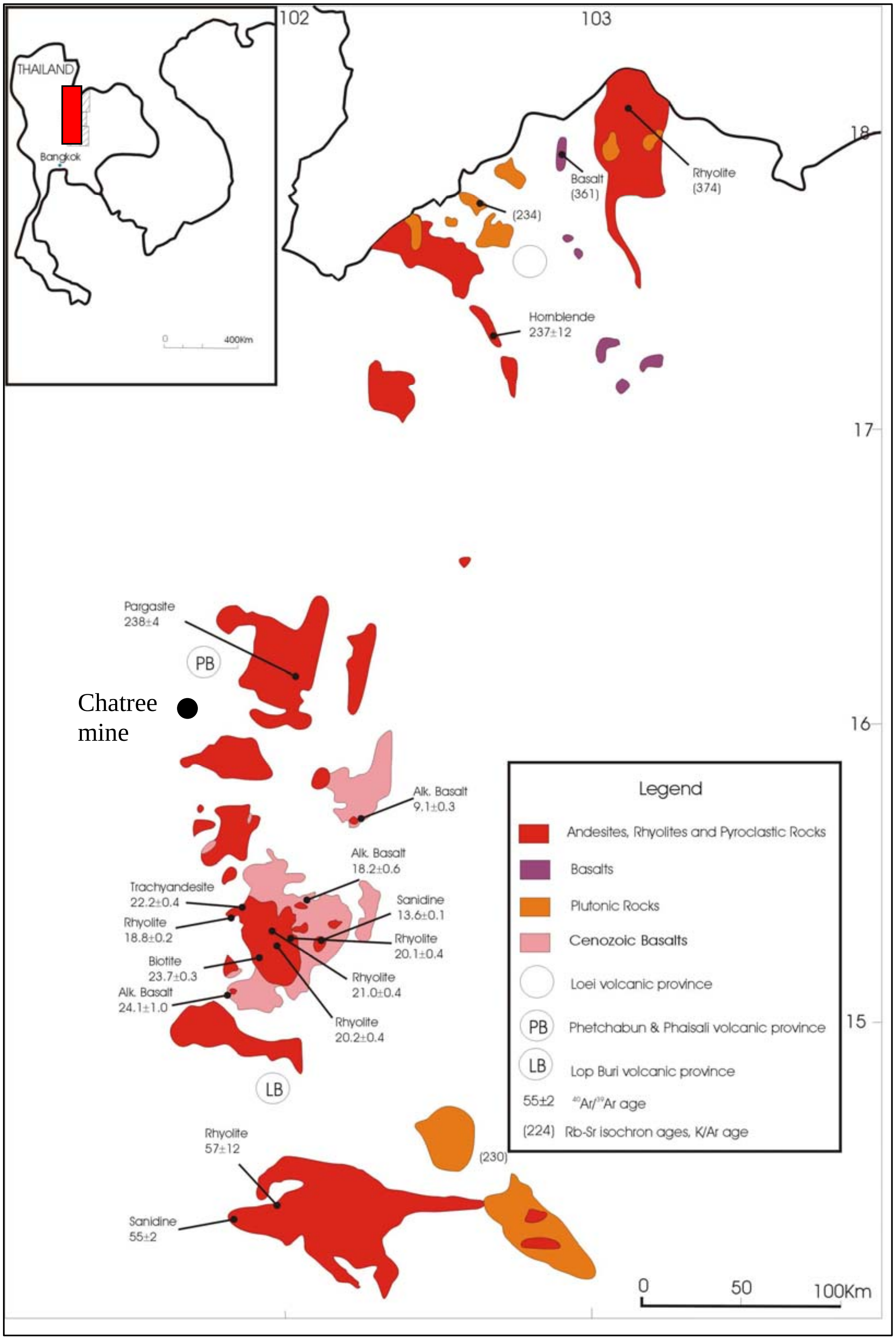

Figure 2.5 *Age of units within the Loei Petchabun Volcanic belt (Intasopa,, 1993)*

The volcanic rocks in central part of the LVb have undergone low grade (Green schist) metamorphism and alteration due to the highly altered nature of the rocks at the Chatree mine, highly mobile elements cannot be used to classify the volcanics here. Dedenczuk (1998) classifies these rocks as sub alkali based on Ti/Y-Nb/Y and Zr (P_2O_5 x 10 000) against wt% TiO_2 or Nb/Y. Dedenczuk (1998) and Intasopa (1992) also detected clinopyroxene – olivine fractionation trends. Decreasing Fe and Mg and increasing levels of Al suggests they were water saturated plagioclase free melts typical of an island arc setting. Dedenczuk (1998) plotted his samples into the field for oceanic or Island arc basalts. On further analysis during this study (involving re-plotting Dedenczuks data), the samples fall in the field for continental arc setting (Chapter 6).

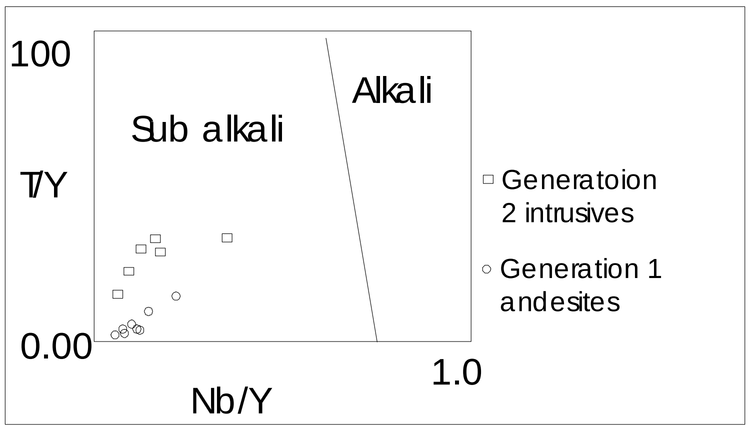

Figure 2.6 *The Ti/Y-Nb/Y discrimination diagram for basalts shows that the Petchabun rocks fall in the Sub alkali field (after Dedenczuk, 1998).*

After the generation of the LVb there were multiple episodes of collision and suturing of all tectonic blocks in the Middle Triassic to Miocene and generation of I and S type granite belts.

During the Miocene (to recent) basalts in the Lop Buri area (south of Petchabun) were generated in the LVb. $^{40}Ar/^{39}Ar$ ages reveal that several volcanic eruption episodes occured between 55 Ma and 9 Ma. Based on trace element data and isotopic signatures (using the Sr^{67}/Sr^{68} method) the Lop Buri basalts are interpreted as being derived from low degrees of partial melting of a an un-depleted sub-continental lithospheric mantle source (Intasopa, 1993). The basalts in the Lop Buri area have generated in response to continental extension as a result of the collision between the Indian and Eurasion plates over the last 55 Ma (Intasopa, 1993).

2.4 Local Geology of Petchabun, Central Loei Volcanic belt

The geology of the Petchabun area (refer to figure 2.7) consists of a sequence of Permian sedimentary rocks, Mesozoic non-marine sandstones, shales and limestone and conglomerates (Intasopa 1993). These are intruded by volcanic suites of rhyolite, dacite, andesite and basaltic andesites and their pyroclastic equivalents and are intruded by less abundant granite and diorite (Diemar and Diemar, 1999).

Calcareous sedimentary units consist of locally metamorphosed limestone which is overlain by the upper Carboniferous – Permian unit of metamorphosed tuffaceous sandstone, shale, conglomerate and chert of the Sara Buri Group (Jungyasuk et al., 1983).

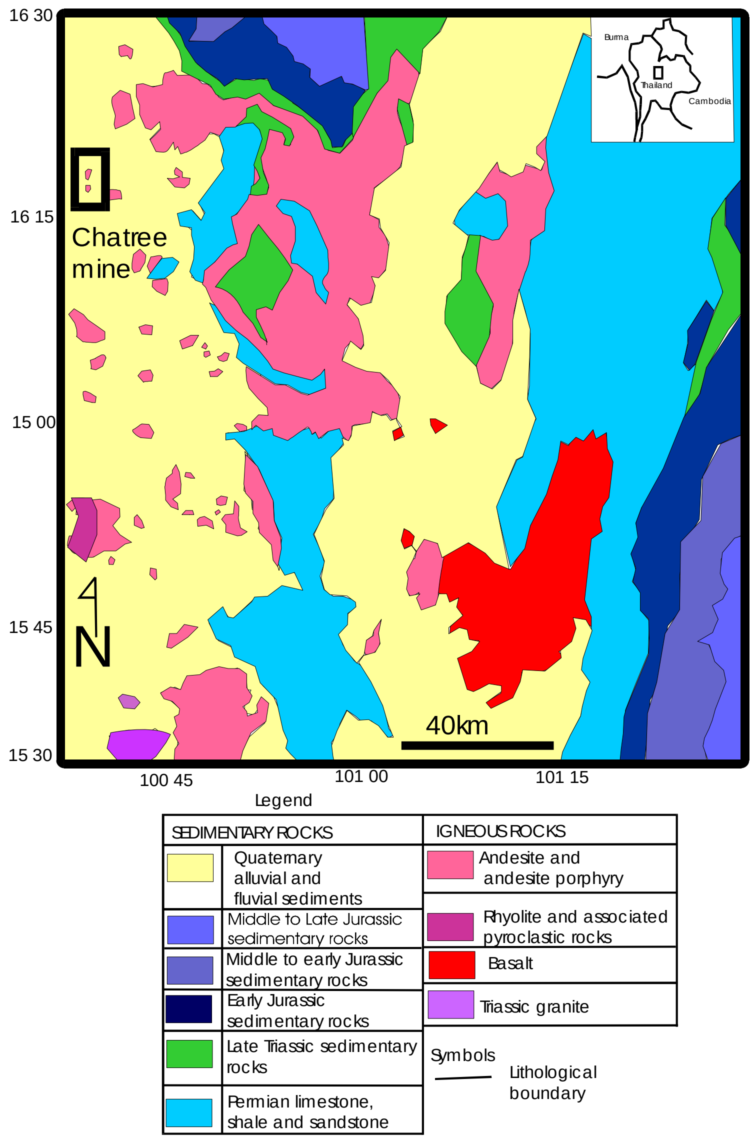

***Figure 2.7** Geology of the Petchabun area (modified from Intasopa, 1993)*

The dominant structural features in the Petchabun (Khao Sai areas) are north-south, north-west and north-east trending regional scale faults which are interpreted to be associated with the collision of the Shan-Thai and Indochina Terranes and subsequent uplift (Diemar and Diemar, 1999).

2.5 Local geology of the Chatree mine

Dedenczuk (1998) and Greener (1999) documented basic observations about the volcanic facies at the Chatree mine. Their work and further division during the production of this thesis has divided the volcanic facies at the Chatree mine into three facies groups that comprise a total of eleven litho-stratigraphic units. The three facies groups include, Non-volcanogenic sedimentary facies, volcanogenic sedimentary facies & coherent facies (Chapter 3).

The volcanic and volcaniclastic sequences are thought to have been deposited near a marine aerial interface due to the occurrence of both shallow marine faunal assemblages and accretionary lapilli (Barron, 1995).

The volcanic facies have undergone multiple phases of alteration. Five separate vein stages occur (Diemar & Diemar, 1999). The early vein mineralogy is dominated by quartz, calcite, adularia and pyrite and later vein mineralogy is composed of illite-smectite, pyrite, quartz and calcite. The major ore lenses are hosted in structures striking 350 degrees and dipping 40 degrees to the west (Diemar & Diemar, 1999).

The volcaniclastics of the Chatree mine dip between 10 & 30 degrees suggesting open folding or tilting of structural blocks in the sequence (Diemar & Diemar, 1999). North-west and north-east striking transform faults have been reactivated offsetting the stratigraphy. Faulting is thought to be related to extension and opening of the Chao Phraya basin in the Tertiary (Diemar and Diemar, 1999).

2.6 Styles of volcanism and volcano types

Preliminary studies of the volcanic rocks at the Chatree mine and the Petchabun area suggest that eruption of the andesite was from a centre nearby. This inference was based on the angular nature of the clasts (Dedenczuk, 1998 & Greener, 1999).

Rutter (1996) made several inferences on the volcano types in the area based from airborne magnetics. From the airborne magnetic images Rutter (1996) interpreted two semi-circular structural features with diameters of 20-30km in the vicinity of the Chatree mine. These were interpreted as caldera rims (see figure 2.8)

The andesitic units at Khao Sai are assumed to be emplaced through an effusive eruption style from a composite andesite volcano (Stephens, 2003) and the pumice breccias have been emplaced through explosive eruption processes from a felsic caldera forming eruption (chapter 3) (Stephens, 2003).

The lack of understanding on the styles of volcanism and nature of volcanoes in the LVb highlights the importance of this study, and for further studies in the area.

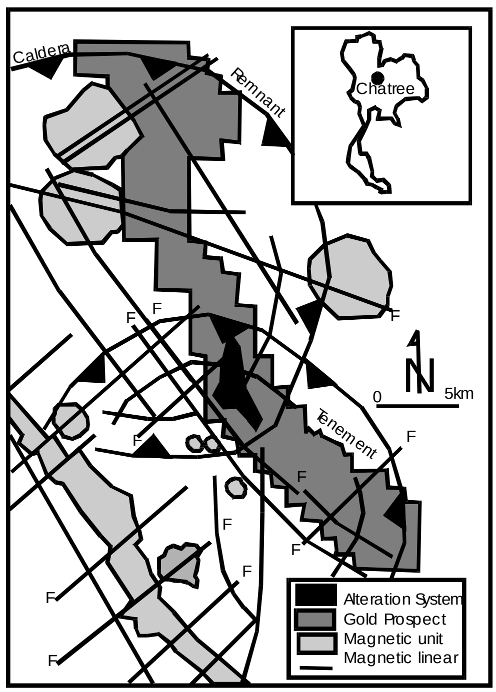

Figure 2.9. *Map or form-lines depicting caldera rim structures from aeromagnetic interpretation (Diemar and Diemar, 1999)*

2.7 Regional Geology of Koh Chang Island

Boonkanpai and Saengsrichan (2004) produced a 1: 50,000 scale geological map of Koh Chang Island. They recorded sedimentary rocks including grey siltstone, sandstone, mudstone and shale (Figure 2.9). These sedimentary rocks are thought to have been deposited in the Triassic based from faunal assemblages. Igneous rocks were grouped several broad categories; ‘rhyolite, andesite, rhyolite porphyry, rhyolitic tuff, andesitic tuff and welded tuff'. Further assessment showed that the flow banded spherulitic rhyolite is the dominant volcanic facies type and diorite outcrops in the southern part of the Island. No other assessment of the regional geology has been undertaken.

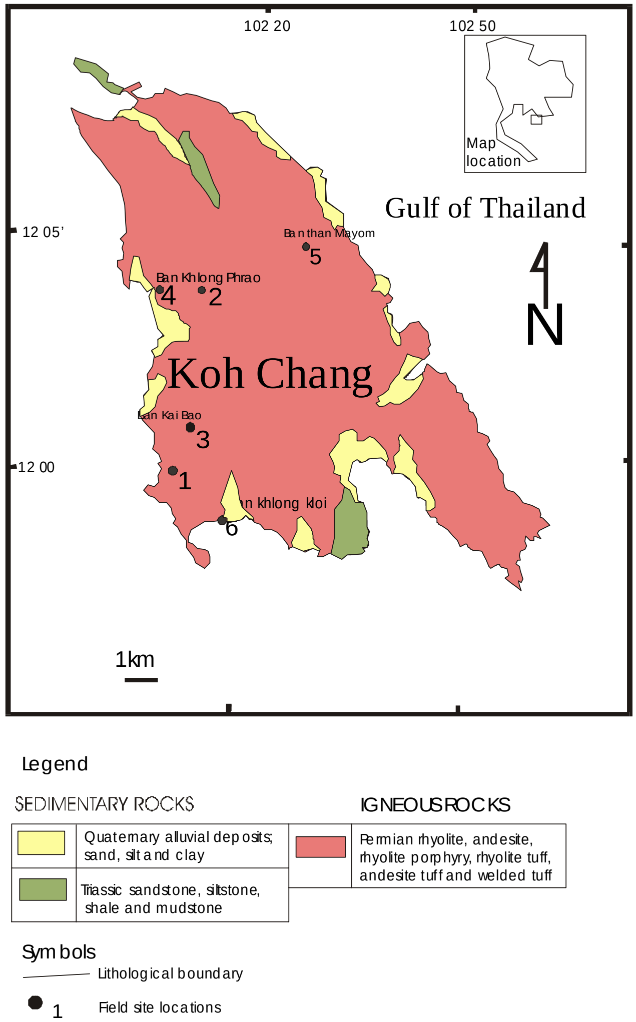

Figure 2.9 *Geological map of Koh Chang Island with locations of outcrop assessed on the Island (modified from Boonkanpai and Saengsrichan (2004).*

2.8 Summary

Thailand is composed of the Shan-Thai and the Indochina Terranes. The LVb was generated during three possible magmatic intervals during the Triassic including one that produced the Permo-Triassic volcanic rocks of the LVb, which are a focus of this study.

The magmatic episodes occurred during and after the closure of a Palaeo- Tethys Oceanic basin which once occurred between the Shan-Thai and the Indochina Terrane (Intasopa,1993; Sithiwathorn,1993).

The LVb volcanic rocks have possibly formed through the subduction of oceanic crust beneath the Indochina Terrane. It is possible that Oceanic arc type systems occurred between the Shan-Thai & Indochina Terrane (Figure 2.10)

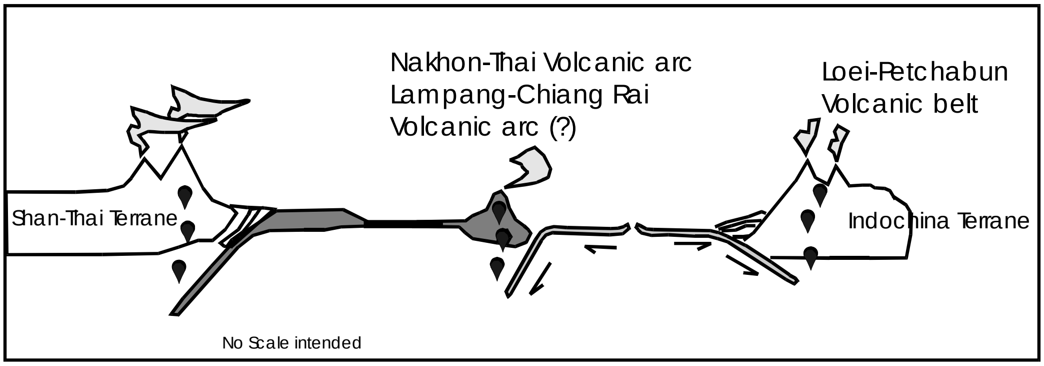

Figure 2.10. *Schematic diagram showing the proposed theories of Intasopa (1993) and Chausiri (2002),*

Chapter 3 : Lithological Facies Divisions of Chatree mine

3.1 General overview

The volcanic facies at the Chatree mine are dominated by thick successions of *polymictic andesitic lithic breccias* which are underlain by a *silicified pumice breccia* and overlain by *feldspar-phyric pumice breccia*. Minor sedimentary facies include a *volcanogenic sandstone*, laminated and commonly carbonaceous siltstone and thinly bedded *limestone*. The succession includes andesitic sills and late-stage andesitic, xenolithic basalt and andesite dykes. The succession is also cross cut by mineralised veins and effected by pervasive hydrothermal alteration.

This chapter describes the facies divisions and units associated with the three major subgroups found in the field area at the Chatree mine based from drillcore and analysis and field outcrops (Figure 3.1 shows the locations of drillcore within the mine lease). The subgroups are non-volcanogenic sedimentary facies, volcanogenic sedimentary facies, and coherent facies.

This Chapter discusses:

1. the stratigraphy of the Chatree mine,
2. the individual facies at the Chatree mine in terms of their geometry, lithology ; composition (primary constituents) , lithofacies and sedimentary structures, textures (grainsize, sorting and shape) , alteration and contact relationships, and
3. the transport and emplacement mechanisms of each facies.

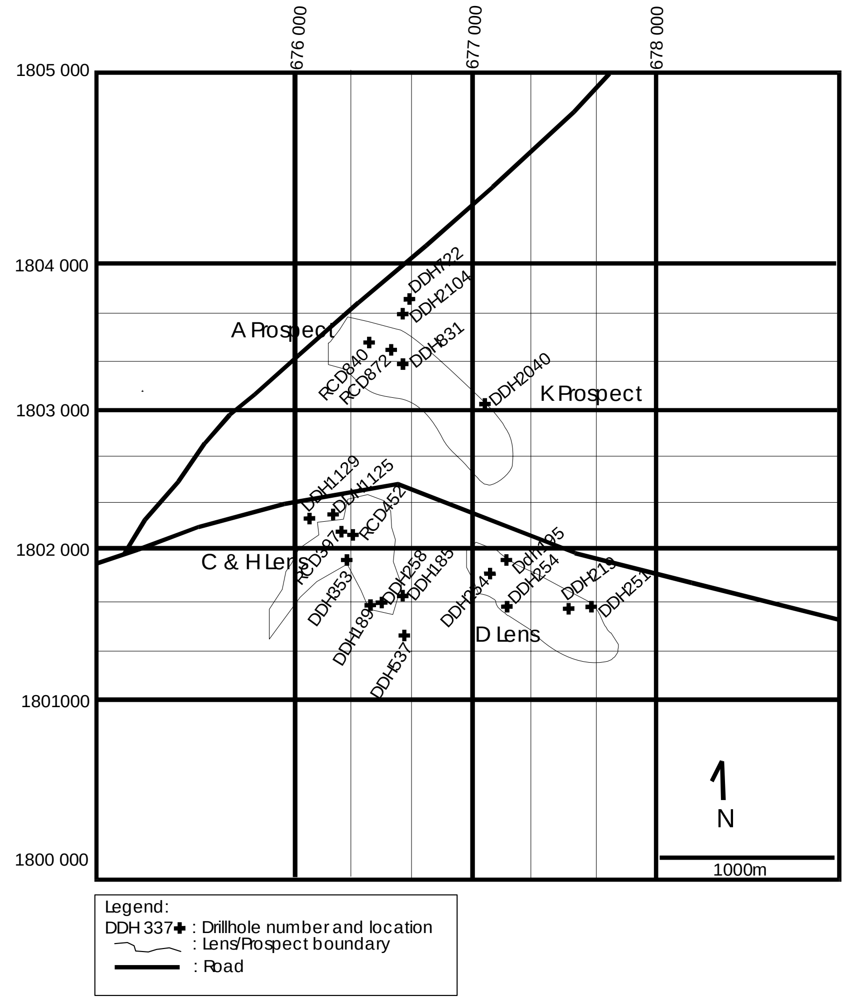

Figure 3.1. *Mine layout and locations of drillcore holes at the Chatree mine, Khao Sai (Diemar & Diemar 2000)*

3.2 Stratigraphy of the Chatree mine

The volcanic facies at the Chatree mine consists of a highly silicified pumice breccia at the base which grades into a thick beds of polymictic andesitic lithic breccia. Minor sedimentary facies are associated with the polymictic lithic breccia facies. These sedimentary facies include a volcanogenic sandstone, laminated and commonly carbonaceous siltstone and thinly bedded limestone.

Coherent facies occur along with the polymictic lithic breccia facies and have been further divided into two groups. One group include coherent facies that are typically conformable with sedimentary bedding & a second group cross cuts bedding. These divisions are based upon the relative position with regard to the andesitic lithic breccia facies. The conformable coherent facies are dominated by andesite composition, whereas the cross-cutting coherent facies are more andesitic to basaltic in composition. The succession is overlain by feldspar-phyric pumice breccia and is also cross cut by mineralised veins & pervasive hydrothermal mineralisation.

3.3 Non Volcanic sedimentary facies

3.3.1 Limestone

The succession at the Chatree mine is dominated mainly by volcanic facies; however, minor limestone occurs within the sequence at A and K prospects (Table 3.1). The upper finer grained parts of the polymictic lithic breccias (laminated siltstone and sandstone) are overlain or interbedded with a fossiliferous limestone (Chapter 4.). Large outsized limestone clasts (20 cm in diameter) can also occur inter-bedded with coarser lithic breccia units.

In the upper portions of the lithic breccia facies the limestone is dark grey/black with large well preserved fossil fragments and whole fossils. The fossils usually occur in a well stratified, normally graded and thinly bedded sedimentary package. It ranges in thickness from 30 cm to 2 m. The fossils are matrix supported. The fossil assemblage is dominated by marine biota, including bryozoans, molluscs, foraminifera, rugose corals, ooids, brachiopods and crinoid stems. The fossils are replaced by carbonate, pyrite and chalcedony.

The large outsized limestone clasts were seen in the lithic breccia facies from K prospect. These clasts are grey black and fine grained (<0.5mm) with large well preserved fragments of fusilinid coral fragments.

Table 3.1. *Location of Limestone in drillcore at the Chatree Mine*

Limestone	Location	Drill core number	Depth (m)	Thickness in drillcore (m)
	A Prospect	A832	115	2
		A840	220	3
		A841	160	3
	K Prospect	K2024	205	3

Interpretation of the Limestone

The fossil assemblages (corals; bryozoans, brachiopods and bivalves) found within the limestone are consistent with a shallow reef environment (Reading, 1978).

The thinly bedded, laminated *limestone* in the upper portions of the andesitic lithic breccia facies represents a quiescence and break in supply of the lithic breccia facies. The limestone clasts in the lithic breccia facies in K prospect represent fragments that the material that has been picked, incorporated into the lithic facies and redeposited (The transport mechanisms of this facies type is described in section 3. 4.2).

The thinly bedded laminated *limestone* has very well preserved fossils. This suggests that there was very little reworking and transportation of the fossil fragments, however the limestone clasts contain fragments of corals that indicate relatively shallow warm and saline quiet water conditions. Corals do not grow in water deeper than 100 m and in water no cooler than 18 degrees Celsius (Jaeison, 1971). However, stalked varieties of crinoids usually below 100m water depth. This implies that there is some variability (Jameison, 1971).

The occurrence of *limestone* interbedded with the host succession of lithic breccias suggests that deposition of volcano-sedimentary facies occurred in a marine environment. The preserved fossils and fossil fragments provide some insight into the characteristics of the depositional environment for the volcanic facies including the shallow depth of emplacement for the succession at the Chatree mine.

3.4 Volcanogenic sedimentary facies

3.4.1 Coarse volcanic sandstone and siltstone

The *coarse volcanic sandstone and siltstone* occurs in A and K prospects and C & H The coarse granule to pebble sandstone in the upper portions of the lithic breccia units grades to a volcanic sandstone. This sandstone is composed of subhedral plagioclase feldspar crystals and fragments, subangular to angular quartz grains, andesitic lithic fragments and Fe-Ti oxide grains. Carbonaceous material and fossil fragments are also present in some domains. The sandstone is interbedded with and/or gradational into laminated siltstone and mudstone with occasional coarser grained gravel lithic-rich lenses. Andesite fragments are sub-rounded, between 3-4 mm across. The andesite comprises of subhedral plagioclase phenocrysts. Amygdales within the clasts are usually replaced by chlorite and carbonate and are red - brown.

In the matrix, the plagioclase feldspar crystals have undergone adularia alteration and are further altered to clays. Quartz is also present but may also be from secondary alteration. Chlorite, illite/smectite and carbonate also occurs in the matrix as secondary hydrothermal alteration. Four varieties of opaques (magnetite, chalcopyrite and pyrite) and rare zircons also occur

The silty layers generally occur with laminated grey-black bands that have rare fragments of woody carbonaceous material. In these siltier zones quartz, carbonate and adularia/felspar are still the dominant alteration components as well as pyrite. The siltstone is finely laminated and disseminated pyrite occurs throughout some layers (interpreted in part to be sedimentary in origin).

Table 3.2. *Location of Volcanic sandstone and siltstone in drillcore at the Chatree mine*

Facies Division	Location	Hole number	Depth (m)	Depth extent (m)
Volcanic sandstone and siltstone	A Lense	A872:	172	4
		A872:	130	10
		A872:	105	7
		A2104	170	30
		A2105	100(interbedded)	140
		A831	102	5
		A722	120	5
	C Lense	C189	70	5
	H Lense	H397	89	9
		H1129	175	5

Interpretation of the Coarse volcanic sandstone and siltstone

Sedimentary structures were difficult to decipher due to the narrow diameter of the drill-core. The gradation from sand to silt-grade particles and laminated mudstone in the upper portions of the polymict andesitic lithic breccias suggests that deposition may have been controlled by a density driven current (associated with the deposition of the breccia facies). Parallel laminations and the abundance of delicate plant fragments suggest that the high energy flow regime was combined with relative quiescence. In drill-core the upper flow regime in this current was combined with deposition from suspension (Reading, 1978).

The gradation from sand to silt and mud is similar to the deposits found in the upper portions of a high density turbidity current (Walker, 1984; Lowe, 1982). The grading suggests that deposition of the heavier mass was accompanied by finer material being held by suspension in the water column. During a hiatus in deposition (after deposition of lithic breccia facies) the suspended material could fall out of the water column and be deposited as thin graded beds.

A large amount of carbonaceous material occurs within these beds. This material has low settling velocity similar to medium sand and silt and also behaves in a similar way, being incorporated into the facies from suspension. The material also occurs in coarser domains and may have been picked up and incorporated into the lithic-rich mass flow and held in these domains from the overriding load. This material was possibly picked up from a nearby vegetated landmass or from material that was floating on the water surface (Walker,1984). Carbonaceous logs were observed during mine excavation (Marsoe, pers. com., 2004). The origin of this material is uncertain due to the nature of transportation of this facies. Possible environments of origin include estuarine or lagoonal systems. These systems often occur adjacent to or associated with a vegetated landmass. These types of environments usually occur behind barrier islands and reef systems (Reading, 1978). Pyrite in black shales implies anoxic swamp environments. Carbonaceous material may have been sourced elsewhere and redeposited within these settings.

There is also a high proportion of red silt and sand grade material disseminated throughout the coarse granule *volcaniclastic sandstone and siltstone* package. This was possibly picked up from partly oxidised or hydrothermally altered clasts or selective alteration.

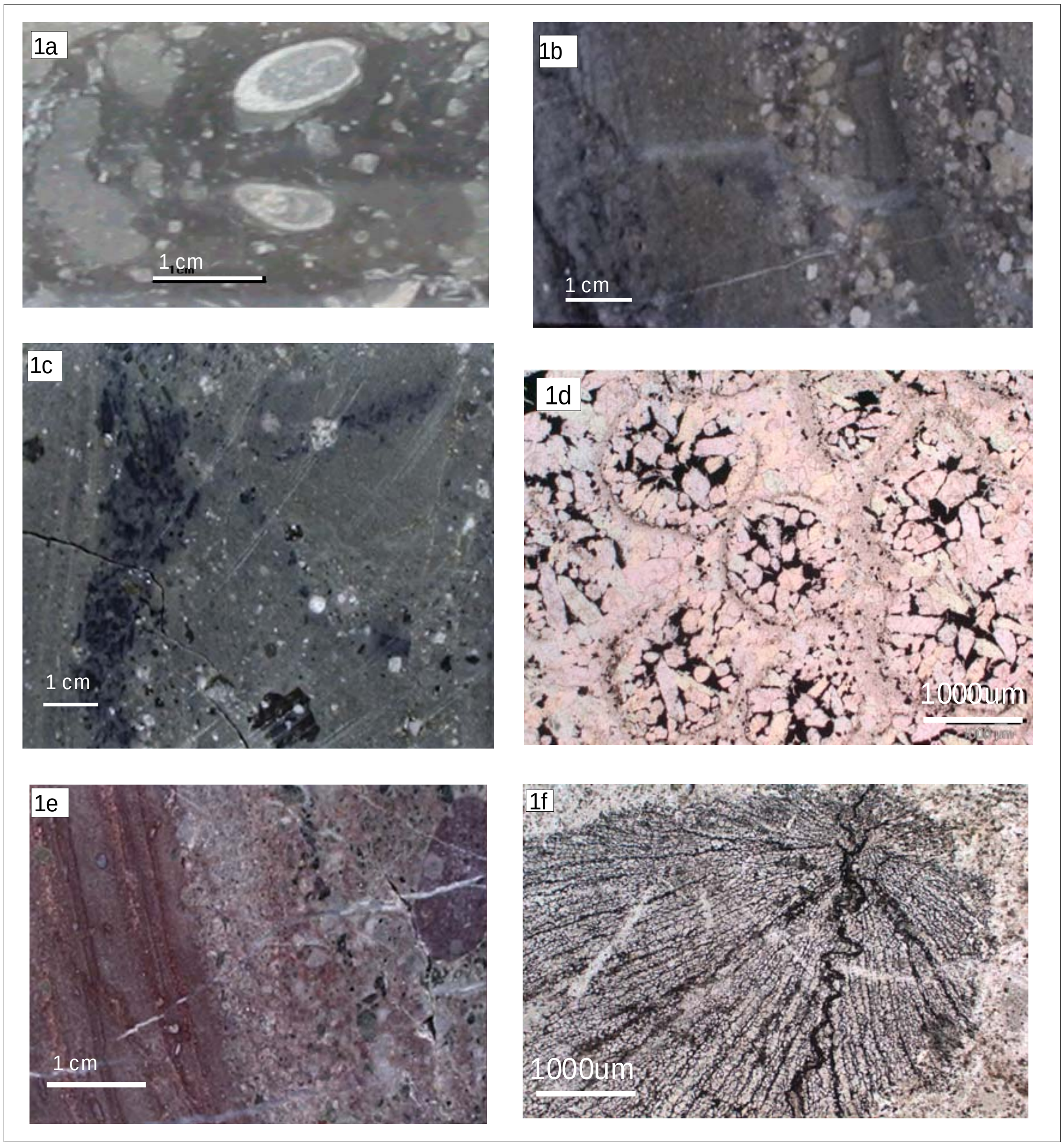

Plate 1a. *Shell fragments in limestone (sample number; K112 DC 2024, depth; 134 m, K Prospect).**Plate 1b**. Fine sand-silt contains gravely lenses (sample number: A45 DC 2024, depth, 112 m, K Prospect).* ***Plate 1c*** *carbonaceous dark grey-black material in the upper portions of the polymictic andesitic lithic breccia (sample number:A44, depth:115 m, K Prospect)* ***Plate 1e*** *Coarse red-granule sandstone grades into a sine sand (sample number; A44 DC, DC: RCD2024, depth; 82.5 m, K Prospect).* ***Plate 1f.*** *Cross section of a woody stem from a carbonaceous lens in the volcanogenic sandstone (sample number; A 57, DC number: RCD872, depth, 75 m, A Prospect).*

3.4.2 Polymictic andesitic lithic breccia / Polymictic andesitic and basaltic lithic breccia facies

The *polymictic andesitic* lithic breccia occurs mostly in A prospect and to a lesser extent in C and H Lens (Table 3.3). This facies is thickly bedded with each lithic breccia bed being 20 m to 40 m.

The *polymictic andesitic lithic breccia* are poorly sorted and dominated by dense, subangular andesite fragments with rare vesicular andesite clasts. Clasts vary in phenocryst content, vesicularity and alteration. There are three main clast types in the andesitic lithic breccia, with a fourth clast type in the basaltic andesitic lithic breccia facies.

In both the *polymictic andesitic lithic breccia* and the *polymictic andesitic and basaltic lithic breccia*, the lower parts of the beds are massive and clast supported. The middle to upper portions are matrix supported. The clasts are coarse pebble to boulders in the lower portions. In the middle to upper portions clasts fine up from a coarse pebble to gravel breccia into well stratified coarse sandstone and a muddy siltstone. Limestone lenses can occur within the succession higher up in the stratigraphy. There are multiple beds of this unit.

The most abundant clast type (1) is 1-50 cm, subangular plagioclase phyric andesite. These clasts have a high proportion (20 % - 30 %) of 1 to 2 mm coarse subhedral to euhedral plagioclase feldspar crystals phenocrysts and minor (6 %), 1 - 2.5 mm pyroxene phenocrysts. The pyroxene phenocrysts have been altered to chlorite and clays. The groundmass is evenly crystalline containing plagioclase felspar and rare amygdales. The groundmass has been hydrothermally altered; quartz, adularia, chlorite clay and calcite all pervasively alter the groundmass. Red discolouration of some clasts is due to a dusting of haematite and /or adularia. The amygdales constitute 5 to 7 % of the rock volume and are infilled by quartz, calcite, clay and adularia. There are no identifiable glassy margins associated with this clast type.

The second clast type, a plagioclase feldspar and hornblende phyric andesite is also subangular to subrounded and 1- 10 cm in diameter. It is composed of subhedral 1 to 2mm plagioclase feldspar phenocrysts (15 – 20 %) and 1 mm amphibole crystals (1-5 %)

in a finer grained (< 0.5 mm) evenly crystalline tabular plagioclase phyric groundmass. There are no amphibole phenocrysts in this clast type. There are no identifiable glassy margins in this clast type.

The third clast type consists of mudstone and siltstone. This clast type is rounded to subangular, ranging from 2-4 cm in diameter and are pale cream to grey and occur throughout the unit. The mudstone and siltstone clasts consist of a high proportion of plagioclase felspar and are sometimes highly silicified. 10 % of the mudstone/siltstone clasts contain a high proportion of carbonaceous material (which constitutes 20 % by volume).

Lower down in the stratigraphy in Prospect A, an additional clast type has been identified; a basaltic clast type is abundant, forming the *polymictic andesitic and basaltic lithic breccia*. In this facies, the basaltic clasts range from 1 to 5 cm in diameter with rare outsized clasts sometimes exceeding 15 cm. This clast type is dark brown-grey subangular to subrounded, composed of altered plagioclase feldspar, pyroxenes, rare olivine and amphibole, opaque phases include magnetite, chalcopyrite and pyrite. The basalt clasts have a fine grained groundmass (<1 mm) with 1 mm pyroxene and 1.5 mm acicular to tabular feldspar crystals. There is absence of any glassy margins to these clast types.

The matrix between the clasts in both the polymictic lithic breccias is commonly highly altered. It consists of fine to coarser grained assemblages of rounded to subhedral (1-2 mm) plagioclase crystals, which are replaced by adularia carbonate, and quartz, whereas pyroxene crystals are largely replaced by chlorite. Fine-grained euhedral pyrite is sometimes disseminated throughout the clasts and the matrix. Fe-Ti oxides including magnetite, chalcopyrite also occur.

Table 3.3. *Location of Polymictic andesitic lithic breccia facies in drillcore at the Chatree mine*

Facies Division	**Location**	**Hole number**	**Depth (m)**	**Thickness in drillcore (m)**
Polymictic andesitic lithic breccia	A Prospect	A872	268	30
		A872	170	30
		A840	220	12
		A840	207	4
		A840	285	5
		A2104	275	15
		A2024	250	10
	C Lense	C189	218	23
Polymictic andesitic and basaltic lithic breccia	A Prospect	A872	336	25
		A872	299	29
		A872	295	>310
		A2104	205	45
		A722	120	15
		A8331	130	>7
	H Lense	H1129	160	10
		H1129	149	12

Interpretation of the Polymictic andesitic lithic breccia facies / Polymictic andesitic and basaltic lithic breccia

The clasts are blocky, angular and dense. Their characteristics are consistent with brittle fracture of a poorly vesiculated magma or lava. In particular the clast shape resembles, hyaloclastite or autobrecciation (Yamagishi, 1993). The clast supply rate may have been boosted by this quench fragmentation or autobrecciation. Quench fragmentation produces aggregates that are coarse to angular or finely granulated and involves the non explosive fracturing and disintegration of quenched lavas and intrusions (Yamagishi, 1987) . Autobrecciation also involves the non explosive fragmentation of flowing lava in a subaerial setting and contains only rare finer clasts (Yamagishi, 1987).

There is not much evidence for clast abrasion and little reworking. The lack of any widespread oxidation of the clasts indicate that most clasts are unlikely to be from a subaerial source. Nevertheless a subaerial component is possibly present as indicated by plant debris and shallow water fossils.

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Mudstone and other accessory clasts may have been locally collected and redeposited by the slurry flow that also transported coarse andesite (and basalt) pebbles to boulders (Cas & Wright, 1978).

Transport Mechanisms

The lowest part and central section of each bed of polymictic andesitic lithic breccia is massive and coarser grained as is typical for high particle concentration gravity flows where water is the interstitial medium (Lowe, 1982)**.** These coarser sections possibly moved via of tractional sediment transport due to high particle concentration.

The upper portions consist of stratified and normally graded sand and silt-grade units. These finer particles were probably held in suspension during tractional sediment transport. After current deceleration, finer particles fell out of suspension. This is indicative of density sorted gravity flows (Lowe, 1982). The upper portion represents a more dilute and turbulent gravity flow as there is abundant lighter clasts and carbonaceous material.

The middle section is poorly sorted and matrix supported. This is characteristic of a more cohesive flow such as a debris flow. A cohesive flow contains a high proportion of finer material as the interstitial medium, and as such it is capable of supporting large clasts. Debris flow deposits are very poorly sorted, usually with large clasts in a finer grained matrix (Lowe, 1982).

The *polymictic andesitic lithic breccia* facies type is characterised by a basal tractional portion, a more cohesive middle portion and a turbulent upper portion which is not typical for a high particle concentration turbidity current but is possibly the product of a more transitional 'slurry flow' (transitional between a turbidity current and debris flow). The presence of a poorly sorted middle portion of this facies suggests that the facies may have transformed from a more fully cohesive debris flow. Subaqueous debris flows can transform into slurry flows, provided sufficient ambient water can be mixed into the interstitial medium to reduce the fluid strength and viscosity sufficiently to allow interstitial fluid turbulence to develop (Lowe, 1982).

An alternative type of transport mechanism is the flow may have initially began as a slurry flow (where enough water was able to be incorporated into the interstitial medium) and the body of the flow is cohesive, and larger particles are supported in the cohesive water-sediment matrix (Lowe, 1982).

There is a lack of sedimentary structures typical of an above wave base position such as cross bedding and ripple structures. Hence, the sequence is interpreted to have been deposited below wave base.

Source Characteristics

Red, possibly oxidised lava clasts suggests the possibility that some clasts could have been oxidised and hence be sourced from a subaerial environment. The coarse nature and poor sorting and a large volume of the breccia facies reflect high supply rate of clasts. This large supply may be due to the susceptibility for collapse of a nearby volcanic edifice or fragmentation of a lava flow. As the clasts are typically angular, it would appear that the volcanic detritus has not been extensively reworked and has been rapidly deposited.. The dominantly dense nature and angular shape of the clasts are consistent with the bulk of the volcanic debri being sourced from brittle fracture of a coherent unit such as a lava.

Debris flows are initiated by slumping-sliding on relatively steep slopes and are commonly associated with alluvial fans, marine slopes, delta fronts and the slopes of subaqueous volcanoes (Cas & Wright, 1978). Debris flows are known to flow several tens of kilometres carrying very large boulders well away from source (Cas & Wright,1978). Many documented accounts of debris flows have been associated with stratovolcanic terrains (Mullinex & Crandell, 1962; Mt St. Helens; Schmicke, 1967, eastern margins of the Cascades arc; Janda et al., 1981, Mt St Helens).

Proximity to Source and Depositional setting

A significant proportion of the thickly bedded volcaniclastic lithofacies is interbedded with fossiliferous limestone supporting the proposal that the bulk of the volcanic pile has accumulated in a subaqueous setting. The presence of coral fragments in the limestone indicative of a shallow marine setting interbedded with the mass flow deposits indicate that the mass flow type deposits may have travelled across a relatively shallow marine setting or deposition was close to that setting. Fossil evidence may also suggest that the some debris flows were deposited into deeper (>100 m) marine environments.

The presence of plant fragments/carbonaceous material in the breccia pile indicates that a partly emergent vegetated land area containing eruptive-vents and/or lava flows was nearby.

The reddish lava clasts ma be the product of a subaerial eruption but could also have formed in a hydrothermal setting. The lithic breccia facies are thick and predominantly massive with a high proportion of angular lithic fragments. The nature of the facies suggests the source was relatively proximal. The presence of sedimentary clasts indicates that the flow may have eroded the upper parts of previously deposited beds. The coarse nature of most clasts and the greater proportion of the lithic breccia unit than the sedimentary facies indicates relative proximity to these flows and/or source vents (based on conclusion made by McPhie et al., 1994) .

3.4.3 Monomictic lithic breccia

This facies occurs in C, H and D lens (Table 4). It is dominated by very angular, 2 to 10 cm plagioclase phyric andesite clasts. There is usually a concentration of larger clasts and not a gradation of different clast sizes. The clasts occasionally display jigsaw fit texture, but usually they have been rotated considerably. The facies is clast supported with a coarse sand to silt grade particles, dark grey, felspar phyric, highly silicified (dark grey quartz flooding) matrix. The quartz matrix has a grey colour because of the presence of sulfides (e.g., pyrite) (pers. Com. Kromkhun, 2004)

The andesite clasts contain 1-2mm calcite replaced plagioclase phenocrysts in a fine grained feldspar-and pyroxene-phyric groundmass. In the groundmass, cumulate crystals of replaced feldspar, amphibole and titanomagnetite phases are present. Blocky pyrite is also distributed throughout the groundmass.

The matrix varies in components. Some domains are composed of a fine grained (>1 mm) grey black highly silicified matrix. Other domains are coarser grained (2 mm) consisting of rounded feldspar and quartz crystals occasionally containing large (1 cm) dark black carbonaceous fragments which are sometimes very well preserved.

This facies has a large relative thickness sometimes exceeding 20 m in drillcore. It occurs in C and D lens and often encloses or occurs at the boundaries of a coherent units. It is intruded by or associated with the pseudoclastic andesite in D lens and often occurs along with extensive veining in C and D lens.

Table 4. *Location of the monomictic andesitic lithic breccia in drillcore at Khao Sai*

Facies Division	Location	Drillcore number	Depth	Depth in Drill-core (m)
Monomictic andesitic lithic breccia	A Prospect	A831	125	4
		A2024	205	6.5
	H Lens	H1129	163	20
	D Lens	at boundaries of cohesive units		
	C Lens	at boundaries of cohesive units		

Interpretation of the Monomictic Andesitic Lithic Breccia

This facies is very extensive in drillcore and is commonly associated with coherent units in D and C lens. Its apparent association with the margins of coherent units in drillcore along with the angular nature of the clasts could lead to the assumption that this facies is a type of re-sedimented hyaloclastite. However, the *polymictic andesitic lithic breccias* are moderately porphyritic and are not texturally glassy in spite of some alteration. This lack of glassy texture suggests against hyaloclastite. The clasts are often similar sized, unlike the gradation of large and small clasts concentrated together like hyaloclastite.

The clasts occur lodged in a very fine grained (silt like) quartz rich matrix. Sometimes exhibit soft sediment deformation but most likely represents syn-emplacement deformation caused from the movement of the hydraulic fluids. In one sample from drillcore there is a sharp contorted and irregular boundary between a the quartz rich matrix and a coarser sandstone. These sediments make up the matrix for the monomictic lithic fragments. In this sample the lithic fragments occur between the contorted boundary and also in the two sediment types. This feature is similar to a soft sediment deformation feature. It is possible that this type of contortion was due to infilling of open fractures in the brecciated andesite.

The angular nature of the clasts suggests brittle fracture or hydraulic brecciation due to brittle shearing from faulting (Sillitoe,1985). There is little evidence for mass transport processes, but clast rotation was probably due to fluid movement.

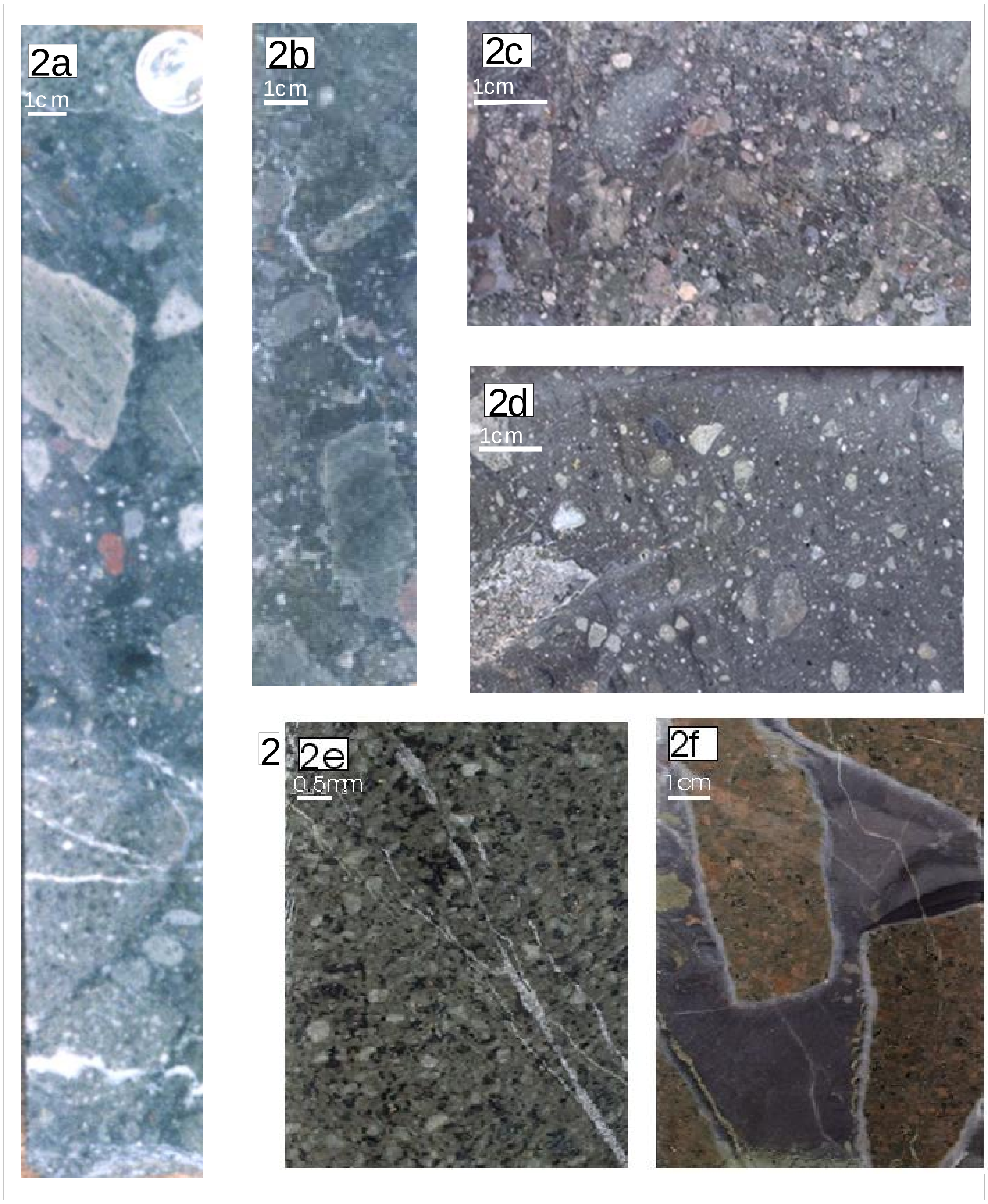


Plate 2a. & Plate 2b. *Poorly sorted angular clasts from the polymictic andesitic lithic breccia (DC: RCD2104, depth; 156 m, A Prospect).* ***Plate 2c****. Clast supported polymictic andesitic lithic breccia (A33; depth,111 m, K Prospect).* ***Plate 2d****.Matrix supported andesitic lithic breccia (sample number:,A46 DC 2040 number; depth, 113 m, K prospect).* ***Plate 2e.*** *Plagioclase phyric clast from the polymictic andesitic lithic breccia (sample number: A43, depth: 116 m K prospect).* ***Plate 2f****.The monomictic lithic breccia has glassy matrix and coarse angular clasts (sample number C82, DC: RCD258, depth;56 m, C Lens).*

3.5 Pumice Breccia

There are two compositionally distinct pumice breccia facies at Khao Sai; a *polymictic silicified pumice breccia* and a *felspar-phyric, polymictic pumiceous and lithic breccia*. The *silicified pumice breccia* facies occurs beneath the Andesitic lithic breccia facies and Andesitic and basaltic lithic breccia facies in prospect A (Table 5 & 6). The *polymictic feldspar phyricc pumiceous and lithic breccia* occurs higher up in the stratigraphy above all the facies divisions. This facies is extensive, occurring in the upper parts of the stratigraphy preserved at the Chatree mine.

3.5.1 Polymictic silicified pumice breccia

The *Polymictic silicified pumice breccia* facies is over 10 m thick, with coarse pebble to cobble size clasts. The facies is generally matrix supported, moderately to poorly sorted consisting of variably flattened angular to ragged dacitic pumice clasts and minor sub angular andesite clasts (5-15 mm). The base of this facies was not intersected by selected drillcore. The lower-most and upper portions are lithic-and crystal-rich, matrix-supported and poorly sorted. By contrast, the middle portions are diffusely stratified, pumice- and crystal-rich with rare lithic fragments. The upper portions are stratified & more matrix supported. Sand to granule layers occur in the upper portions. Pumice and lithic clasts are matrix supported in a matrix consists comprising silicified zones with 2-4 mm quartz crystals (10 %) and 3 to 5 mm quartz fragments. Finer subhedral to anhedral plagioclase crystals (10 %) also occur in the matrix.

Uncompacted pumice clasts are 2-5 cm across and subangular and ragged in the lower and upper portions of the facies. The middle portions are dominated by variably elongate/arcuate and flattened smaller, 0.5 to 2 cm long pumice clasts. The pumice clasts are commonly green-grey due to chlorite alteration. Secondary carbonate alteration is prevalent throughout the pumice and matrix.

The lithic fragments are angular to subangular, and generally 3-4 cm in diameter. They are usually feldspar-phyric andesite, dominated by subhedral to euhedral plagioclase feldspar phenocrysts in a finer grained plagioclase-phyric groundmass. Basaltic clasts are also common with an amphibole, feldspar and pyroxene-phyric groundmass with abundant pyroxene phenocrysts (20 %). Some basalt clasts contain a high proportion of disseminated pyrite. The lithic clasts occur throughout the facies but are concentrated in the lowermost portions and the uppermost portions.

This unit occurs in the lower most portion of A Prospect in drill core. It ranges from 10 to 30 m, the base was not exposed.

Table 5. *Location of the Polymictic lithic and silicified pumice breccia*

Facies Division	Location	Hole number	Depth (m)	Thickness in drillcore (m)
Polymict lithic and quartz phyric pumice breccia	A Prospect	A2104	100	10
		A2105	310	15
		A722	135	35
	K Prospect	K2024		

Interpretation of the silicified pumice breccia

The *polymictic silicified pumice breccia* facies was deposited in a marine environment and is interpreted to be the product of a subaqueous, volcaniclastic mass flow deposit.

Transport mechanism

The polymictic silicified pumice breccia is thickly bedded, massive, graded and has density stratification in the upper portions of the beds. They are composed of dacitic pumice, crystals (mainly quartz and feldspar), volcanic lithic clasts and non volcanic sedimentary clasts. In some portions, the pumice clasts define a bedding parallel foliation/lamination possibly formed through diagenetic compaction.

The observed types of sedimentary features are indicative of high particle concentration gravity flows (McPhie & Allen, 2003). Beds deposited from submarine, water supported pumiceous gravity currents are typically very thick, massive and graded. These deposits occur from flows that are thought to reflect high volumes and supply rates (McPhie & Allen, 2003). The upper portions grade from a coarse pebble breccia to a coarse sandstone with diffuse bedding. This characteristic may indicate that there was an initial high particle concentration due to a declining stage of the current (lower division) followed by a more dilute, possibly turbulent waning phase (McPhie & Allen, 2003). The presence of sedimentary clasts indicate the submarine gravity currents passed across and incorporated wet mud substrate during movement of the flow (McPhie & Allen, 2003).

Depositional Environment

The pumice breccia has no recognisable structures indicative of above wave base conditions (such as hummocky cross stratification & cross bedding). The presence of limestone above the facies suggests a subaqueous environment. Furthermore, the fact that the *silicified pumice breccia* is intercalated with fossiliferous sedimentary facies suggests a subaqueous environment.

Source and character of the pumice

The pumice in the mass flow deposit was sourced from an explosive felsic event. It is possible that the eruption was generated directly from a caldera forming eruption. In the lowermost portion of the drillcore there is a high proportion of pumice clasts and very few exotic clasts indicating that the pumice may have been reworked from unconsolidated pumice breccia (Gifkins et al., 2000)**.**

As the surface texture of the pumice is not preserved, it cannot be determined whether quenched margins are present to indicate whether the source volcano was subaqueous or subaerial. Either scenario can produce large volume explosive eruptions. Subaqueous pumiceous mass flows originating from these eruptions can extend up to 250 kilometres from source (Carey & Sigurdsson, 1979 based from data from the Lesser Antilles Arc.).

The pumice clasts are flattened in the central portion of the facies. This type of flattening is also quite irregular in drillcore indicating that the most likely cause for compaction was from normal digenetic processes (Gifkins et al., 2000).

3.5.2 Polymictic feldspar rich pumiceous lithic breccia

This facies contains sub-angular to sub-rounded 0.5 to 20 mm andesite clasts with rare outsized (15 cm) clasts consisting of mudstone (50 %), andesite (10 %) and pumice (5 %) which occur in a felspar phyric matrix. The central portion is clast supported with coarser (5 cm) sub-angular clasts. The upper contact is not exposed. The lower portions of this facies are matrix-supported, the basal-most section (bottom 50cm of the facies) also consists of course (3-5cm) clasts.

Pebble and cobble sized clasts together with coarse sand grade particles occur in the basal section followed by a reverse grading and a normally graded upper portion.

Sub rounded, black or green/grey and laminated mudstone clasts are abundant. These clasts are 1.5 to 7 mm across but rare outsized 10 cm clasts also occur. Outsized mudstone clasts occur in the central portion of the facies.

Pumice clasts are variably compacted. In C lens the pumice clasts are dominantly flattened. The flattened pumice clasts are wispy, 0.5 to 1 cm long green grey, fiamme-like with ragged sometimes arcuate margins. In some portions of the unit the glassy texture in the pumice is preserved and vesicles are clearly discerned. Some of the dacite clasts are sub-angular and dark green chlorite altered with rare tabular equent phenocrysts of quartz and felspar. These dacite clasts often occur in the central portion of the facies and may reflect relict, unflattened pumice clasts or non vesicular juvenile clasts.

Andesite clasts are less common. They are sub-rounded and consist of 3-4 mm tabular euhedral to subhedral plagioclase phenocrysts in a fine-grained possibly silicified groundmass. There are also less abundant red brown (oxidised) sub rounded andesite lithic fragments which sometimes contain euhedral plagioclase phenocrysts.

Rare aphanitic and relatively unaltered basalt clasts occur; they consist of tabular plagioclase feldspar, pyroxene, titanomagnetite (magnetite) and minor olivine.
There are also clasts consisting wholly of large quartz crystals (possibly vein material).

The matrix consists of rounded 1 mm tabular and rounded plagioclase feldspar and titanomagnetite crystals. The matrix is composed of < 0.5 mm grey/pale cream felspar grains . Small lenticular <1 mm wispy mudstone fragments or flattened altered pumice are scattered throughout the matrix.

Table 6. *Location of the* ***p****olymictic feldspar rich pumiceous lithic breccia in drillcore at the Chatree mine*

Facies Division	**Location**	**Drillcore number**	**Depth down hole (m)**	**Thicknessin drillcore (m)**
Polymictic lithic and felspar phyric pumice breccia	C Lens	C189	35	10
	H Lens	H1125	200	40
	D Lens	D251	29	1
		D219	20	17

Interpretation of the polymictic felspar rich pumiceous lithic breccia

Transport Mechanisms

Based on the sharp basal contact, the poor sorting, massive/diffusely bedded nature in the upper portions of the facies, resedimentation is assumed to have occurred from a highly concentrated flow. Poor sorting suggests that the large clasts have been supported in a finer grained matrix similar to cohesive flow (Lowe, 1982).

The facies exhibits characteristics similar to both high density turbidity current and a cohesive debris flow deposit. The characteristics of the facies that correspond to a high density turbidity current are in the lower and upper portions. Pebble and cobble sized particles together with coarse sand occur in the lower portion. Beneath this there is a coarser clast supported basal section. The lower portion is reversely graded, the matrix coarsening upward from a silty matrix grading to a coarser sand and more abundant clasts. Above this there is a normally graded upper portion, the matrix fining up to silt sized particles and the abundance of clasts decreases. This characteristic is produced when flow velocity decreases and suspended clasts are deposited rapidly from a turbulent suspension (Lowe, 1982). Although the clasts are supported in a finer grained matrix similar to a cohesive or volcaniclastic debris flow, but the lack of grading and stratification suggests that turbulence played a role in suspension (Lowe, 1982).

Evidence for transport, reworking and post eruptive re-sedimentation indicated through modification of primary clast shapes. Some clasts are rounded indicating transport and reworking; i.e. there is a mixture of non volcanic particles (laminated mudstone clasts) and a variety of compositionally different volcanic particles (porphyritic felspar phyric clasts and finer grained basaltic clasts), and clasts which show the effects of weathering (reddened oxidised andesite clasts). The pumice shows little evidence for being reworked. The whispy character of the pumice is possibly from flattening and glassy texture of the pumice preserved. Many lithic fragments were presumably picked up during transport of the pumice as mass flows although some may be vent derived.

Source Characteristics

The *polymictic feldspar rich pumiceous lithic breccia* facies consists of a high proportion of polymict clasts which have been weathered and eroded from a pre-existing, unconsolidated volcaniclastic and sedimentary environment (Lowe,1982). It is possible that large caldera forming eruptions excavate the vent and can contribute to a wide variety of clasts. The pumice fragments and felspar phyric matrix was derived from a more felsic explosive caldera forming eruption which may have also triggered the mass flow processes. Due to the altered nature of the pumice it is uncertain as to whether the explosion occurred in a subaqueous or subaerial setting.

There were possibly multiple source areas of the clasts as there is an abundance of clasts with different compositions. Non-vesicular andesite and basalt clasts were possibly picked up and incorporated into the mass flow from a fragmented lava flow, exposed sill or dyke. The mudstone was possibly picked up from a wet or unconsolidated substrate. The laminated mudstone fragments were being derived from a subaqueous unconsolidated substrate. The abundance of lithic clasts may indicate that the flow is more proximal to the volcanic edifice or indicate that the facies observed represent the lower portion of the flow as denser clasts are often deposited first and in the lower parts of the flow.

Depositional environment

Turbidites are diagnostic of subaqueous, below wave base marine depositional settings but the sedimentary features (stratified upper portions) of the facies does not preclude a subaerial or lacustrine setting. The lack of many exposures of the upper portions of this facies and the lack of limestone interbedded or above the facies means that the depositional environment cannot be constrained.

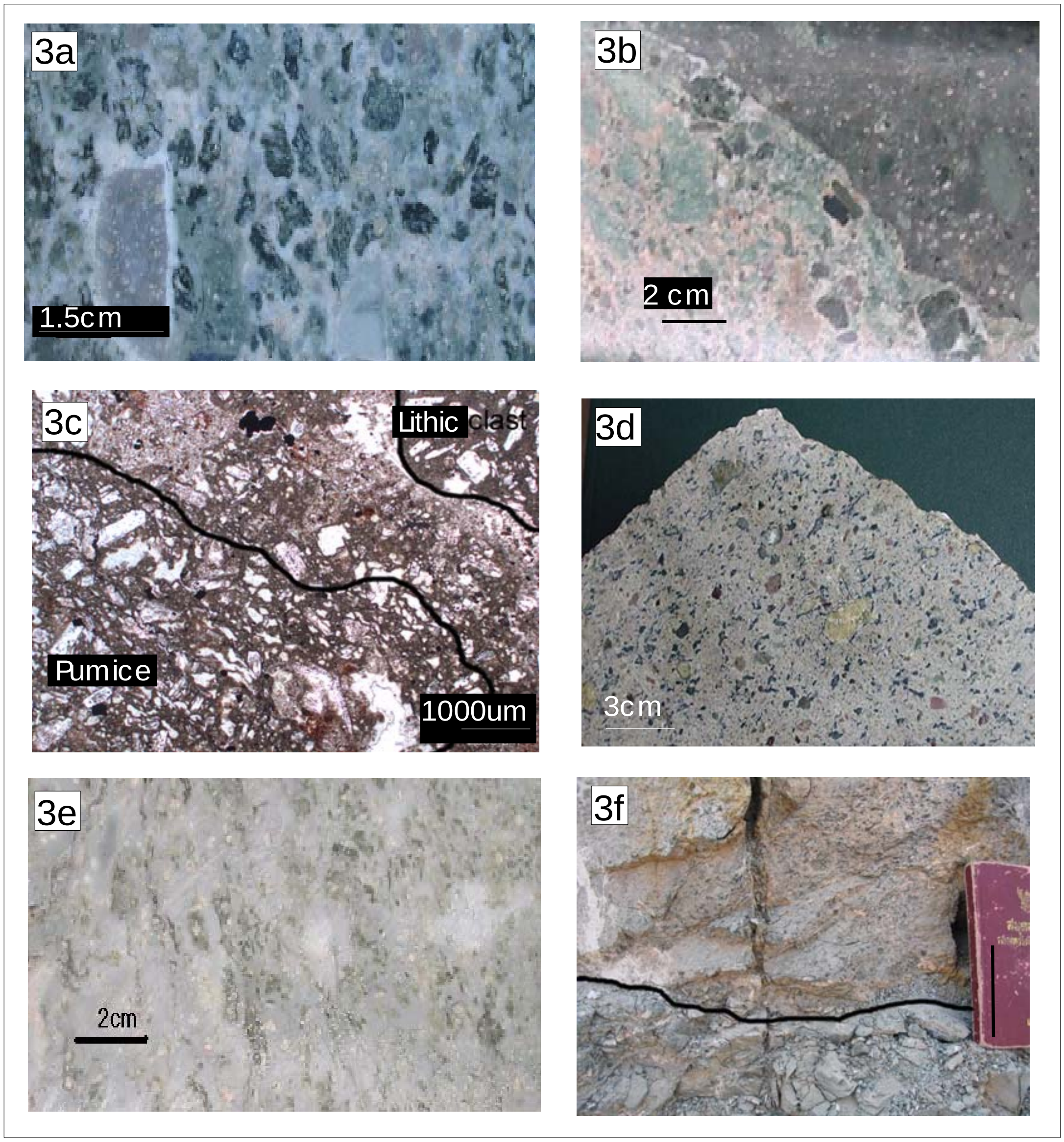


Plate 3a. *Silicified pumice breccia from A Prospect (Sample number; A79, DC; RCD 2104, depth; 250 m),* ***Plate 3b****. Polymictic felspar phyric pumice breccia from C pit (sample number C61).* ***Plate 3c****. Silicified pumice breccia from A Prospect (sample number A78, DC: RCD2104, depth;340 m).* ***Plate 3d****. Polymictic feldspar phyric pumice breccia from C pit (surface exposure, C pit).* ***Plate 3e****. Silicified pumice breccia from A prospect (sample number A77, DC: RCD2104, depth; 330 m).* ***Plate 3f****. Contact between the polymictic feldspar phyric pumice breccia and a very sheared polymictic andesitic lithic breccia (C pit).*

3.6 Coherent Facies

3.6.1 Conformable and cross cutting facies

The position of the conformable and cross-cutting in drill-core is in Tables 7 and 8. The conformable facies are conformable to the *polymictic andesitic lithic breccia facies*. The cross cutting coherent facies cross-cuts all volcanogenic sedimentary facies at the Chatree mine.

Plagioclase-phyric andesite

This *plagioclase-phyric andesite* is moderately to highly porphyritic with (15 %-30 %) euhedral to subhedral 2-3 mm plagioclase phenocrysts and less abundant (5 %) altered feldspar phenocrysts in a green to grey, fine-grained (0.5 mm) equigranular groundmass. The groundmass contains K-feldspar, apatite, interstitial chlorite, (5%) amphibole, and opaques including Fe-Ti oxides with minor pyrite.

The plagioclase phenocrysts are dusted with hematite and overprinted by sericite, patchy carbonate and minor epidote. The rims are often altered to adularia. Amphibole is altered to chlorite, sericite, carbonate and less commonly sphene. Xenoliths occur within the *plagioclase-phyric andesite* in C Lens (C189, depth: 137 m). These xenoliths are (3-5 cm in diameter) gneissic in composition and contain coarser (2-3 mm) equigranular aphyric euhedral plagioclase feldspar and amphibole than in the host. The xenoliths are unevenly distributed throughout the unit. They make up less than 10 % of the rock volume. There has been very little alteration of this unit in C Lens.

In D Lens the plagioclase phyric andesite includes sparse to abundant amygdales. The amygdales are 2 mm, circular to ragged in shape and are commonly infilled adularia, silica, clays, chlorite and carbonate.

The upper and lower margins of the *plagioclase-phyric andesite* are paler (grey–cream) and finer grained (0.5 mm) when there is a contact with the polymictic andesitic lithic breccia. The contact with the pseudoclastic unit is gradational. The plagioclase phenocrysts are larger (3-4 mm) and more abundant (30%) in the interior. This facies is usually conformable with the andesitic lithic breccia but often inter-fingers the host succession. Larger scale (20-50 cm) lobate features also occur at the margin of the plagioclase phyric andesite with the polymictic andesitic lithic breccia. In some areas, this facies also cross cuts the host succession. The margins are 10-20cm thick. In C and D lens, the *plagioclase-phyric andesite* reaches up to 40 m in thickness. In prospect A the facies is thinner ranging in thickness from 2 to 10 m. The xenolithic andesite in C Lens varies in thickness from 6 to 30 m.

Pseudoclastic facies

This facies only occurs in D lens where it reaches up to 30 m in thickness. It is characterised by patchy zones of carbonate and chlorite replacement alteration of a finer grained felspar phyric equigranular groundmass (0.5 mm). The groundmass is also intensely silicified in parts. Pyrite is disseminated throughout this groundmass. The coarser (1-2 mm) carbonate and chlorite altered zones are 2 to 4 cm in diameter and have unclear ragged margins which are distributed irregularly throughout the unit.

This facies occurs throughout D lens at multiple stratigraphic positions (2 occurances) and can reach up to 100 m in thickness. It displays no clear bedding but often has a gradational contact with more coherent plagioclase phyric andesitic units. Faults and sheared zones often intersect this unit.

Sparsely feldspar-phyric andesite

A *sparsely, feldspar-phyric andesite* is present in A Prospect and C and H lenses. This facies is composed of sparse 1 mm felspar phenocrysts (<5 %) in a groundmass of albite, K-felspar, sericite, chlorite, carbonate and epidote. Sparse amygdales are infilled by carbonate and epidote. The opaque phases in the groundmass are dominated by Fe-Ti oxides (mostly magnetite) and minor chalcopyrite and pyrite.

The feldspar phenocrysts are altered to K-feldspar and minor sericite, chlorite, carbonate and epidote. The amygdales often show a rim of K-felspar and rare sphene and may also contain quartz, chlorite, carbonate, apatite and pyrite.

This facies ranges in thickness, from being thinnest in A prospect (1.5 m), 4 m thick in C Lens and 3 to 10 m in H lens and is usually conformable with the host succession of *polymictic andesitic lithic breccias*. It also cross cuts the host succession and can also crosscut the *plagioclase phyric* andesite. The contacts are sharp and close to the margins, the texture is finer grained (<1mm) phenocrysts.

Table 7. *Location of the conformable and crosscutting coherent facies in drillcore at the Chatree mine, Chatree mine.*

Facies division	Location	Hole number	Depth (m)	Thickness in drillcore (m)
Plagioclase feldspar phyric andesite	A Prospect	A872	340	>10
		A2104	243	>8
		A840	177	2
		A2104	277	3
	D Lens	D254	83	6
		D195	95	>6
		D195	47	20
	C Lens	C189	137	40
Sparsely feldspar phyric andesite	A Prospect	A872	336	4
		A872	318.8	4
		A872	302	2
		A872	268.5	1.5
		A872	212	5
		A2104	199	4
	C Lens	C189	177	>3
		C189	135	3

3.6.2 Cross cutting / unconformable facies

Coarsely porphyritic andesite ('Porntherp Porphyry')

This facies is 4 m thick and only occurs in D Lens. The major phenocryst phases consists of large 5 mm sericite altered plagioclase (20 % - 30 % by volume), and chlorite and sericite altered acicular to tabular 3 mm amphibole (5 %). The groundmass consists of a fine grained assemblage of albite, carbonate, sericite, chlorite, quartz, sphene, apatite, and some opaques (possibly magnetite). This facies cross cuts the whole succession and is 4 m thick. The margins are sharp and finer grained.

Pyroxene - olivine - feldspar phyric basalt

This facies only occurs in D Lens and is up to 16 m thick. It is fine-grained, moderately to richly porphyritic consisting of iddingsite and carbonate altered 1-2mm olivine (10 %), partly sericite altered clinopyroxene (5 %) and some larger (2 mm) plagioclase (10 %), and altered 2-7 mm subhedral pyroxene (15 %) in a grey to green groundmass. These ferromagnesian phases are wholly to partially replaced by calcite and chlorite.

The groundmass dominantly consists of fine grained (<1 mm) wispy, acicular plagioclase felspar crystals (80%) and 15% blocky and rarely tabular and elongate opaque minerals of titanomagnetite, pyrite and chalcopyrite. Fine chlorite, sericite and carbonate has replaced some of the felspar crystals. The opaque phases consist mostly of Fe-Ti oxides (magnetite) with minor pyrite and chalcopyrite.

The most notable alteration feature of this facies is the circular alteration halo of calcite surrounding the replaced pyroxene phenocrysts (alteration spots).

At the margins there is a loss of pyroxene crystals and an increase in altered olivine phenocrysts (15%). The facies cross cuts the *polymictic andesitic lithic breccia facies* and the *plagioclase-phyric andesite*.

Xenolithic basaltic andesite

This facies is up to 30m thick in C Lens and up to 15m thick in D Lens. This facies is fine grained and moderately porphyritic consisting of phenocrysts of 3 mm green hornblende (10 %), clinopyroxene (5 %) and iddingsite altered olivine (2 %). The groundmass consists of albite (80%), secondary quartz, carbonate, clay, chlorite and opaque phases. The opaque phases consist of Ti Oxides, including magnetite, pyrite, chalcopyrite.

Table 8. *Location at depth in drillcore of unconformable/crosscutting coherent facies at the Chatree mine, Khao Sai*

Facies division	**location**	**Drillcore number**	**Depth (m)**	**Thickness in drillcore (m)**
	H lens	H452	132	10
Hornblende phyric andesite	D Lens	D249	26	4
		D254	83	10
		D251	39	3
Porphyritic andesite	D Lens	D249	27.4	3
Clino-pyroxene-olivine and feldspar phyric basalt	A Prospect	A840	193	1.5
		A2104	299	7
Xenolithic basaltic andesite	D Lens	D254	52	3
		D219	28	4
		D195	94	>6
		D249	12	16
Plagioclase phyric xenolithic andesite	C Lens	C185	99	>15
		C185	58	6
		C185	5	30
Pseudoclastic facies	D Lens	D251	23	10
		D254	83	14
		D254	45	20
		D219	41	30
		D195	71	20
		D195	24	30
		DD249	38	27

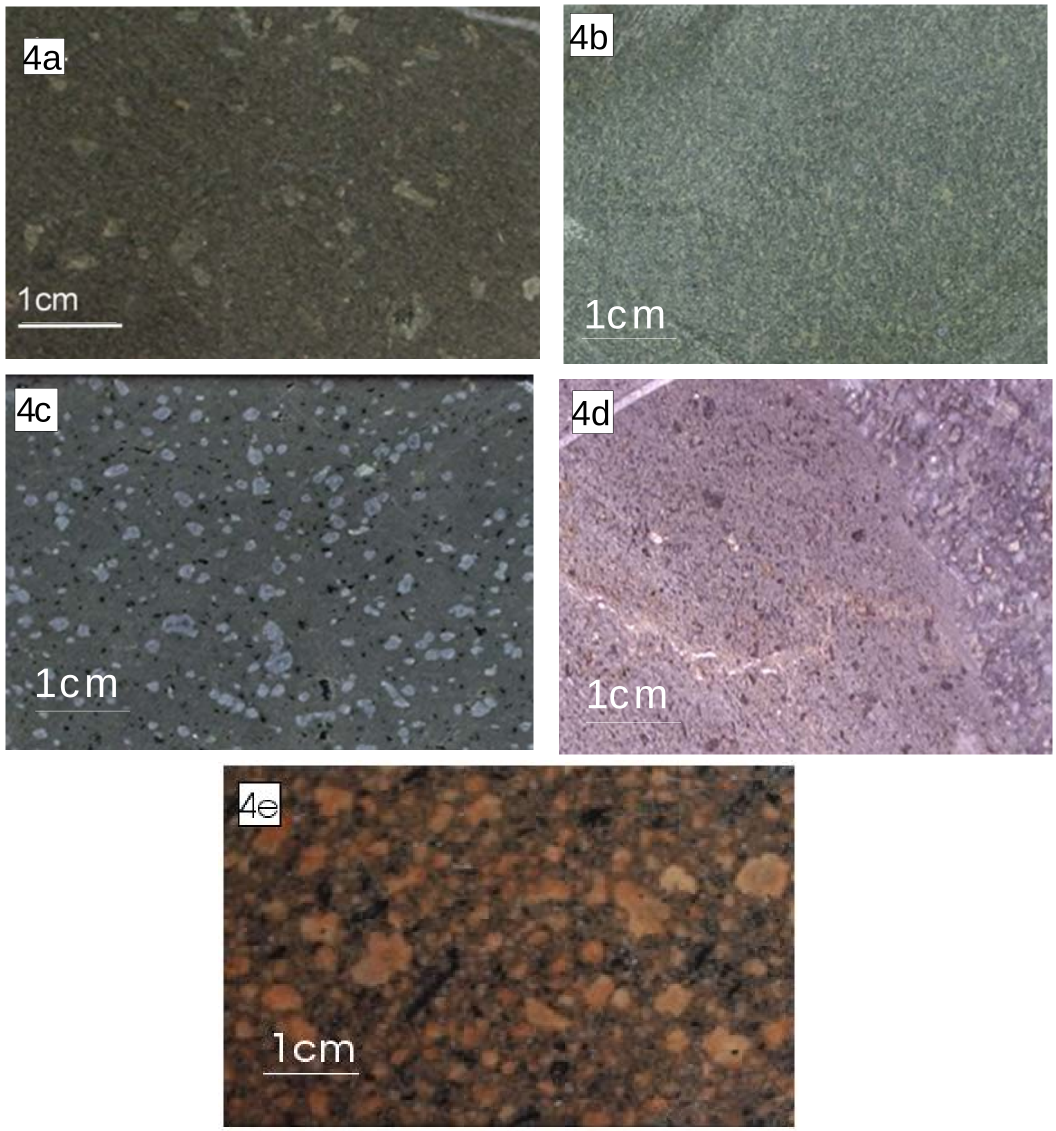


***Plate 4a**. Plagioclase phyric andesite (sample number;,D67, surface outcrop, D pit). **Plate 4b**. Sparsely felspar phyric andesite (sample number;A2 DC 2104: depth:345m A prospect). **Plate 4c**. Olivine-clinopyroxene basalt dyke (sample number; A10 DC; 2104 depth, 320m, A Prospect). Plate 3c. Sparsely felspar phyric andesite with gneissic xenolith (sample number; D100, surface outcrop, D pit). **Plate 4d**. Coarsely plagioclase phyric andesite (sample number D67;surface uotcrop, D pit)*

Xenoliths also occur in this facies. These xenoliths are gneissic, and range up to 6cm in diameter and contain 1.5 mm equigranular chlorite altered plagioclase feldspar (20 %), followed by quartz and hornblende and minor biotite and Fe-Ti oxides. These xenoliths are irregularly distributed throughout the unit. The opaque phases (magnetite) in these xenoliths occur along with chalcopyrite and pyrite crystals, rare garnet and zircons.

Interpretation of coherent facies

The two subgroups; the generally conformable coherent facies and the cross cutting facies will be interpreted independently.

Conformable/crosscutting coherent facies

The generally conformable and crosscutting *plagioclase-phyric andesite* and the *sparsely felspar-phyric andesite* represents syn volcanic intrusions or sills based from textural and geometrical characteristics. Textures such as peperite associated with the intrusion into water/wet sediment was absent in outcrop and drill-core.

Textural Characteristics

These facies have chilled upper and lower contacts when they are conformable to the host polymictic andesitic lithic breccia succession. When this facies cross cuts the host succession both margins are chilled. The nature of textures in upper and lower chilled contacts of the sills are the same; being finer grained with a loss of major phenocryst phases.

The facies are relatively fine-grained (aphanitic) and are characteristic of high level intrusions (sills). This interpretation is based from the textural character of the groundmass; most phenocryst phases are finer grained and have cooled relatively quickly (Cas & Wright, 1987). The sills most likely post-date the enclosing sequence of andesitic lithic breccias.

The Plagioclase-phyric and Sparsely felspar-phyric andesite intrusions show tongues or lobes projecting into the host volcano-sedimentary package but blocky and fluidal peperite is absent at the margins and in the host sediment. Peperite commonly occurs along the margins of coherent facies when there has been interaction with unconsolidated or poorly consolidated usually wet sediment and typically forms where magmatism and sedimentation are contemporaneous (McPhie et al., 2002). The lack of peperite domains along the margin of the sills indicates that the host breccia package was relatively consolidated, firmly compacted and water unsaturated before intrusion, in spite of deposition of the host succession being constrained to a subaqueous setting (Zimanowski, 2002). Nevertheless, peperite can also be widely dispersed within the host sediment and can be difficult to discriminate especially in a coarser grained host (Squire & McPhie, 2002) and may reach distances of up to 100m away from the host succession (Skilling et al., 2002).

The are several other reasons why peperite does not form when coherent facies intrude. Mingling is favoured when the density and viscosity of the magma and host sediment are the same a density contrast may exist between the hot, coherent facies with the breccia facies (Skilling et al., 2002),. Extensive contact metamorphism, lithification and some types of alteration will also prevent peperite formation, (Skilling et al., 2002). Other processes which prevent peperite formation include the sustained development of a vapour film between the sediments and coherent facies upon intrusion and lack of convection within this vapour film (Lavine & Aalto, 2000). The weight of the above succession may have minimised this convection exerting sufficient pressure to reduce oscillations within the vapour film that is necessary for the formation of peperite (Lavine & Aalto, 2000).

Disturbance or destruction of bedding within the lithic breccia unit is difficult to determine in drillcore but the sills are broadly conformable with any possible bedding.
The fluid and lobate contacts are thought to have formed from soft sediment deformation due to loading caused from density differences between the host and intrusive (also recorded by Kazuriko Kano, 2001 and Lavine & Aalto, 2000). These types of features can also be caused from directed stress exerted by the lava as it flowed (Lavine & Aalto, 2000).

Sill Geometry

In D Lens, the *plagioclase-phyric facies* is thicker and crosscuts the succession than in A Prospect, the most farthest prospect where the facies is conformable to the host succession. In C and D Lens the *plagioclase-phyric andesite* has a large relative thickness suggesting that it either represents an area closer to a feeder dyke or the coherent facies has ponded in this area. In A Prospect the *plagioclase-phyric andesite* is much thinner and less conformable, possibly representing an area further away from the feeder dyke. A similar trend is also apparent for the *sparsely felspar phyric andesite*. Skilling et al. (2002) suggests that large igneous intrusive domains can appear connected to a parent intrusion by a narrow neck, such as a feeder dyke to a sill.

The cross-cutting coherent facies (in the conformable and crosscutting facies subdivision) are likely to represent dykes which are feeders to the stratigraphically higher sills.

Interpretation of crosscutting coherent facies

The other coherent facies which include the Porphyritic andesitic dacite, Pyroxene-olivine-felspar phyric basalt and the xenolithic andesite crosscut nearly all lithologies (excluding the Plagioclase phyric pumice breccia). These facies are thought to represent later stage dykes. They have chilled contacts at both margins and usually crosscut the remnant bedding in the host succession. They are also assumed to be later stage as they cross cut the broadly conformable facies in A Lens (direct contact at 345 m A872).

Relationship of the lithic breccia facies to coherent facies

The Andesitic lithic breccia succession contains a large amount of un-oxidised blocky and irregular minor basalt clasts and abundant andesite clasts. The succession has been intruded by sills. There is no positive evidence for intrusion and dynamic mingling of the sills with this host succession. There is very little evidence that the clasts are pyroclasts as they are rarely vesicular or ragged. Rather, the presence of sedimentary structures including graded bedding and diffuse stratification in the upper portions of the beds and the absence of any widespread jigsaw fit texture (in most lenses) indicates the facies underwent lateral transport before being deposited (similar to the Ba volcanic group in Fiji; McPhie, 1994).

3.7 Summary

Thick (40m thick) successions of *polymictic andesitic lithic breccias* dominate the lithological facies at the Chatree mine, Khao Sai. The breccias are composed mostly of poorly sorted, dense, sub-angular pebbles and rare boulders of andesite, basalt and mudstone fragments. The lower portions of these beds are coarse and clast supported, the upper part is finer and matrix supported. These upper portions are composed of laminated, carbonaceous siltstone and occasional fossiliferous limestone lenses. This facies division has been derived from the break up of a relatively proximal partly emergent andesitic centre and transported by mass transport processes in a subaqueous setting.

A *polymictic silicified pumice breccia* occurs below the andesitic lithic breccias and the Felspar phyric lithic rich pumice breccia and lithic breccia unit occurs above. These breccia facies have also been transported through mass transport processes and reflect relatively voluminous explosive eruption from a felsic centre some distance away.

The succession of *polymictic andesitic lithic breccias* are intruded by a *plagioclase-phyric andesite* and a *sparsely-felspar phyric andesite*. These sills have little interaction with the host package indicating that they intruded sometime after the deposition and consolidation of the *polymictic andesitic lithic breccias*.

Late stage dykes including the fine grained *plagioclase-phyric xenolithic andesite*, *porphyritic andesitic dacite ('Porntherp Porphyry)*, *sparsely hornblende-phyric basalt*, a *pyroxene-olivine-plagioclase phyric basalt*, a *basaltic andesite* and *xenolithic basalt dyke* crosscut the quarts bearing pumice breccia, the andesitic lithic breccias and andesite sills indicating that their intrusion post dates the deposition/intrusion of most other facies.

Chapter 4: Correlation of Facies at the Chatree mine

4.1 Introduction

This Chapter correlates the major volcanic facies in D, C and H lens and A and K prospects at the Chatree mine based from textures & lithofacies. Correlations are made from stratigraphic logs based from drillcore analysis. Locations of drillcore are seen in Figure 4.1. The best correlation is made within lenses and prospects, there is limited correlation between lenses and prospects. Details of individual logs are in Appendix 1.

4.2 Facies and correlation of facies in A and K Prospects

4.2.1 Facies at A and K Prospects

Prospect A occurs on a small hill named Khao Mo. Five drillcore logs were produced from this prospect (drill-hole numbers include; E872, E840, RCD 2104, RD831, E722). K prospect occurs on the south eastern flank of Khao Mo and one drillcore log was assessed from here (DC:2024). Due to the close proximity of A and K propsect, stratigraphic logs from both prospects are correlated.

A-prospect is dominated by the polymictic andesitic lithic breccia and a polymictic andesitic and basaltic lithic breccia. The deepest core drilled (350 m) showed a highly silicified pumice breccia at depth. The polymictic andesitic lithic breccia reaches up to 190 m and comprises multiple mass-flow events. Periodic breaks in the supply of the lithic breccia is reflected by the occurrence of the volcanogenic sandstone and siltstone and limestone. The limestone occurs deep in the stratigraphy, and also higher up. There is also an up sequence change to a greater proportion of finer grained sedimentary facies in the upper portions of many drill-hole indicating a decreasing supply of lithic clasts higher up in the stratigraphy.

The lithic breccia facies are cross cut by the *plagioclase-phyric* and *sparsely-feldspar phyric andesite*. The coherent facies in A and K prospect are thin (5 m thick) in comparison to the other areas in the mine. Figure 4.2 summarises the facies at K and A prospect.

4.2.2 Correlation of facies at A and K Prospects

The limestone occurs in the upper portions of drillcore RCD2024, 2104 1, 872 and 831. In A prospect (Figure 4.3), the *polymictic andesitic lithic breccia facies* is correlated well throughout all selected drillcore. Three separate flow units have been able to be traced throughout the bulk of the drillcore assessed. The volcanogenic sandstone and siltstone marks the upper portion of the slurry flow deposit. The *silicified pumice breccia* occurred at depth in two logs. The *plagioclase-phyric andesite* occurs at depth in the two deepest holes can be correlated (although not shown) and the sparsely feldspar phyric andesite higher up in the stratigraphy can also be correlated (Figure 4.3).

The thicker, massively bedded polymictic andesitic lithic breccia from E872 probobly represents areas that are closer to the source. The higher proportion of finer sedimentary facies (E840) represent areas that are distal to the collapse site.

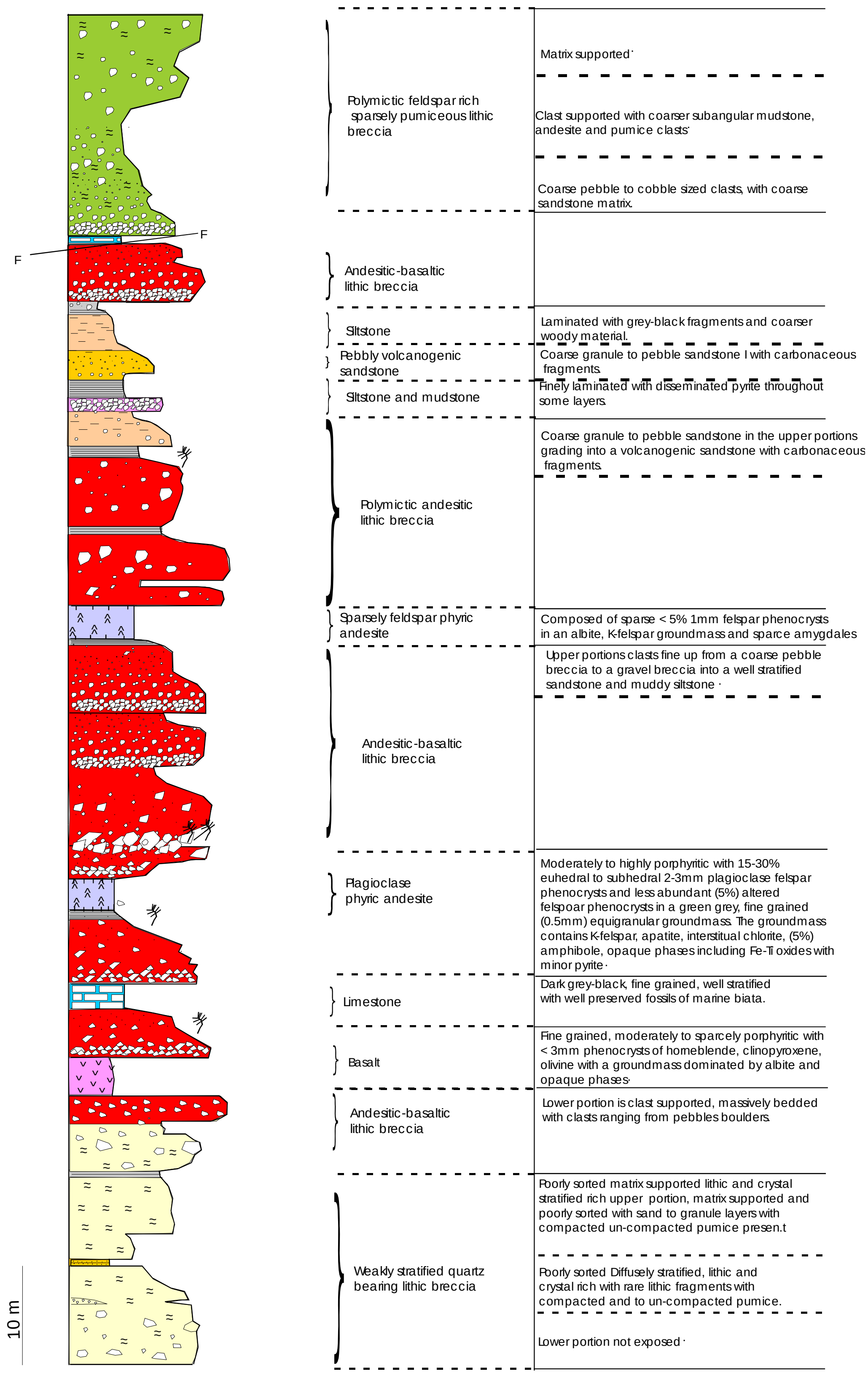
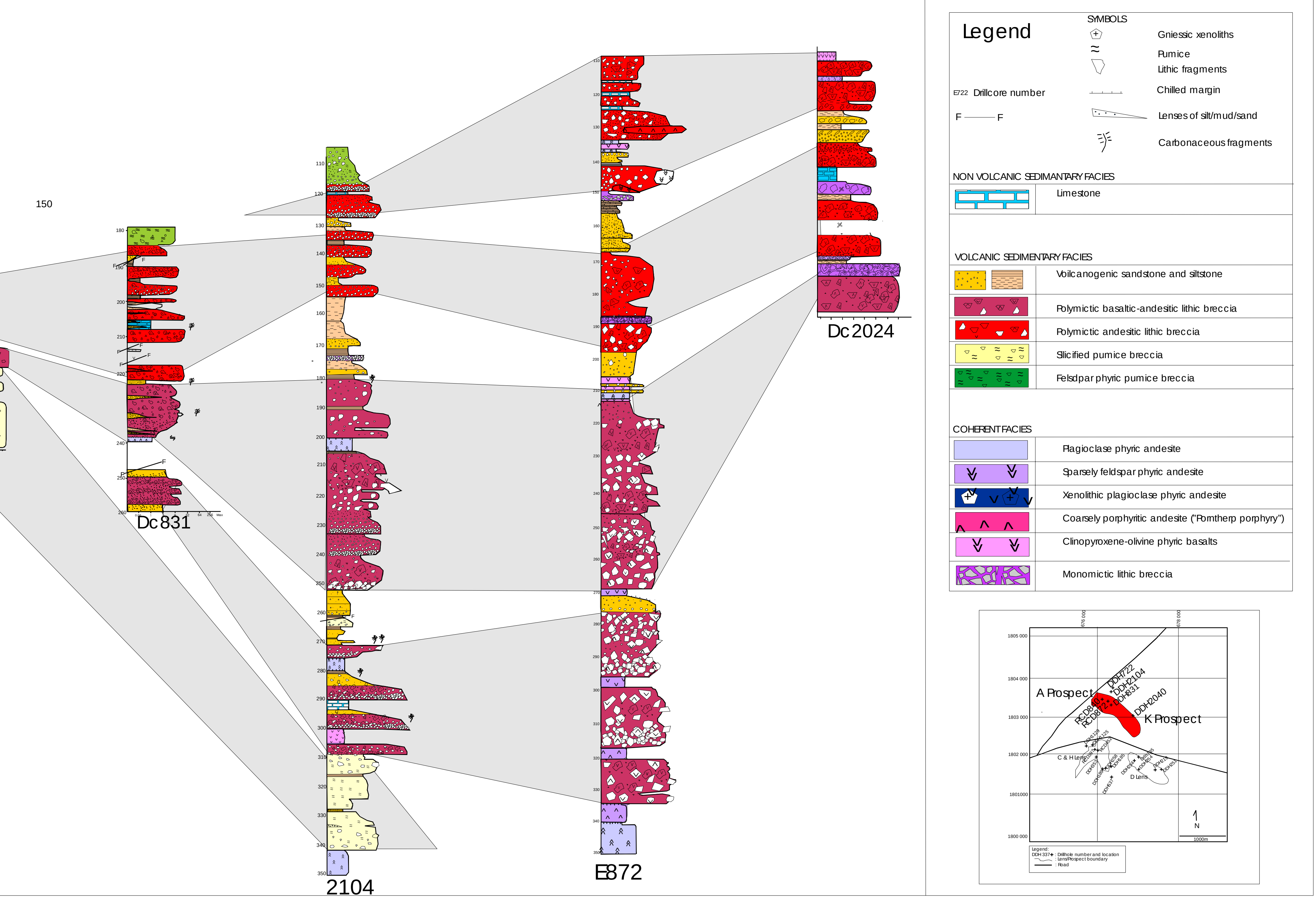


Figure 4.1. *Summary stratigraphic log depicting the major facies in A and K prospects*

Correlation of facies in A and K Prospects



4.3 Volcanic facies and correlation of facies in D Lens

4.3.1 Volcanic facies from D Lens

Six drill core were analysed from D lens (including DDH219, DDH254, DD251, DDh249 and E195). These were dominated by thick intervals of *plagioclase-phyric andesite* and *sparsely feldspar-phyric andesite*. These sills are cross cut by numerous basalt and xenolithic andesite dykes (Figure 4.3).

The volcanic facies have undergone intense alteration evident in the thick intervals of the pseudoclastic facies. The *monomictic andesitic breccia* facies also occurs and is associated with veining and sheared zones.

4.3.2 Correlation of facies from D Lens

The *pseudoclastic facies* is correlated throughout all drillcore. The *xenolithic plagioclase-phyric andesite* is correlated in RC195 and RCD249. The *plagioclase phyric* and *sparcely felspar phyric andesites* are difficult to correlate possibly because thick dykes cross cut most facies in this area (Figure 4.6).

Summary stratigraphic log

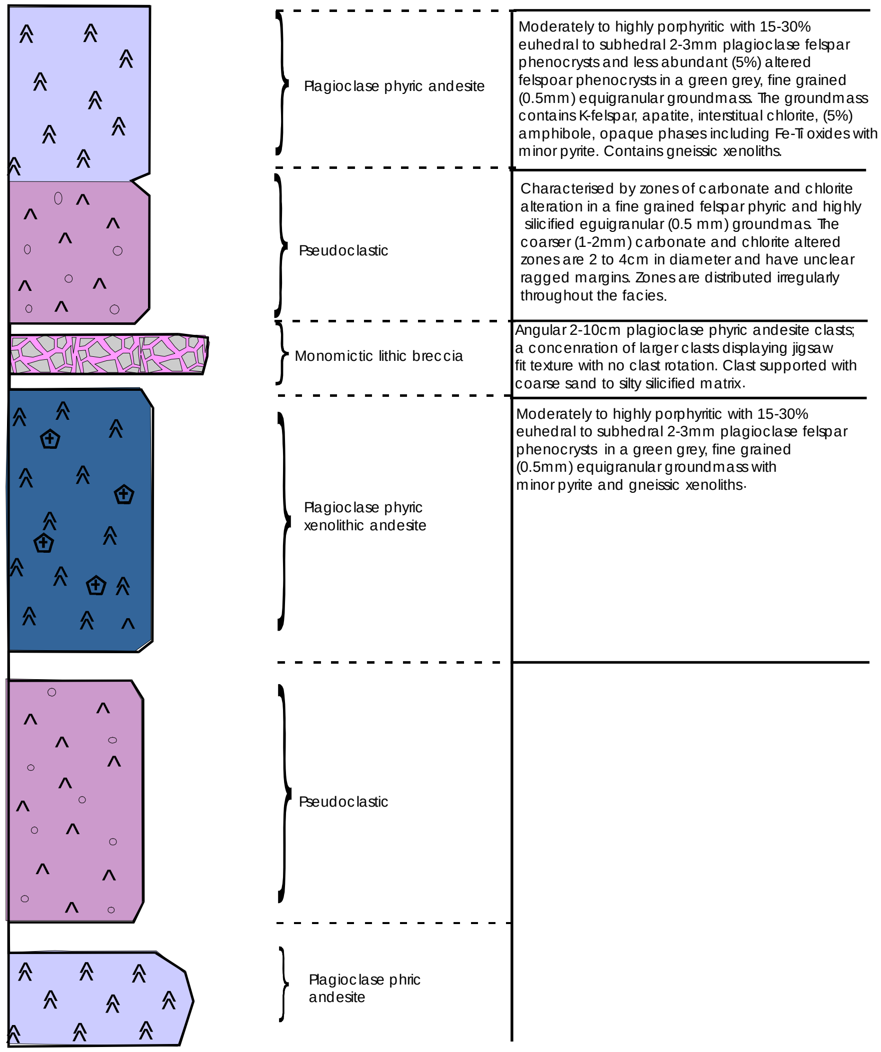


Figure 4.3 *Summary stratigraphic log of the volcanic facies in D Lens*

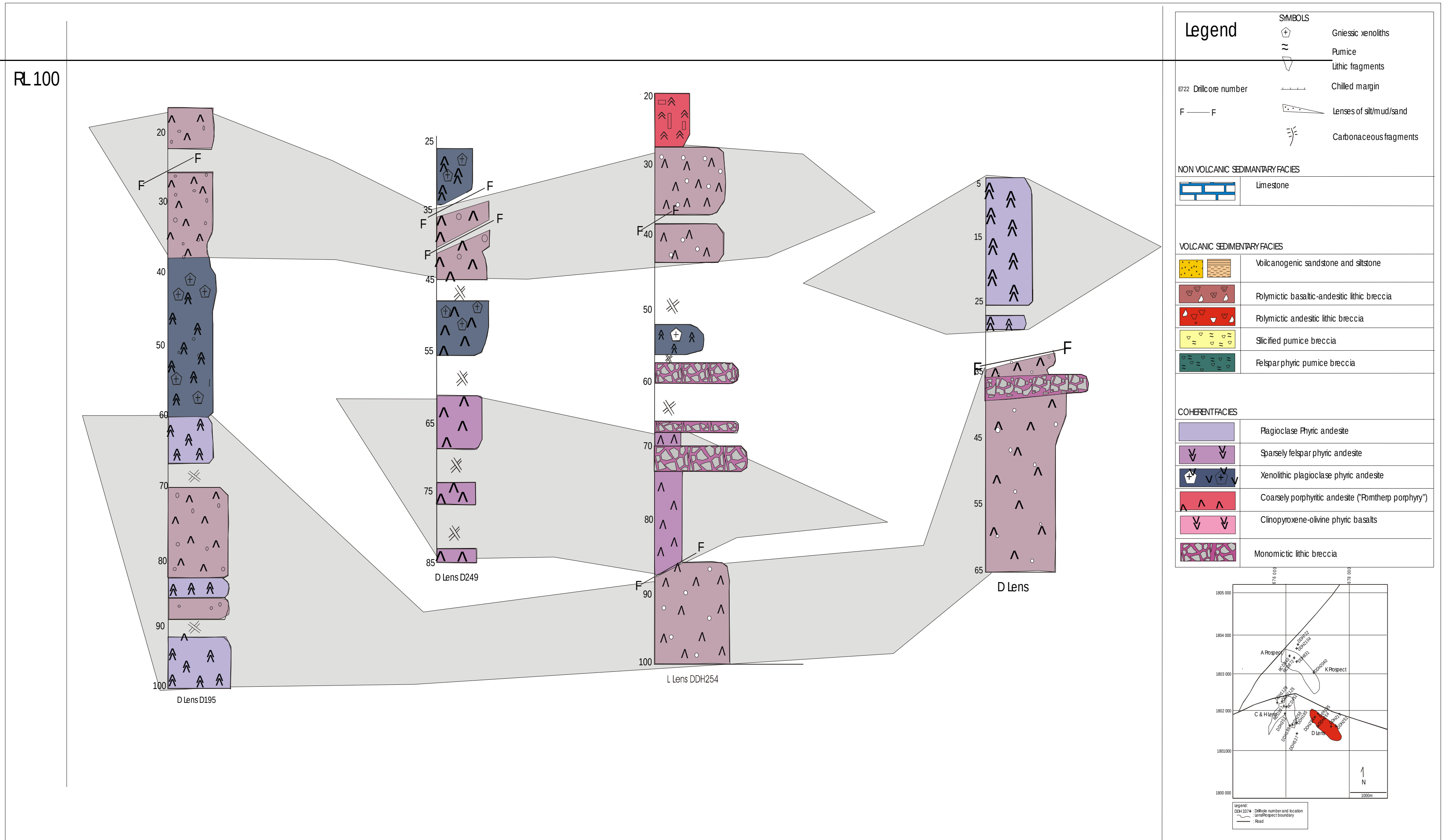


Figure 4.4 Correlation of facies in D lens

4.5 Volcanic facies and correlation of facies in C and H lens

4.4.1 Volcanic facies of C and H Lens

C and H lens are dominated by the *sparsely* feldspar-phyric andesites and *plagioclase phyric andesites* and volcaniclastic facies. The plagioclase phyric andesite is up to 50 m thick in C lens. Volcano-sedimentary facies include a thick 120 m interval of feldspar phyric sparsely pumiceous lithic breccia, *polymictic andesitic lithic breccia* (20 m thick) and monomictic andesitic lithic breccia (20 m thick). Andesitic lithic breccias are present but less widespread than A prospect (figure 4.4).

4.4.2 Correlation of facies in C and H lens

Correlation can be made between the *plagioclase-phyric andesite* and the *sparsely felspar phyric andesite*. The polymictic andesitic lithic breccia facies higher up in the stratigraphy and the monomictic andesitic lithic breccia facies can be correallated between drillcore (figure…).

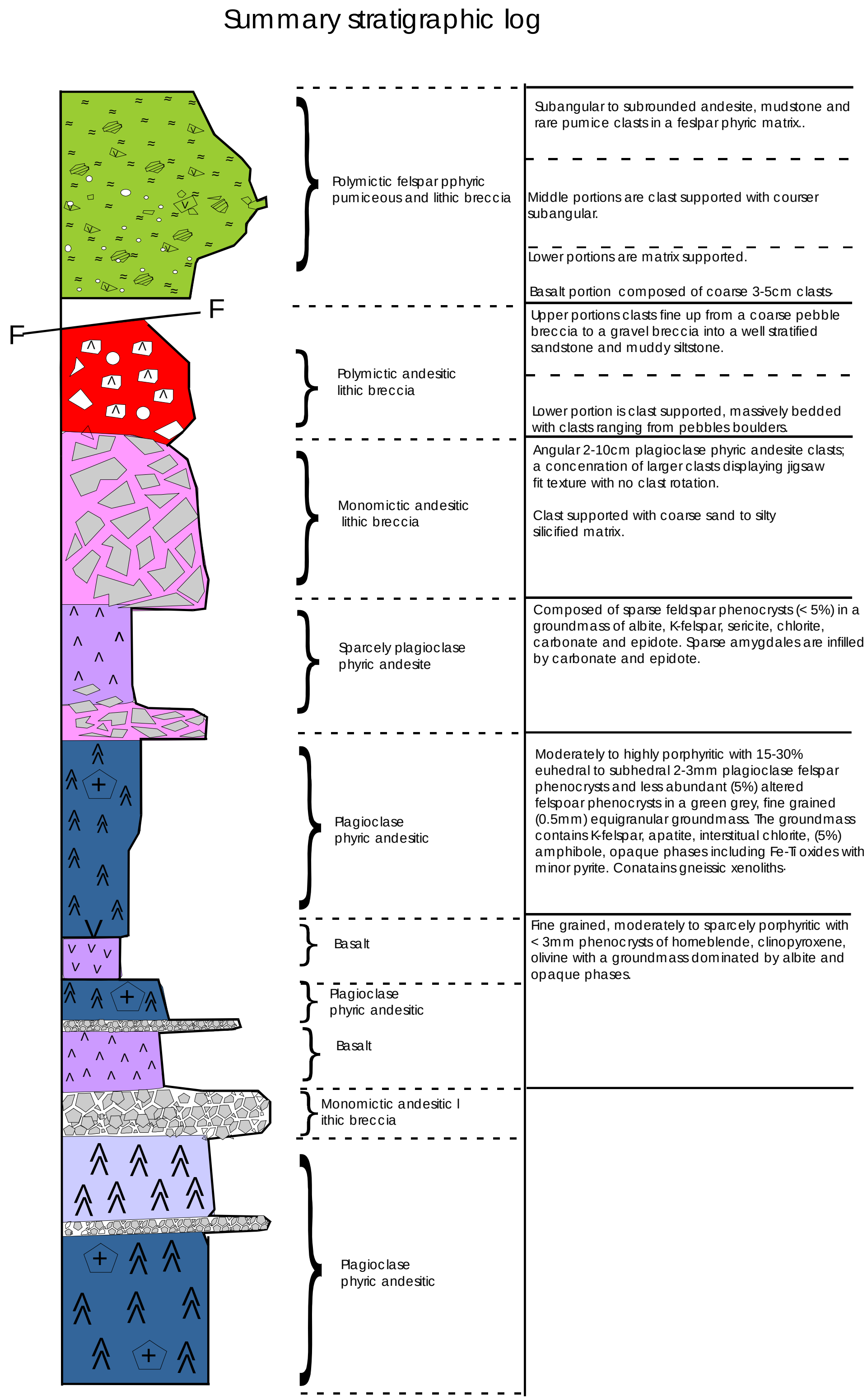
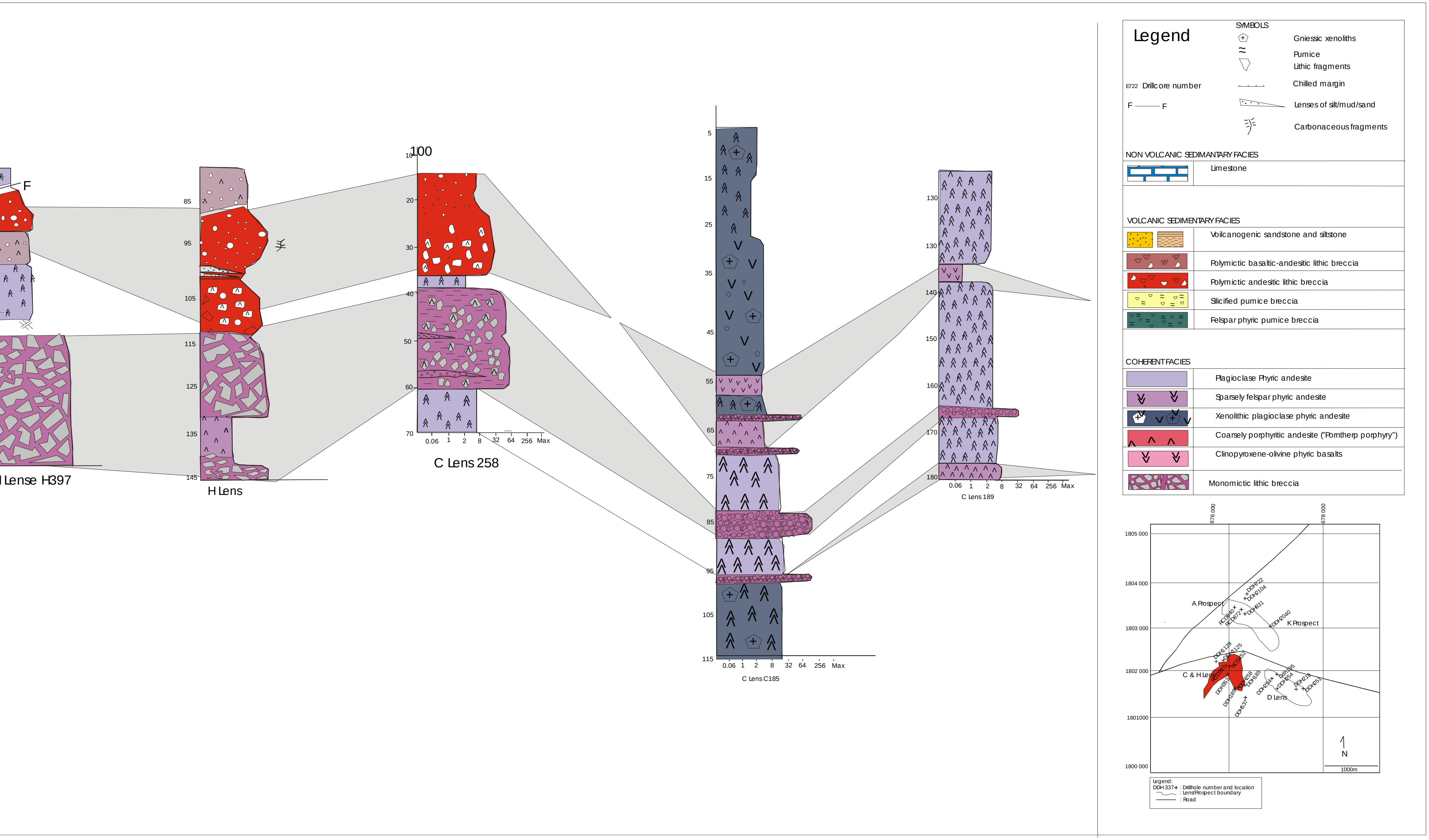


Figure 4.5. Summary stratigraphic log for C and H len.s



f facies from C and H lenses

5.5 Position of Mineralisation

Mineralisation is associated with veining, faulting and sheered zones in the mine and is related to coherent facies in D and C and H lens. Mineralised veins. The occurrence of the thick intervals of the pseudoclastic facies in D and C /H lens is associated with the sills Mineralised veins are also hosted in the polymictic andesitic lithic breccia and Polymictic andesitic-basaltic lithic breccia and the pumice breccia at the base of the stratigraphy in A and K prospect. The felspar phyric sparsely pumiceous lithic breccia lacks any appreciable mineralisation but is cross cut by veins and brecciated in some areas. The dykes that cross cut the succession are mineralised.

5.5 Summary

A and K prospect are dominated by the polymictic andesitic lithic breccia and polymictic andesitic lithic breccia facies. From the correlation of separate beds, three separate debris flow (slurry flow) deposits can be identified.

In C and H lens the stratigraphy is dominated by coherent facies and the volcano-sedimentary facies to a lesser extent. The felspar phyric pumice breccia is thick and not laterally extensive.

The coherent facies are the dominant facies type in D lens. These facies are cross cut by xenolithic andesite and basalt dykes making the sills difficult to trace or correlate though drillcore.

Mineralisation is associated with veins located proximal to the sills and the polymictic andesitic lithic breccia. The felspar phyric breccia lacks any appreciable mineralisation.

Chapter 5 : An assessment of selected volcanic facies in Loei-Petchabun Volcanic Belt

5.1 Chapter overview

This Chapter describes selected andesitic to dacitic Permo-Triassic volcanic lithologies in the Petchabun area, and the Triassic volcanic and non volcanic facies located further south on Koh Chang Island. Outcrop in the Petchabun area was assessed at Khao Phanom pa, Wichian Buri and Khao Sap Noi (refer to Figure 5.2). Outcrop from Koh Chang Island was assessed at Ban Khlong Phran, Ban Hat Sai Khao, Ban Khlong Kloi and Khao Khlong Mayom and Ban Than Mayom falls (Figure 4.2).
This chapter aims to:

1. Provide information about the volcanic rocks outside of the Petchabun region and the Chatree mine,
2. describe and interpret of the volcanic facies from Koh Chang Island,
3. describe selected volcanic rocks in the Petchabun region in terms of their petrography and lithofacies associations.

5.2 Limitations and scope

Assessment of outcrop in the field was limited to often poor exposures. The outcrop assessed in the Petchabun region briefly and descriptions mainly focus on the textural characteristics from samples collected.

Koh Chang Island is located in a national park. The outcrop is obscured by thick vegetation and exposures were limited. Good exposures at the waterfalls are located attourist centres where sampling through hammering the rock was not permitted. This provided some limitation to the scope of the descriptions in this chapter.

5.3 Selected volcanics in the Petchabun region

5.3.1 Amphibole-plagioclase phyric andesite at Khao Panompa

Khao Panompa is situated west of Khao Sai and occurs adjacent to an extensive area mined for alluvial gold (refer to Figure 5.1). The andesite is exposed at a small quarry; it is massive and contact relationships were not encountered during time in the field.

The andesite is moderately porphyritic with a fine-grained (<0.5 mm) equigranular grey to green groundmass with 0.7 mm 10 % subhedral plagioclase feldspar phenocrysts and acicular to tabular, 20 %, 4 to 6 mm amphibole phenocrysts and minor (<5 %) tabular to blocky (2-3 mm) biotite phenocrysts.

This non vesicular; coherent facies is crosscut by amphibole bearing veinlets also containing epidote and sphalerite along the perimeter of the veins. Free gold associated with pyrrhotite, chlorite and chalcopyrite also occurs. Plagioclase feldspar phenocrysts are replaced by epidote.

5.3.2 Polymictic pumiceous and andesitic lithic breccia at Khao Sap Noi

A 10 m section of outcrop was observed 1-2 km south of Khao Sap noi, north of Khao Sai. This is a poorly sorted, clast supported and massively bedded unit composed of angular to splintered clasts in a finer grained silicified matrix. There are 3 different clast types.

The most abundant clast type is angular, 3-7 cm. These clasts are porphyritic with 1-2 mm tabular (15-25 %) plagioclase felspar phenocrysts in a finer grained (<2 mm) equigranular plagioclase phyric groundmass. The second most abundant clast type is 3 cm diameter composed of 10%, 2 mm tabular plagioclase felspar phenocrysts in a red-purple equigranular (<2 mm), with 5% clinopyroxene groundmass with 10% infilled amygdales.

The third most abundant clast types are 5-6 cm subangular, pumiceous fragments which contain 2-3 mm vesicles. The least abundant clast is 2-4cm across, consisting of fine grained (<1mm) angular mudstone.

The facies is clast supported within a medium-grained, green to grey (2 mm) sandy to silty crystal rich groundmass (containing quartz and felspar crystals). Quartz veins crosscut the outcrop. These veins are ragged (3-7 cm across) and contain breccia fragments.

This facies has similar characteristics to the *polymictic andesitic lithic breccia facies* assessed in drillcore at the Chatree mine. The facies is polymictic and the clasts in this outcrop are also very angular indicating that there has been minor reworking through transportation.

5.3.3 Polymictic andesitic and basaltic lithic breccia at Wichian Buri

A 15 m long outcrop was assessed outside of the township of Wichian Buri (Figure 1.2). This outcrop showed a crudely bedded, matrix-and clast-supported facies dominated by polymictic, poorly sorted angular clasts. The western portion of the outcrop is composed of finer grained (5 cm) matrix supported clasts. The medial section of the outcrop contained coarser grained generally clast supported fabric with some matrix supported domains. The eastern end of the outcrop contains larger clasts (up to 30 cm) which are matrix supported.

The most dominant clast type is porphyritic andesite, containing 2-3 mm (15%) tabular plagioclase felspar phenocrysts. The groundmass is finer grained and equigranular. These clasts are angular and range from 5 to 30 cm. A more oxidised or reddened coarse grained andesite clast is also present and contains 30 % plagioclase- feldspar phenocrysts

The second clast type consists of a fine grained (0.06 mm) equigranul basalt clast composed of pyroxenes, Fe-Ti oxides and plagioclase. The clasts are subangular, 2-5 cm grey to black, equigranular There are also fine grained (0.06 mm) subangular 2 cm mudstone clasts. The matrix is generally 1-2 mm dominated by plagioclase rich silt-sand.

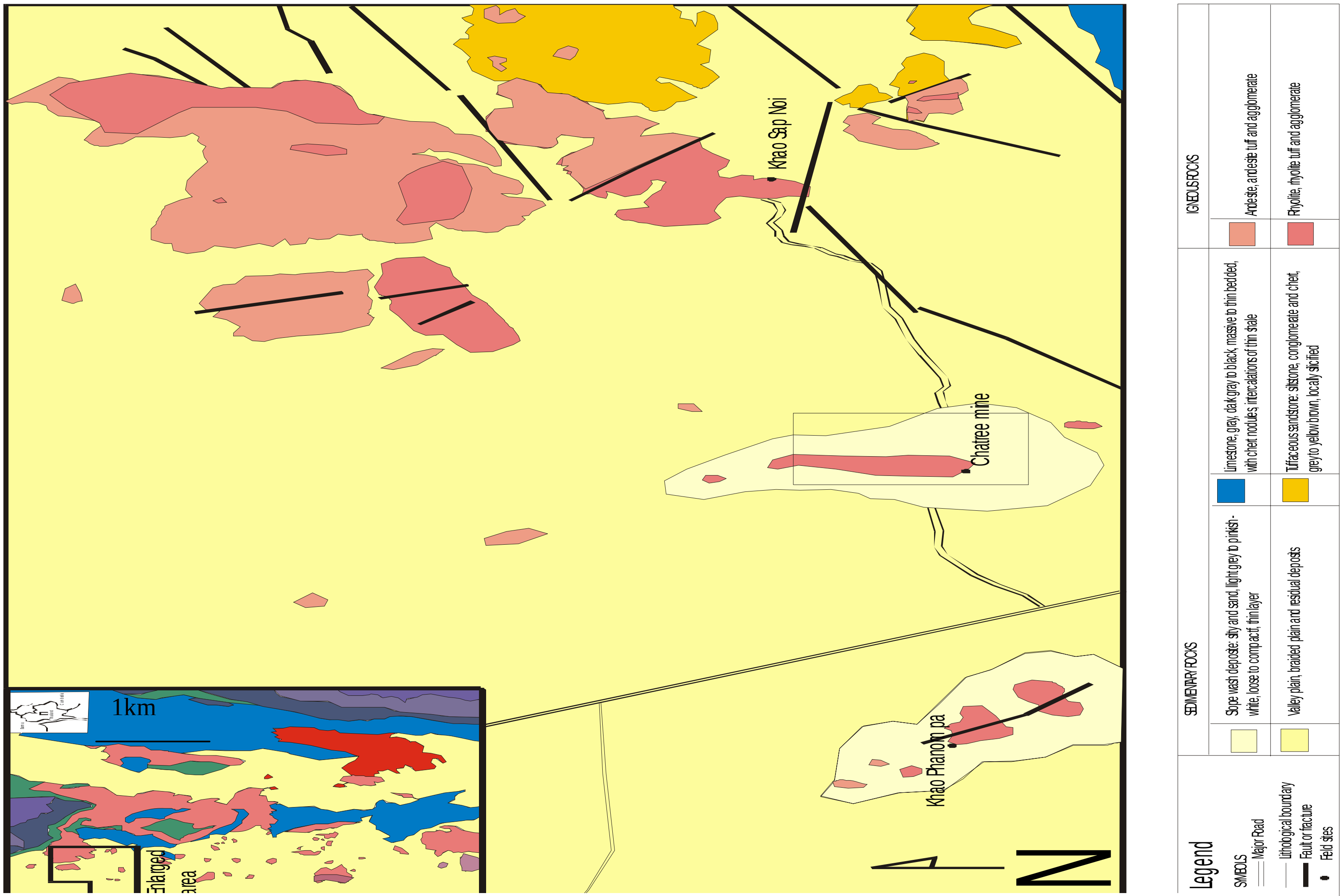


Figure 5.1 *Geological map of the Thab Khlo region (Petchabun province) showing the location of the Chatree mine, and locations of outcrop mentioned in the text (Radmanee, 1993)*

5.4 Volcanic and non-volcanic facies at Koh Chang

On Koh Chang Island (Figure 5.2) a flow banded spherulitic rhyolite and a rhyolitic pumice breccia was assessed, these volcanic rocks were associated with Triassic siltstone and sandstone.

5.4.1 Pebbly Sandstone

A pebbly sandstone was assessed at Hat Sai Khao. This sandstone is medium bedded (50 cm) and moderately to poorly graded. It is composed of sparse coarse 3 to 2cm sub-rounded mudstone and quartz phyric pebbles in a matrix composed 1mm rounded quartz grains. 2-3cm. In the upper portions of the beds 5cm thick intervals of silt occur. The silt is purple-cream and has a weak cleavage. The siltier layers lack any coarse clasts. The cleavage strikes 4degrees and dips 40degrees NW.

Further north, near Ban Khlong Son sandstone also outcrops. This sandstone is also medium grained consisting of plagioclase and felspar grains. Sparse pebbles also occur. At this outcrop the sandstone is reddened and has rare shell casts.

5.4.2 Rhyolites

Flow banded spherulitic rhyolite

Observations of flow-banded spherulitic rhyolite was made at Khlong Phlu and Than Mayom waterfall (outcrop locations refer to figure 5.2). The rhyolite consists of 2-4 mm, subhedral to euhedral, plagioclase feldspar phenocrysts and 5-10% round quartz phenocrysts in a plagioclase-phyric, quartz rich groundmass. In hand specimen and thin section, 60-80%, 0.5 to 3.0 mm spherulites were observed. In some samples, chains of bowtie spherulite were present. Flow banding strikes a NE-SW direction.

Monomictic rhyolitic lithic breccia

A monomictic rhyolitic lithic breccia was seen at Khlong Phlu waterfall. This breccia is composed of quartz rich 30 cm angular clasts. The facies is clast supported and the matrix is composed of smaller 2-3 cm clasts in a quartz-rich groundmass.

Interpretation

Eruption style and environment of eruption

The rhyolite is porphyritic and shows flow banded textures. These characteristics are typical for lava domes and shallow intrusions that have formed from an effusive eruption. Contact relationships were poor in the field, however the lack of any peperitic margins indicates a more extrusive eruption style.

The lava forms two emplacement units. There is a finer spherulitic rhyolite at Ban Kai Bao and a second emplacement unit at Ban Khlong Phrao and Ban than Mayom which has coarser spherulites and a flow banded texture. The dimensions are relatively small, being less than 500 m by 500 m. The dimensions are more typical for an extrusive dome that has erupted in a more subaqueous setting . The associated sandstone with rare fossil casts combined with the autoclastic, margin indicates that the rhyolite probably intruded in a subaqueous setting.

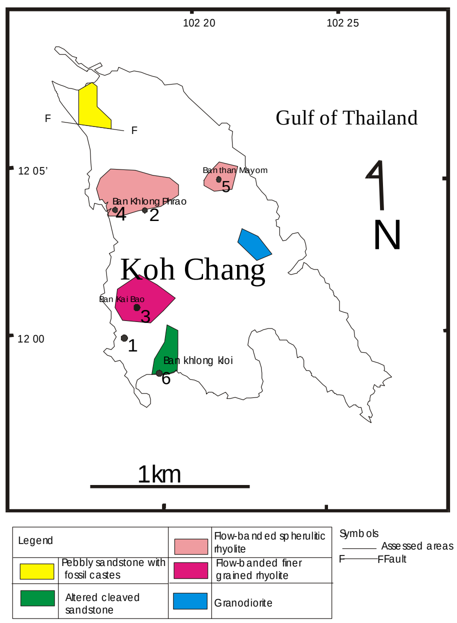


Figure 5.2 *Geological fact-map showing lithologies seen in the field*

5.5 Summary

Lithologies that are more coarsely porphyritic occur close to the Chatree mine (Khao Phanom pa). This litho facies is associated with alluvial gold in the Petchabun province. Facies that are quite similar the polymictic andesitic lithic breccia at the Chatree mine was seen at Khao Sap Noi located close to the Chatree mine and at Wichian Buri which occurs further south.

On Koh Chang Island a flow banded spherulitic rhyolite and associated autobreccia was encountered. This facies is interpreted to be eruted from an effusive eruption style and may represent an extrusive possibly subaqueous lava flow or dome.

Chapter 6: Geochemistry and Petrology

6.1 Methodology and chapter overview

Major and trace element geochemistry of sixteen representative samples selected from the Chatree mine and other localities within the LVb (Khao Sap Noi, Khao Phanompa and Koh Chang) have been investigated in this study. The samples were analysed using XRF (Robinson, 2000). All samples were crushed in a tungsten carbide mill. The samples contained very little vein material and no xenoliths. In addition, samples from previous studies (Dedenczuk, 1998, and Kromkhun, 2004) were replotted to provide a greater database for geochemical assessment

The samples from the Chatree mine include the pumice breccia facies, coherent crosscutting and generally conformable andesites and clasts in the lithic breccia facies. Samples from other areas in the Loei-Petchabun Volcanic belt (LVb) included andesites from Khao Phanom pa, plagioclase- hornblende porphyry from Khao Sap Noi and the flow banded spherulitic rhyolite from Koh Chang Island.The sample name and number is given in Table 6.1.

Specific aims of this Chapter are:

1. to give the petrographic and geochemical characteristics of the volcanic rocks at Khao Sai,
2. To interpret the tectonic setting of the volcanics at Chatree mine (and other regions of the Loei- Petchabun Volcanic belt) on whole rock geochemical data,
3. to compare the results of this study to those of Dedenczuk (1998) and Krompkhun (unpublished data, 2004), and to relate this work to more regional studies completed by Intasopa (1993) and Singharajwarapan (1994).

6.2 Previous work

The volcanic units in the (LVb) are considered by Intasopa (1993) to have erupted during three discrete epochs; the late Devonian-Carboniferous, the Triassic and the Tertiary. Volcanism (mafic to intermediate compositions) in the Petchabun Province (including the Chatree mine) is thought to have erupted during the Late Palaeozoic. Intasopa (1993) dated the Devonian tholeiitic basalts in this region (from holocrystalline augite and plagioclase) based on Rb-Sr isochron age of 361 ± 11 Ma. Intasopa (1993) also dated andesite, basaltic andesites and spilites (see Chapter 2) as Triassic, based from absolute $^{40}Ar/^{39}Ar$ ages of hornblende as 238 ± 4 and 247 ± 12. the basaltic rocks I have variable K_2O (up to 0.8 wt %) Na_2O and P_2O_5. the volcanics in the LVb are typically sub alkaline, enriched in Rb, Ba, Th, Ta and K relative to Mid-Ocean Ridge Basalts MORBs). She concluded multiple stages of evolution of the Loei-Petchabun Volcanic belt. Sr-isotope work done by Intasopa (1993) suggests that the magmas were sourced from a heterogeneous mantle (Intasopa, 1993).

Singharajwarapan et al., (1994) undertook research on the Pak Pat volcanics, located in the Sukhothai fold belt, east of the LVb in the Sukhothai fold belt. These are also Permo-Triassic in age and include lavas, breccias with compositions ranging from basalts to dacites. Based from Rare Earth element (REE) patterns and the inferred tectonic setting the Pak Pat volcanics have similar character to the volcanic rocks in the Loei volcanic belt and comparisons between the two belts will be drawn through this study.

Dedenczuk (1998) undertook geochemical studies on the andesites and basaltic andesites at the Chatree mine, Khao Sai focussing particularly on ratios of major and trace element compositions. This assessment characterised the volcanic rocks (the generally conformable coherent facies and crosscutting coherent facies) as sub alkali and having Island Arc affinities (Dedenczuk, 1998), on further analysis of his data, it is more likely that the volcanic rocks from Chatree mine are from a Continental margin. Dedenczuk (1998) made some discrimination between the generally conformable and the crosscutting coherent facies (refer to Chapter 2) based on major and trace element analysis.

Large Late Triassic granitoid bodies intrude the LVb (Cobbing et al.) These granitoids are thought to have been emplaced prior to the suturing of the Indochina and Shan-Thai Terranes. The occurrence of these bodies indicates significant crustal thickening.

6.3 Petrography

The analysed volcanic rocks from the Chatree mine are moderately to poorly porphyritic. The samples for analysis have phenocryst assemblages that are least replaced by chlorite, epidote and sericite. Plagioclase phenocrysts are the most abundant type of phenocrysts. They are subhedral to euhedral and are largely replaced by calcite, epidote and sericite. Groundmass constituents are predominantly lath shaped plagioclase and titanomagnetite.

The volcanic rocks sampled elsewhere in the LVb range from porphyritic to equigranular. The flow banded spherulitic rhyolite from Koh Chang Island (sample: Koh Chang and 2004) is moderately porphyritic composed of well developed spherulite textures and subhedral to euhedral K-feldspar phenocrysts. The groundmass is composed of eguigranular quartz which has been altered to minor chlorite and sericite.

The andesite from Khao Phanom pa consists of plagioclase and ambhibole phenocrysts in an equigranular groundmass. This groundmass consists of actinolite, titanomagnetite and quartz. Cross-cutting quartz veins also contain white mica and epidote. Samples assessed for geochemical analysis were free of this vein material. The moderately to coarsely porphyritic andesite from Khao Sap Noi contains tabular euhedral phenocrysts with microphenocrysts of clinopyroxene, Fe-Ti oxide laths and amphibole. Groundmass constituents are predominantly plagioclase, very minor clinopyroxene and oxides.

6.4 Alteration

Based on the occurance of weak chlorite throughout most rocks of the district (in areas away from the Chatree mine), it appears that the rocks in the LVb have experienced sub-greenschist facies regional metamorphism (Della Pasqua and Khin Zaw, 1999, Singharajwarapan et al., 1994). Metamorphism acts to mobilise major elements in rocks and therefore providing accurate information about the tectonic setting and source characteristics of altered rocks can be difficult. However, the least mobile elements are used in this study to provide information about the origin and tectonic setting of the Chatree mine and other areas in LVb.

Mobilisation of major elements under hydrothermal alteration and weathering can be assessed in terms of alkalis (Na+K) and silica. Hughes (1973) reports that rocks affected by some form of alteration will fall outside the ‘igneous spectrum’ as illustrated in figure 6.1 Four samples analysed as part of this study clearly fall outside this spectrum.

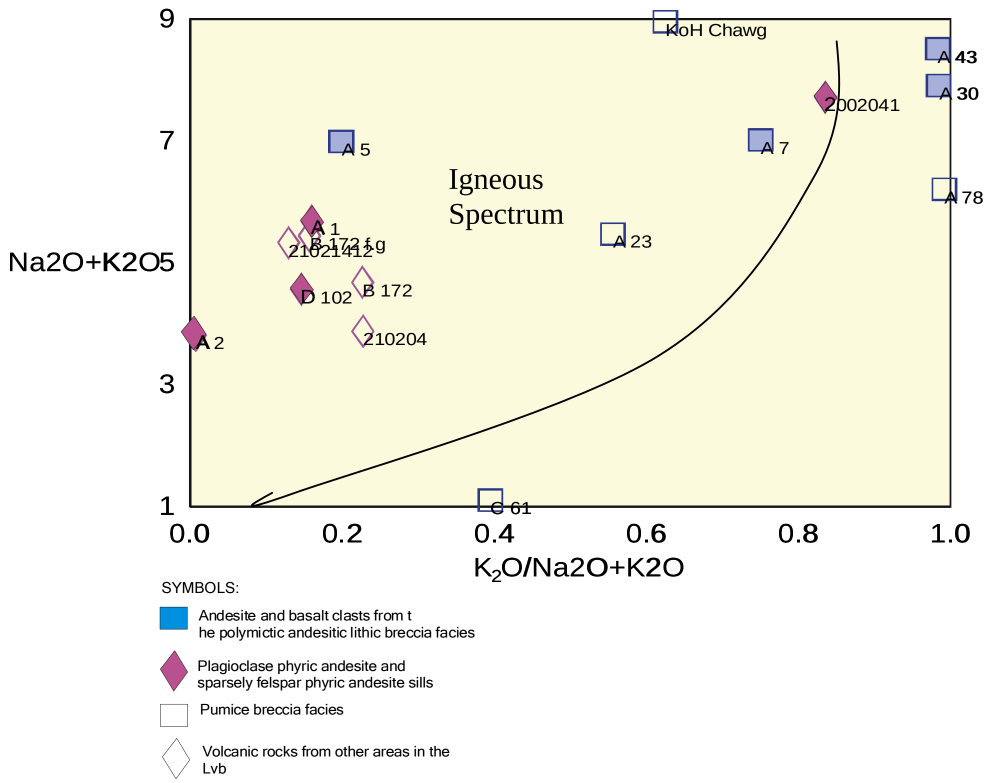
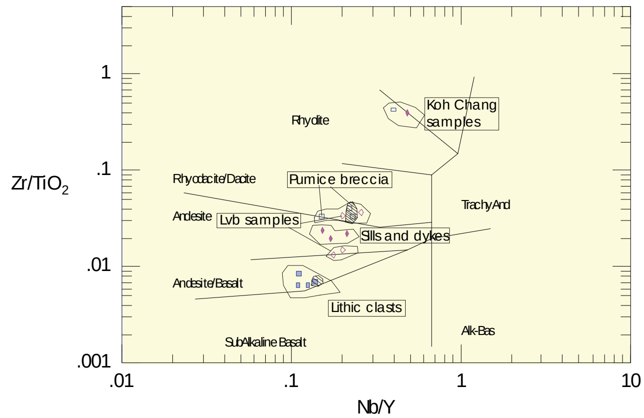


Figure 6.1 *Na-K variation diagram showing "Igneous spectrum" for altered rocks. After Martinsson (1997). Sample numbers refer to table 5.1.*

These samples are andesite (A43, A Prospect) and basalt clast (A30, A Prospect) from the *polymictic andesitic lithic breccia facies* and also the *feldspar phyric pumice breccia* (C61, C Lens) and a *polymictic silicified lithic breccia* (A78, A Prospect) from the Chatree mine. Petrographically, the andesite and basalt clasts are composed of mineral assemblages that have been replaced by silica and chlorite. The pumice breccia samples show evidence of undergoing intense leaching. Petrographic and chemical data are consistent with these samples being affected by alteration and their mineralogy consists of quartz, sericite, chlorite and a sedimentary component. All other rock samples fall within the igneous spectrum.

6.5 Geochemical classification

According to the classification scheme of Winchester and Floyd (1977) (Figure 6.2) the rocks from the Chatree mine consist of andesites and basaltic andesites with the pumice



breccia facies falling within the field of dacites. The samples collected from outside the Chatree mine, in the LVb, consist of rhyolites (Koh Chang), dacites (Khao Sap Noi) and andesite (Khao Phanom pa). The classification of Winchester and Floyd (1977) is used.

Figures 6.2 *(a) The Zr/TiO2 and Nb/Y rock discrimination diagram (after Winchester & Floyd, 1977) from the andesite andesite/basalt clasts from the polymictic andesitic lithic breccia, andesite sills and dykes from the Chatree mine and Khao Phanom pa, 3. represents the field for the polymictic andesitic lithic breccia facies from the Chatree mine and the Porphyry from Khao Sap Noi. 4. shows the rhyolite samples from Koh Chang Island.Dashed lines show samples that fall outside the igneous spectrum.*

Compared to Figure 6.3, in a total alkali vs silica diagram, the rocks from the Chatree mine and the LVb fall in a similar compositional field although some samples from the Chatree mine fall into a more transitional intermediate field. The LVb samples and pumice breccia samples are clearly affected by alkali depletion.

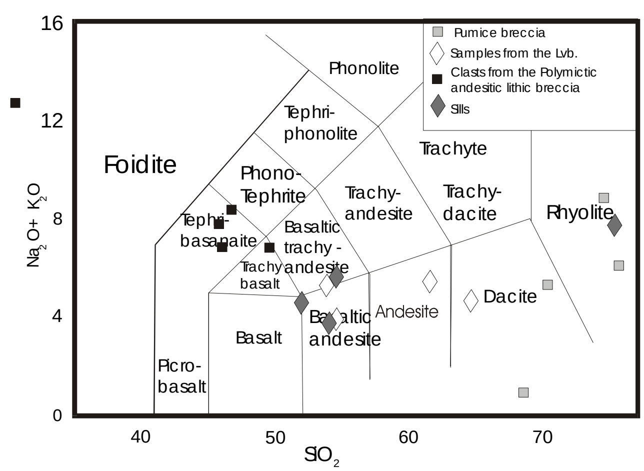


Figure 6.3 *Total Alkali vs SiO_2 variation diagram for the samples from Chatree and other samples collected in the LVb.*

The AFM diagram shown in figure 5.4 highlights the calc alkaline nature of most of the altered Loei rocks, with some being more transitional into the tholeiitic series.

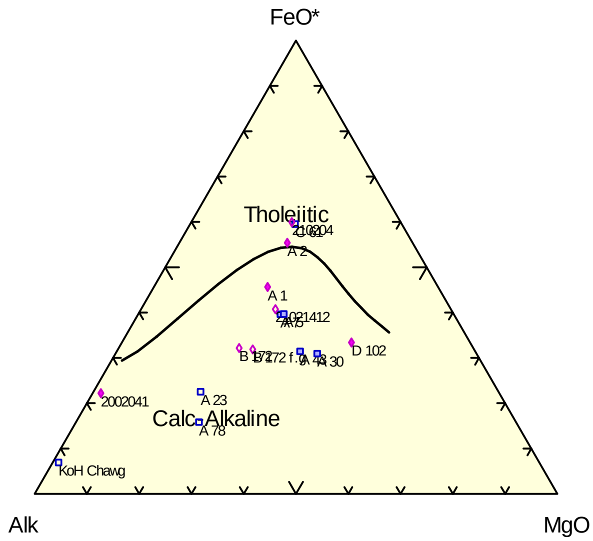


Figure 6.4 *AFM diagram of the samples from the Chatree mine and LVb. Tholeiitic and Calc-Alkaline fields from Rollinson (1997)*

6.6 Major and trace element compositions

To minimise the effect of element mobility, major and trace element variations are plotted against Zr/TiO_2 values (figures 5.5-5.9 in Appendix 2) as a measure of differentiation. Information from each samples can be seen in table 5.1.

6.6.1 Basalt and Andesite clasts from the Chatree mine

The basaltic andesite samples from the Chatree mine (sample numbers A43, A7, A5 and A30) have a variation in SiO_2, TiO_2, FeO, CaO and MgO in comparison to a small range in Zr/TiO_2. The andesite and basalt clasts from the lithic breccia facies are characterised by low SiO_2 (45-50 wt %), P_2O_5 (~0.2 wt %) and TiO_2 (0.5 wt %). They have high Al_2O_3 (18-20 wt %) and MgO contents (6-10 wt%) and variable amounts of K_2O (~2-8 wt%), Na_2O (~1-6 wt %), MnO (0.1-0.6 wt %) and CaO (0-5 wt %).

Trace element abundances are characterised by low Nb, Cr, La, Pb, Ni, Zr, Zn, Y, Ce and Nd and higher in mobile trace elements; Cu, Ba, Sc and V. Figure 6.10 shows the MORB normalised trace element compositions of the andesite/basalt rocks (after Pearce, 1983). The samples are depleted in Nb relative to Ce and are enriched in Ba and Rb.

Sample Number	**Sample name and Location**	**Sample Number**	**Sample location**
C61	Feldspar phyric pumice breccia; Khao Sai (surface, C Pit)	**A2**	Sparsely feldspar phyric andesite, Khao Sai (A872, 337.3m)
A43	Andesite clast, Khao Sai (DC2104, 216m)	**A23**	Weakly compacted pumice breccia; Khao Sai (A2104, 339.2m)
A78	Silicified pumice breccia, Khao Sai (RC722, 162.6m)	**A1**	Plagioclase phyric andesite; Khao Sai (A872, 348.4m)
A7	Andesite (clast with amygdales); Khao Sai (A872, 285.5m)	**B172**	Coarser grained plagioclase hornblende porphyry from Khao Sap Noi
210204	Khao Panompa andesite	**21021412**	Horneblende phyric porphyry at Ban Dong Chareon
B172	Fine grained Plagioclase-horne blende porphyry; Khao Sap Noi	**A5**	Andesite clast; Khao Sai (A872, 325.4m)
2002041	Flow banded spherulitic rhyolite from Koh Chang Island	**D102**	Amphibole – plagioclase phyric andesite (?); Khao Sai (D195,87.4m)
, Koh Chang	Flow banded spherulitic rhyolite Koh Chang Island	**A30**	Basalt clast, Khao Sai (A2104, 301.3m)

Table 5.1 Sample number, facies type and location of outcrop

6.6.2 Plagioclase phyric and sparsely felspar phyric andesites from the Chatree mine

The *plagioclase-phyric* and *sparsely feldspar-phyric andesites* from the Chatree mine (sample numbers D102, A2, and A1) also show a small variation in SiO_2, TiO_2, FeO, CaO and MgO in comparison to a small range in Zr/TiO_2.

The *plagioclase phyric* and *sparsely felspar phyric* andesites are have low K_2O (~1 wt%) medium to low SiO_2 (55 wt %), Al_2O_3 (15-17 wt %) and TiO_2 (1.5 – 0.9 wt %). They have high CaO (5-8 wt %) and P_2O_5 and Na_2O (3.5-5 wt %) and variable amounts of MnO (~0.2 wt %), MgO (~4 wt %) and CaO (0-5 wt %). The plagioclase phyric andesite from D lens (D102) has high MgO (9 wt %).

Trace element abundances are characterised by low Ba, La, Ce, Nb, Rb, Y, Pb, Zn, and Nd and higher As, Ni, Sr and V. Figure 5.11 shows the MORB normalised trace element compositions of the andesites (after Pearce, 1983). The sparsely felspar phyric andesite is depleted in Ba whilst the plagioclase phyric andesites are relatively enriched. All samples are depleted in Nb.

6.6.3 Pumice breccia facies from the Chatree mine

The *polymictic feldspar rich pumice breccia* facies and *polymictic silicified pumice* breccia from the Chatree mine (sample numbers A23, C61, A78) show variation in SiO_2, TiO2, FeO, CaO and MgO in comparison to a small range in Zr/TiO_2.

The pumice breccia facies have low TiO2 (O.25 wt %), MnO(>0.1 %), Al2O3 (10-14wt %) and MgO (1-2 wt %). The samples have high SiO_2 (68-78 %) and variable amounts of CaO (~0.5-5 wt %), Na_2O (~.01-2.5 wt %) and K_2O (~1-6 wt %).

Trace element abundances are characterised by low Zr, Nb, Cr, Ni, Zn, Pb, As, Y, Ce, and La and higher Cu, Rb, V, Sc, Sr and V. Figure 5.12 shows the MORB normalised trace element compositions of the pumice breccia facies (after Pearce, 1983). The pumice breccia facies show enrichment of Ba and Rd and depletion of Nb, P and Ti.

6.6.4 Andesites, rhyodacites and rhyolites from the LVb

The basaltic andesites, rhyodacites and rhyolites from the LVb (sample numbers 2104, 21021412, B172, and Koh Chang) show large variation in SiO_2, TiO_2, FeO, CaO and MgO in comparison to a small range in Zr/TiO_2. The samples from the LVb can be divided into two respective groups based from Zr/TiO_2 signatures. The Koh Chang Group has a higher Zr/TiO_2 ratio compared to the Petchabun-LVb group.

The andesites from the LVb group include samples from Khao Phanom pa (sample number 210204) Ban Dong Chareon (sample number 21021412) and a dacite from Khao Sap Noi (sample number B172, refer to table 6.1)have variable P_2O_5 and SiO_2 (55-65 wt %) and MgO (~4 wt%). The samples have low K_2O (~0.1 wt %), Al_2O_3 (14.17 wt %) and low MnO (<0.2 wt%) and higher Na_2O_3 and CaO contents.
The samples from Koh Chang Island have high K_2O (~6 wt %), SiO_2 (75 wt %) and low P_2O_5 (~0.1 wt%), Al_2O_3 (~13 wt %), Na_2O (~3 wt %) , CaO and TiO_2 (<0.01 wt %).

Trace element abundances for the LVb group are characterised by low Y, Rb,Ce, Nd, La, Cr, Nb, Ni, Pb and As and higher Sr, Ba (especially for sample B172). The samples from Koh Chang Island have high Nb, As, Pb, Rb, Zr and low Sr, Ni, Zn, Cu, Ba and Sc.

Figure 6.13 shows the MORB normalised trace element compositions of the samples collected from the Petchabun/LVb group and Koh Chang Island (after Pearce, 1983).

Trace element abundances for the LVb are characterised by low Nb, Cr, La, Pb, Ni, and higher Sc and V. Figure 6.13 shows the MORB normalised trace element compositions (after Pearce, 1983). The samples in the Petchabun/LVb group are depleted in Rb and Nb and are enriched in Ba, Ce and P. The rhyolites from Koh Chang Island show high Rb, Nb, Ce, Hf and Y and are depleted in Ba, P, Ti.

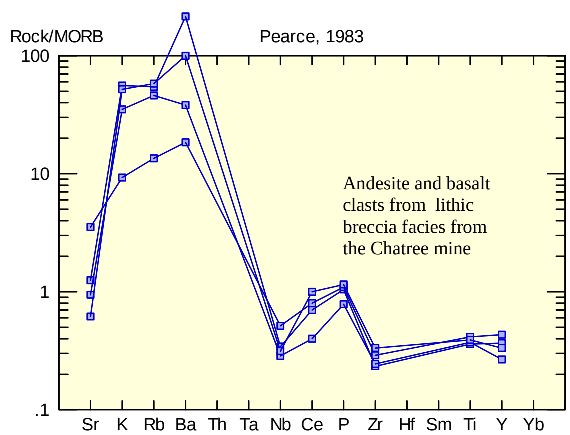


***Figure 5.10** MORB-normalised diagrams of andesitic and basaltic clasts from the Polymictic andesitic and basaltic lithic breccia facies at the Chatree mine (norm. values after Pearce, 1983).*

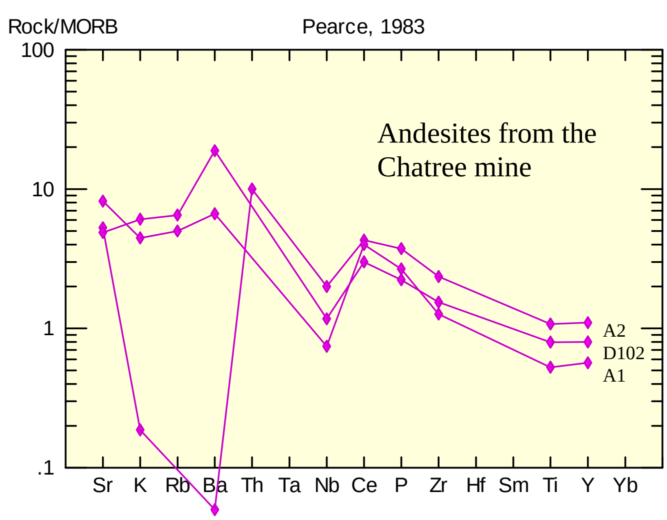


***Figure 5.11** MORB-normalised diagram of the plagioclase phyric and sparsely feldspar phyric andesites from the Chatree mine (norm. values after Pearce, 1983).*

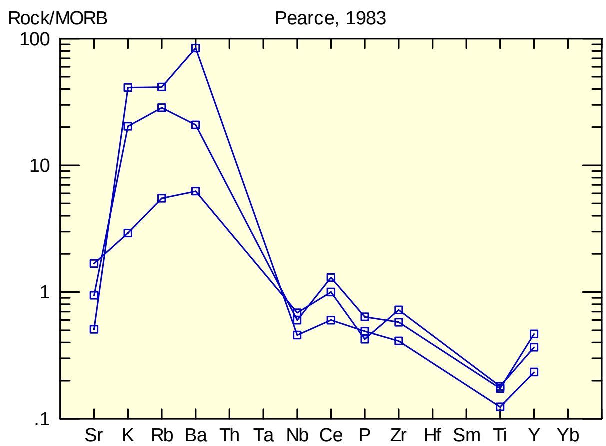


Figure 6.12 *MORB-normalised diagram of the pumice breccia facies from the Chatree mine (norm. values after Pearce, 1983).*

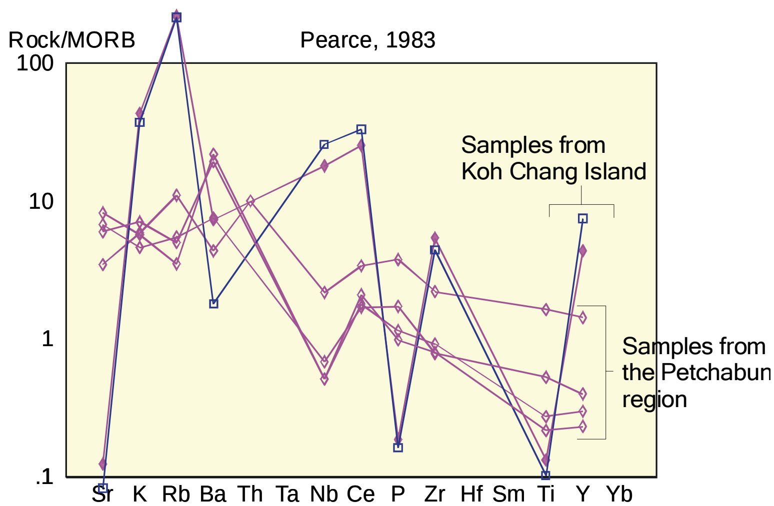


Figure 6.13 *MORB-normalised diagram for samples collected from Koh Chang Island and the Petchabun region of the LVb. (norm. values after Pearce, 1983).*

6.7 Tectonic environment

The samples collected within the LVb (at the Chatree mine, Khao Sap Noi, Khao Phanom pa and Koh Chang Island) vary in time and space. Based from sampling, it is difficult to constrain a geochemical model for the origin of all these rocks. The more mafic samples from the Chatree mine will be used to ascertain the tectonic origin.

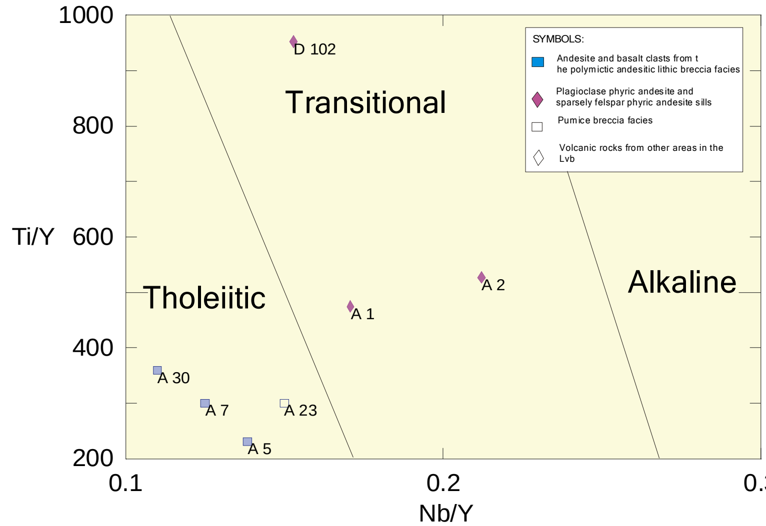


Figure 6.14 *Trace element discrimination diagram for the more mafic rocks of the Chatree mine after Pearce (1982)*

Trace element and major element discrimination diagrams are used to determine the tectonic setting and rock type. The volcanic rocks at Khao Sai have the geochemical characteristics of an active convergent margin setting. The samples in the LVb are characterised by lower Ti concentrations and low to intermediate levels of Zr typical for a volcanic arc type setting.

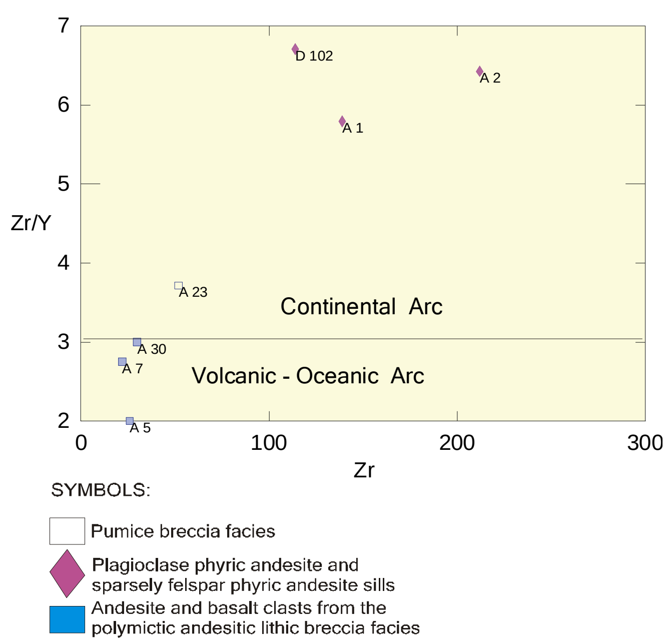


Figure 6.15 *Zr/Y vs Zr discrimination diagram for the andesite sills and clasts from the polymictic lithic breccia facies from the Chatree mine (after Pearce, 1983).*

The collision setting for the basaltic andesites can be discerned from Zr/Y vs Zr values (after Pearce 1983). According to this diagram the clasts in the polymictic andesitic lithic breccia facies fall within the field for an Oceanic arc setting and the plagioclase phyric and sparsely felspar phyric andesites fall in the field for continental arc type setting similar to the Pak Pat volcanics, located east of the Chatree mine (refer to section 6.8).

6.8 Correlation of data

Data obtained from Dedenczuk (1999) and Krompkhun (unpublished, 2004) is used to further identify the tectonic setting of the volcanic facies at the Chatree mine. Dedenczuk (1999) and Krompkhun (unpublished data, 2004) undertook whole rock and trace element geochemistry on the sills and dykes at the Chatree mine. They also crushed whole rock samples of the polymictic andesitic lithic breccia facies, these samples included multiple clast types and the matrix. This data will be compared and correlated with the whole clasts.

Their data suggests that the andesite sills, dykes and clasts are transitional (figure 5.7). The data obtained from Dedenczuk (1998) has been re-assessed using similar plots of Zr/Y vs. Zr (figure 5.8). On further analysis, his data shows that the sills and andesite dykes from the Chatree mine plot within the field for a continental margin setting. This is also confirmed from and Krompkhuns (unpublished, 2004) data.

On the Nb-Zr-Y ternary diagram (after Meschede, 1986), there is a general scatter of data points. The dykes from the Chatree mine plot within the field for within plate tholeiites and volcanic arc basalts. The single clasts and whole samples of lithic breccia fall in a field for Within Plate Tholeiites and Volcanic Arc Basalts, Within Plate Tholeiites and N-type MORB and Volcanic Arc basalts. The sills fall within the field for Within Plate Tholeiites and Oceanic Arc Basalts

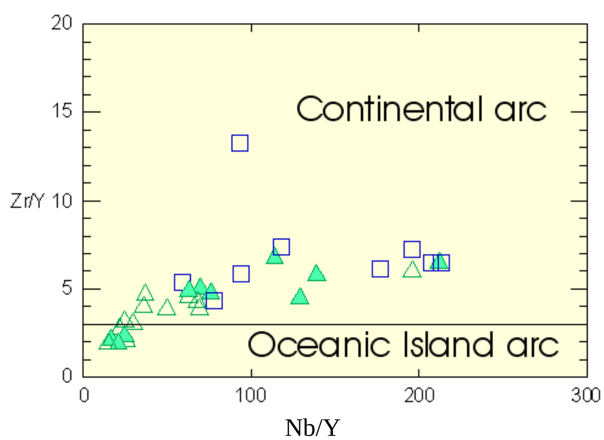


Figure 6.16 *Zr/Y vs Nb/Y discrimination diagram for the andesite sills, dykes and lithic breccia facies from the Chatree mine.*

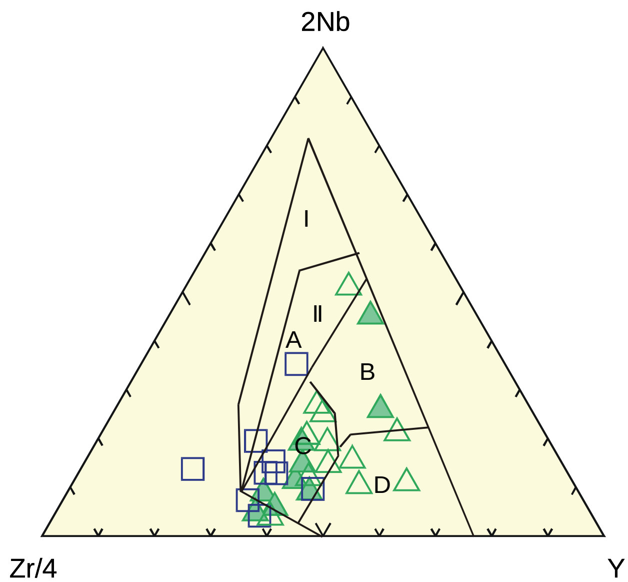


__Figure 6.18__ The Zr-Nb-Y discrimination diagram for basalts (after Meschede, 1986). The fields are defined as follows: AI, within-plate alkali basalts; AII, within-plate alkali basalts and within plate tholeiites; B, E-type MORB; C, within-plate tholeiites and volcanic-arc basalts; D, N-type MORB and volcanic arc basalts.

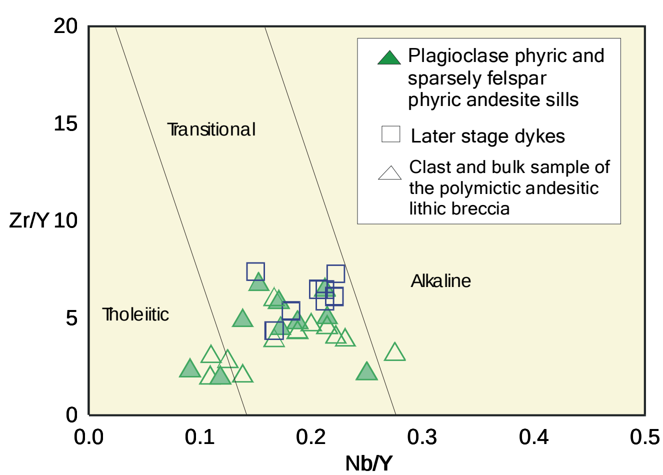


__Figure 6.17__ Zr/Y vs. Zr discrimination diagram for the andesite sills, dykes and lithic breccia facies at the Chatree mine

The Pak Pat volcanics, which include lavas and breccias have similar REE patterns and Ti-Y-Zr-Nb relationships to the clasts from the Chatree mine which implies an Island Arc Setting to the east of the succession, also during the Permo-Triassic. They have low abundances of TiO_2 (0.37-

1.15 wt%), P2O5 (0.11-0.27 wt%), Nb (<1-4ppm), Y (14-34ppm), Cr (largely between 2 and 37ppm) and relatively low Nb/Y ratios (0.04-0.16ppm)

6.9 Discussion and Interpretation

The process of subduction acts to enrich magmas with LILE, the enrichment of large ion lithopile elements (LILE) and transitional affinities is consistent with a mantle source being modified by a LILE enrichment process.

Based on the available data, the clasts from the andesitic lithic breccia display Island Arc affinities, the sills however display continental arc affinities. This may be consistent with a mantle wedge that was thicker and more contaminated when the sills intruded. This trend was not recognised previously (by Dedenczuk (1999)). The continental arc signature for the bulk samples of the polymictic andesitic lithic breccia is possibly due to contamination from the matrix, analysis of several different clast types. The different arc signature between the sills and the clasts may also be due to the polymictic andesitic lithic breccia facies being more prone to weathering and alteration compared to the sills.

If the data is unbiased from alteration or contamination effects, the data shows that the there may have been an Ocean Island setting in the Permo-Triassic. This makes the setting similar to the Permo Triassic Pak Pat volcanics in the Sukhothai fold belt. By contrast, the bulk of the much younger coherent volcanic facies from the Chatree mine were formed in a continental arc setting. This indicates that a continental margin occurred in the Palaeo-Tethys located between the Shan-Thai and Indochina Terrane prior to their suturing in the Permo-Triassic. This is further corroborated by the presence of large granitoids (up to 15km across) which have been emplaced prior to suturing of these two terranes. It is likely that considerable thickening of the crust occured before these felsic magmas were intruded..

Chapter 7 : Facies architecture, tectonic setting, nature of volcanism and order of eruptive events

7.1 Chapter overview

This Chapter discusses the tectonic setting and facies architecture of the Chatree mine. The tectonic setting identified from analysis of geochemical data (see Chapter 6) allows the setting of the volcanism and timing of events to be assessed. The facies architecture at the Chatree mine is identified from Chapters 3 and 5. This Chapter also allows evaluation of any links that may have existed between the host succession and mineralisation & relationships between the facies divisions (Figure 7.1). This Chapter will integrate the data presented in this thesis. This Chapter will identify;

1. the environment of deposition for the volcanic succession at the Chatree mine,
2. the order of eruptive events,
3. the nature of volcanism associated with the specific facies divisions and the relationship to the facies types,
4. facies architecture of the region,
5. the relative timing of mineralisation in the host sequence, and
6. the nature of volcanism in a convergent margin setting.

7.2 Environment of deposition

In Chapter 3 the environment of deposition for the polymictic andesitic lithic breccia and pumice breccia facies was interpreted to be submarine. The lack of any wave-ripple features in the succession indicates that deposition was likely to have occurred below wave base. The coral fragments in the limestone indicate that a shallow reefal environment occurred close to the area of deposition. The large proportion of carbonaceous and woody fragments found in the breccia facies indicates that a vegetated landmass also occurred nearby. Whole logs have even been revealedduring mine excavation at Chatree (Marsoe, pers. comm., 2004); however their occurence does not constrain the distance from a landmass as logs can travel long distances from source by floatation.

7.3 Event 1

7.3.1 Explosive volcanism

The silicified pumice bearing facies at the Chatree mine reflects explosive eruptions from a more felsic source some distance away. The location of this felsic centre is unknown.

Silicic pumice usually represents the products of a caldera forming eruption. It is uncertain whether this felsic eruption occurred in a subaerial or submarine environment as the surface features of the pumice is not preserved.

7.3.2 Effusive volcanism

The non vesicular and angular clasts in the polymictic andesitic lithic breccia are the re-sedimented products of effusive volcanism. The sharp to curvi-planar margins are most consistent with brittle fracturing generated by fragmentation of a lava flow presumably as quench fragmentation. These andesite lavas possibly erupted in a submarine or subaerial setting as there are only rare oxidised or altered clasts (in A prospect). The lack of reworking of the clasts suggests a relatively proximal to medial lithofacies.

7.3.3 Post-syn eruptive resedimentation

Re-sedimentation of the polymictic lithic breccia facies is interpreted to have occurred under water. The breccia facies show evidence for deposition by a slurry flow. These types of volcaniclastic density currents can transport coarse clasts up to 100km from source (Einsele, 1991) but the general angularity of the clasts and lack of any possible reworking suggests that deposition was relatively proximal to a fragmenting andesitic lava flow. The clasts were transported relatively quickly from their source without time for abrasion and reworking. These andesitic breccias record a relatively large-scale collapse event.

Remobilisation of the pumice breccia debris may have been initiated by local effusive or intrusive events, syn depositional faulting or by related explosions (based from Gifkins, 1999). The pumice clasts in these facies could be derived from pre existing unconsolidated pumice breccia or the pumiceous margins of lava domes (Cas et al., 1990). The pumice has been incorporated into the polymictic andesitic lithic breccia facies as a slurry flow.

7.3.4 Tectonic Setting

Island arc setting

The geochemical data assessed (from Chapter 6) suggests that the clasts from the andesitic lithic breccia facies and the silicified pumice breccia is from an Island Arc setting. The validity of this data does remain speculative due to limitations in sampling. Nevertheless, sedimentary features and the nature of the clasts that make up the andesitic lithic breccia facies at the Chatree mine are similar to typical debris flow deposits produced in an Island arc setting (Cas et al., 1987).. Arc type systems often have a high supply of volcaniclastic material and mass movement of this debris on the flanks of composite cones, calderas and strato-volcanoes. Movement is often through frequent small volume debris flows that redistribute material to lower parts of the volcanic edifice. Debris flows in an Island arc setting are made up of diverse compositions, with mixed clasts of basalt, andesite and dacite clasts which are related to the erosion of pre-existing material not related to eruptive activity. These characteristics are also similar to the polymictic andesitic breccia facies from the Chatree mine.

In an Island-Arc setting deposition of material is often in the marine environment on the flanks of the volcanoes (Cas et al., 1987) on fore-arc slopes and back arc basins. These deposits occur as thick sequences of volcaniclastic sediments (Sigurdsson, et al., 2000) and may also include carbonate debris picked up from the moving flow.

The polymictic andesitic lithic breccia from the Chatree mine has been identified to represent a slurry flow (Chapter 3), a type of debris flow. Although there are limitations with the geochemical data (Chapter 6), the polymictic andesitic lithic breccia at the Chatree mine is similar to the deposits found in the proximal to medial flanks of a composite cone in an Island Arc setting.

Volcano types

The polymictic andesitic breccia and silicified pumice breccia facies possibly formed from a composite cone volcano. Composite cones are common in an Island Arc setting. They have positive topographic relief with steep flanks that have been formed from the accumulation of eruptive products. Many composite cones have complex morphologies, with multiple vents. They can be associated with calderas. Composite cones and calderas can form contemporaneously. The association of intermediate and felsic volcanic rocks at the Chatree mine may eludes to their formation from a composite cone volcano (Sigurdsson, et al., 2000)

7.4 Event 2

7.4.1 Intrusions

The coherent, generally conformable andesite facies dissect and are conformable to the polymictic andesitic lithic breccia facies. They are interpreted to represent sills based from their geometry, the presence of quenched margins on the basal and upper contacts, and a general lack of any patterns in vesiculation discussed in Chapter 3. They are interpreted to have intruded at relatively shallow crustal levels this interpretation is based on the fine grained nature of the phenocryst component, indicating that they cooled relatively rapidly before the phenocrysts could form.

The sills are thin and laterally extensive in A Prospect. In C, H and D Lens however, they are thicker with higher aspect ratios. They have broadly concordant and locally discordant contacts. The shape, dimensions and internal textures in these sills are similar to the morphology of intermediate sills in other shallow marine subsurface successions.

The thicker zones of *plagioclase-phyric and Sparsely feldspar-phyric andesite* are not conformable to the succession of polymictic lithic breccia facies and represent geometries that are more analogous to dykes rather than sills. The Andesitic dykes in C,H and D lens are interpreted to represent the proximal facies and intrusive roots or feeders to the sill complexes.

The lack of peperite along the margins of the sills suggests they were emplaced into a water unsaturated sediment. However, the lack of visible peperite could be due to peperite being difficult to distinguish in a coarser grained host sediment. The sedimentary package may have been relatively consolidated at the time of intrusion (Chapter 3). Sediments become consolidated, less water saturated and lithified at a thickness below up to 200 m above space (Einsele, 1986).

7.4.2 Tectonic setting

Continental arc setting

The geochemical data (Chapter 5) assessed through the production of this thesis, along with interpretation of Dedenczuk’s (1998) and Krompkhun’s (unpublished data, 2004) data suggests that the sills at the Chatree mine are intruded in a continental arc setting, or where the arc was substantially thicker.

7.5 Event 3

7.5.1 Fluid movement, hydraulic brecciation and mineralisation

Mineralisation is hosted within the polymictic lithic breccias and with intense alteration associated with the feeder dykes and sills in C and H and D lens (pseudoclastic texture, chapter 3). Mineralisation also occurs along faults and shear zones within the sequence.

The ore fluids are interpreted to be linked with the fluids derived from the intrusion of the sills that have moved within the volcanic pile after the intrusion of the sill complexes. The sills have undergone some alteration. The mobilisation of hydraulic fluids within the succession may have resulted in the brecciation of the coherent facies and the formation of hydraulic breccias (monomictic lithic breccia, Chapter 3). The time period between the intrusion of the sills and the intrusion of the un-mineralised cross cutting dykes (discussed later) provides a time window for mineralisation to occur.

7.6 Event 4

7.6.1 Explosive eruptions

The polymictic feldspar rich pumice breccia represents the resedimented products of an felsic explosive eruption nearby. The location of this felsic centre is unknown.

7.7.2 Resedimentation

The pumice in the feldspar phyric sparsely pumiceous and lithic rich breccia forms a minor component to the facies division. The deposit is characterised by sedimentary structures typical for turbidity currents. The pumice is angular and shows little evidence for being reworked. Other clasts (including mudstone, basalt and andesite clasts) in the same deposit are relatively rounded and some are oxidised or altered, polymictic and poorly sorted. These clasts were possibly picked by the flow as it travelled and may indicate more proximal component to the exploding caldera. These clasts represent fragments that have undergone greater rounding and transportation before being incorporated into the mass flow deposit.

7.7 Event 5

7.7.1 Intrusions

The cross cutting olivine-pyroxene phyric basalt, coarsely plagioclase phyric andesite and sparsely feldspar phyric andesite dykes cross-cut all lithologies in the Chatree mine. Based from contact relationships, geometry and textural relationships, these intrusions have been interpreted as dykes (Chapter 3) and post-date all lithologies.

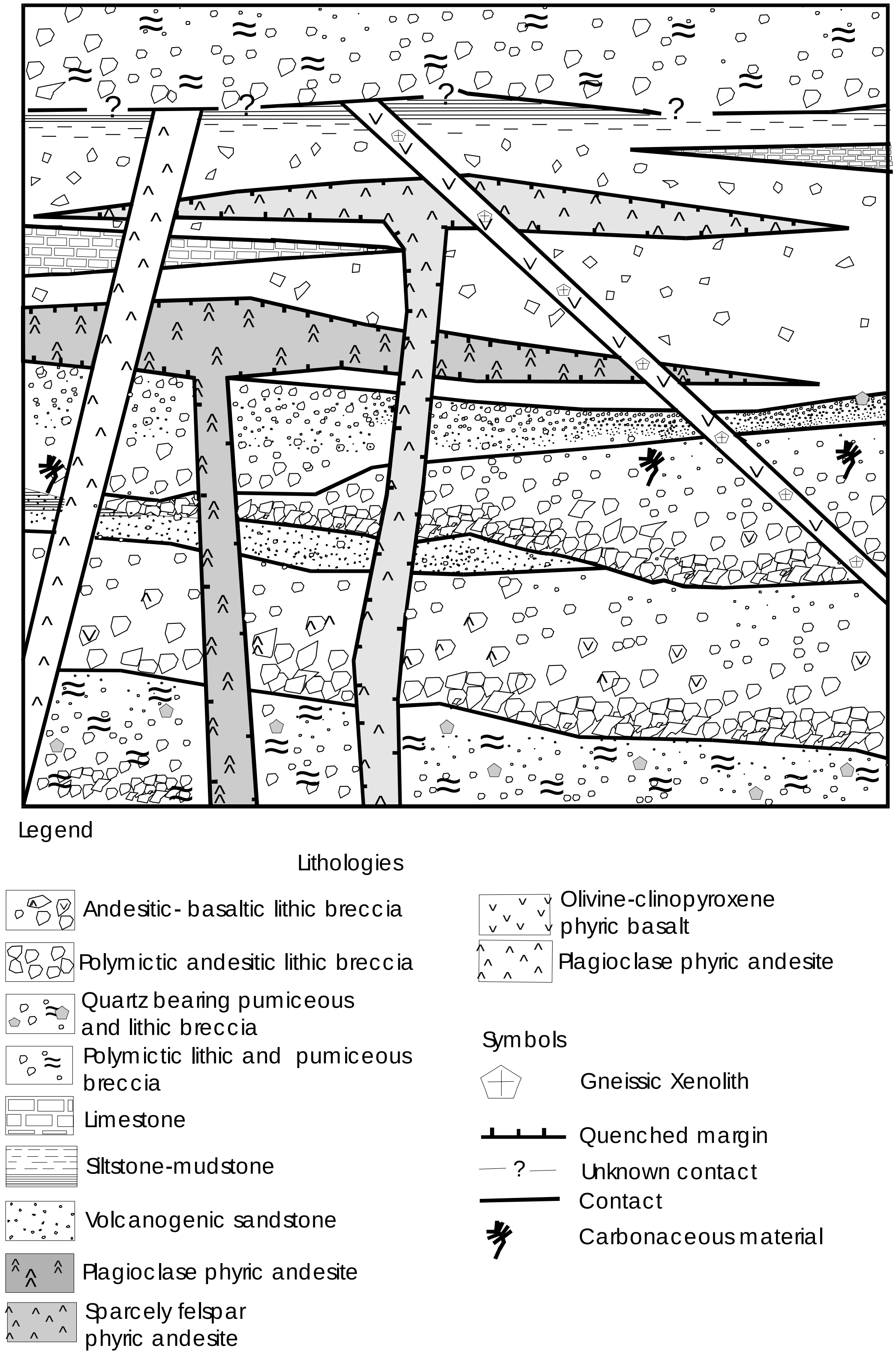


Figure 7.1 *Schematic section of the major facies divisions at the Chatree mine*

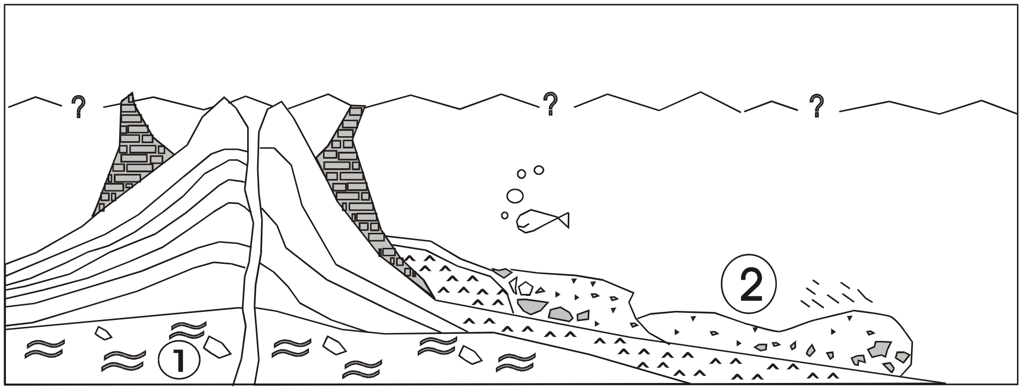


Figure 7.2 *Composite cone in a subaqueous environment with coral reefs, fragmenting lava flows and movement of volcanic fragments as a debris (slurry flow from events 1 and 2).*

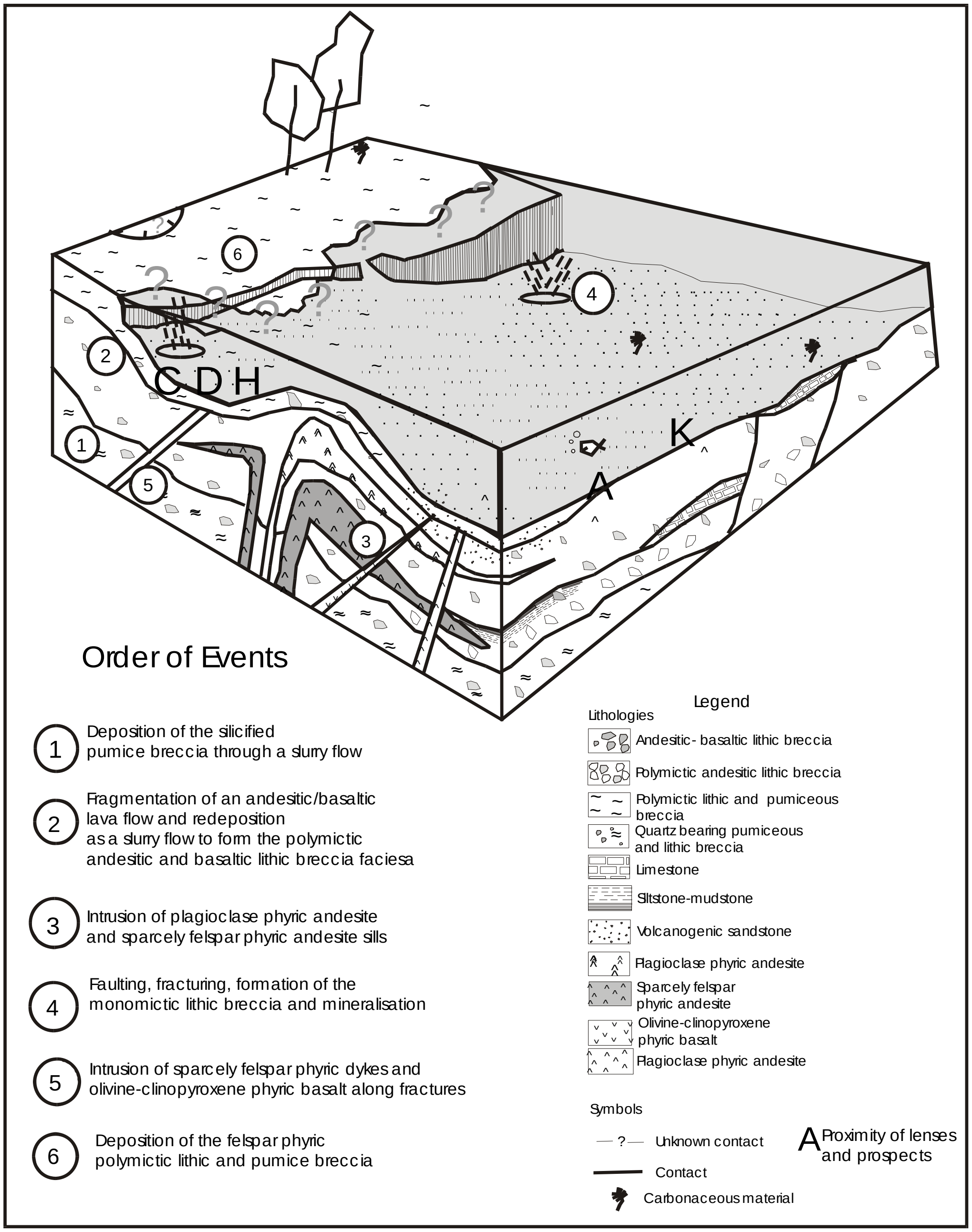


Figure 7.3 *Facies architecture of the Chatree mine*

7.9 Synthesis and Conclusions

The volcanic facies at the Chatree mine represent the products of explosive and effusive eruption styles. Which can be divided into 5 distinct events. The volcano-sedimentary facies are the resedimented products of the fragmented andesite lava and the explosive eruption of a more felsic centre (1st event) . These facies have not undergone a high degree of lateral transport and represent debris flows which may have occurred on the flanks of a once active composite cone.

Andesitic sills intrude the polymictic lithic breccia facies (2nd event). Mineralisation is assumed to have occurred after the intrusion of sills and is associated with fluid movement and hydraulic brecciation (3rd event). Another interval of pumice breccia (the felspar phyric sparsely pumiceous lithic breccia) also records the redeposited products of a more explosive eruption some distance away (4th event). The last event to occur is the intrusion of unmineralised dykes which crosscut the succession (5th event). The dykes and sills have a geochemical character indicative of a continental arc setting.

The sills and polymictic andesitic lithic breccia facies have different geochemical characteristics. It should be noted that this geochemical data is not the basis for the sequence of events but is also related to cross-cutting relationships and the textural character of the facies. The sills and polymictic breccia facies are not related petrographically.

The difference in geochemical signatures between the clasts and sills may be due firstly due to the evolution of an Island Arc setting into a more evolved Continental Arc setting and secondly, which is more likely, to be due to the structural evolution of the Loei fold belt which is host to the Chatree mine. The closure of the Palaeo-Tethys between the Shan-Thai and Indochina Terranes in the late Triassic caused the amalgamation of crustal blocks. The continental arc-type signature of the sills may be a function of this collisional event, which may have acted to thicken the crust or contaminate the sills.

Chapter 8: Summary and Conclusion

8.1 Summary of findings

This project has redefined and interpreted the volcanic facies at the Chatree mine.
The polymictic andesitic lithic breccia and polymictic andesitic and basaltic lithic breccia is interpreted to represent a slurry flow deposit, a type of debris flow. This facies was resedimented quickly from a fragmented lava as the angular nature of the clasts indicate that there was little time for re-working. It does not represent resedimented hyaloclastite margins of the conformable sills as previously thought (Dedenczuk, 1998). The silicified pumice breccia at depth was assessed (for this first time) during this project. This facies represents a more felsic explosive eruption nearby and has similar sedimentary characteristics to the polymictic andesitic-basaltic lithic breccia facies. This facies also represents a slurry flow deposit. The polymictic feldspar rich pumice breccia has been interpreted to represent a turbidity current that has picked up already rounded and reworked fragments as it moved. The pumice in this facies however contains angular glassy fragments that have not been reworked providing evidence that a cladera forming eruption may have triggered the movement of the current.

The plagioclase phyric andesite, and sparsely feldspar phyric andesite represent shallow level sills based from the presence of quenched margins at both upper and lower contacts, their fine grained phenocryst content and their broadly concordant and discordant nature. The feeder dykes to these sills have been interpreted to be more proximal to C, H and D lens. A and K prospects are distal to these feeder zones.

Through correlation of drillcore, slurry flow horizons in the andesitic lithic breccia facies have been delineated. Through the analysis of drillcore, an outline of the stratigraphy of the Chatree mine has been produced, as well as the major facies types and the volanological characteristics of each lens/prospect.

Through this project, subsidiary studies of outcrop close to the Chatree mine, in the Petchabun Province was undertaken. This assessment showed that similar lithologies to the Chatree mine occur outside the mine site and may be linked to similar events that shape the facies at the Chatree mine.

The more silicic rocks on Koh Chang Island, further south in the LVb have been redefined and interpreted as a small part of this project. The flow banded spherulitic rhyolites have been interpreted to represent extrusive domes and their association with marine sediments suggest they erupted in a subaqueous environment.

This project has also used geochemical data to assess the volcanic rocks in the LVb. For the Chatree mine, this data has enabled the differentiation of source characteristics for the sills and lithic clasts in the polymictic andesitic lithic breccia facies and also differentiates facies from elsewhere in the LVb. The correlation with Krompkhuns (unpublished data, 2004) and re-assessment of Dedenczuks (1998) data has re-defined the tectonic setting for the Chatree mine. These rocks are thought to have their origins in a Continental arc-type setting and not an Island arc setting, as previously thought (Dedenczuk, 1998). The clasts in the polymictic andesitic lithic breccia facies, however show Island arc affinities, but there are limitations in this data (Chapter 6).

Based from geochemical data and contact relationships in the field, the sequence of eruptive events and the position of mineralisation and the stratigraphy has been outlined. The first events involved the fragmentation of an andesite (and basaltic) lava/intrusions and consequent rapid deposition triggered by a large scale collapse event and incorporation of material into a slurry flow type deposit, possibly occurring on the flanks of a composite cone, in a subaqueous environment. The *silicified pumice breccia* at the base of this facies represents the re-sedimented products of a more explosive eruption nearby. The second event involves the intrusion of the *plagioclase phyric and sparsely felspar phyric coherent andesite facies* as intrusions or sills. The arcuate and lobate nature of the coherent facies shows that it intruded into relatively unconsolidated sediment. The lack of any peperite in drill core suggests that the host sediment was relatively water unsaturated or lithified. These sills show substantial alteration and their intrusion is thought to pre-date the onset of mineralisation. A second pumice breccia facies; the *polymictic felspar rich pumice breccia* overlies the polymictic andesitic lithic breccia. The sheared contact with the breccia facies indicates that this facies may have been emplaced through faulting. Later stage dykes post date and cross cut mineralisation and help constrain the timing for mineralisation..

8.2 *Possible future work*

The time constraints and limitations on field work has provided some possibilities for future work at the Chatree mine and the LVb. Possible future work may include:

1. Further analysis of separate facies, and age-dating to constrain the timing of mineralisation would be considerably beneficial in the delineation of the volcanic architecture.
2. Assessment of the relationship of the polymictic feldspar rich pumice breccia and rest of the volcanic pile . Further assessment of its contact relationships and relationship to mineralisation may further constrain the volcanic architecture of the region.
3. Correlation of the volcanic facies of the Chatree mine with other areas in the LVb.
4. Further structural analysis and interpretative work on the volcanic rocks at Koh Chang Island and more interpretative work.
5. A comprehensive volanological study of the facies architecture in the LVb.
6. Further sampling of the andesitic lithic breccia clasts to better constrain their tectonic setting and further comparative work to better constrain their relationship to the sills

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APPENDIX I: GEOCHEMICAL and PETROLOGICAL DATA

Sample Preparation

Samples of fresh rock were collected from drillcore and surface exposures throughout the study areas. Samples were prepared by crushing approximately 700-1000 gm in the steel jaw crusher. Approximately 50-100 gm of hand picked fragments up to 1cm across, free of oxidised or weathers rinds,veins or amygdales were blown free with a compressed air gun and ground in a tungsten carbide ring mill for 3 minutes to produce rock powder (<75µm). This powder was used for all XRF analysis.

SUMMARY OF XRF ANALYSIS (X-Ray Fluorescence Analysis)

School of Earth Sciences, University of Tasmania **Phil. Robinson 29/03/2000**

Instrument

Philips PW1480 X-Ray Spectrometer

X-Ray Tubes	3kW max. ScMo anode side window. Elements analysed: Majors, S and Y, Rb, U, Th, Cu, Pb, Zn, Ni, As, Bi, Co, Ga, Tl, Se, W, Br
	3kW max. Au anode side window. Elements analysed: Nb, Zr, Sr, Ba, Cr, V, Sc, La, Ce, Nd, Sb, Sn
	3kW max. Rh anode side window. Elements analysed: Mo, occasionally Nb
Crystals:	LiF 200, LiF 220, PX-1 (for Na and Mg), PE002, Ge111
Collimators:	Coarse (0.7mm) and fine (0.3mm) with auxiliary (0.14mm)
Detectors:	Gas flow proportional counter with P10 gas (10% methane in argon) and Scintillation Counter.
Sample Changer:	Philips 30 position sample holder

Sample Preparation

Major Elements:	Fusion discs prepared at 1100 degreesC in 5%Au/95%Pt crucibles 0.77g sample, 4.125g Norrish Flux (Lithium borates/La2O3 mix), 0.055g LiNO3 for silicates.Platinum/gold moulds used for cooling. Sulphide bearing samples have a mix with more LiNO3 as oxidising agent and the mix is preignited at 700 degreesC for 10 minutes. Ore samples and ironstones use 12/22 flux and a higher flux/sample ratio. Dolomites and limestones need pure lithium tetraborate as a flux.
Trace Elements	Pressed powder pills (3.5 tonnes/cm^{-2}) with 10 grams sample. Binder used is PVP-MC.

Corrections

Corrections for mass absorption are calculated using Philips X40 software with De Jongh's calibration model and Philips (or CSIRO) alpha coefficients. Compton scattering is also used for many trace elements.

Calibration

Pure element oxide mixes in pure silica, along with international and Tasmanian standard rocks are used. Numerous checks of standard rocks and pure silica blanks are run with each program.

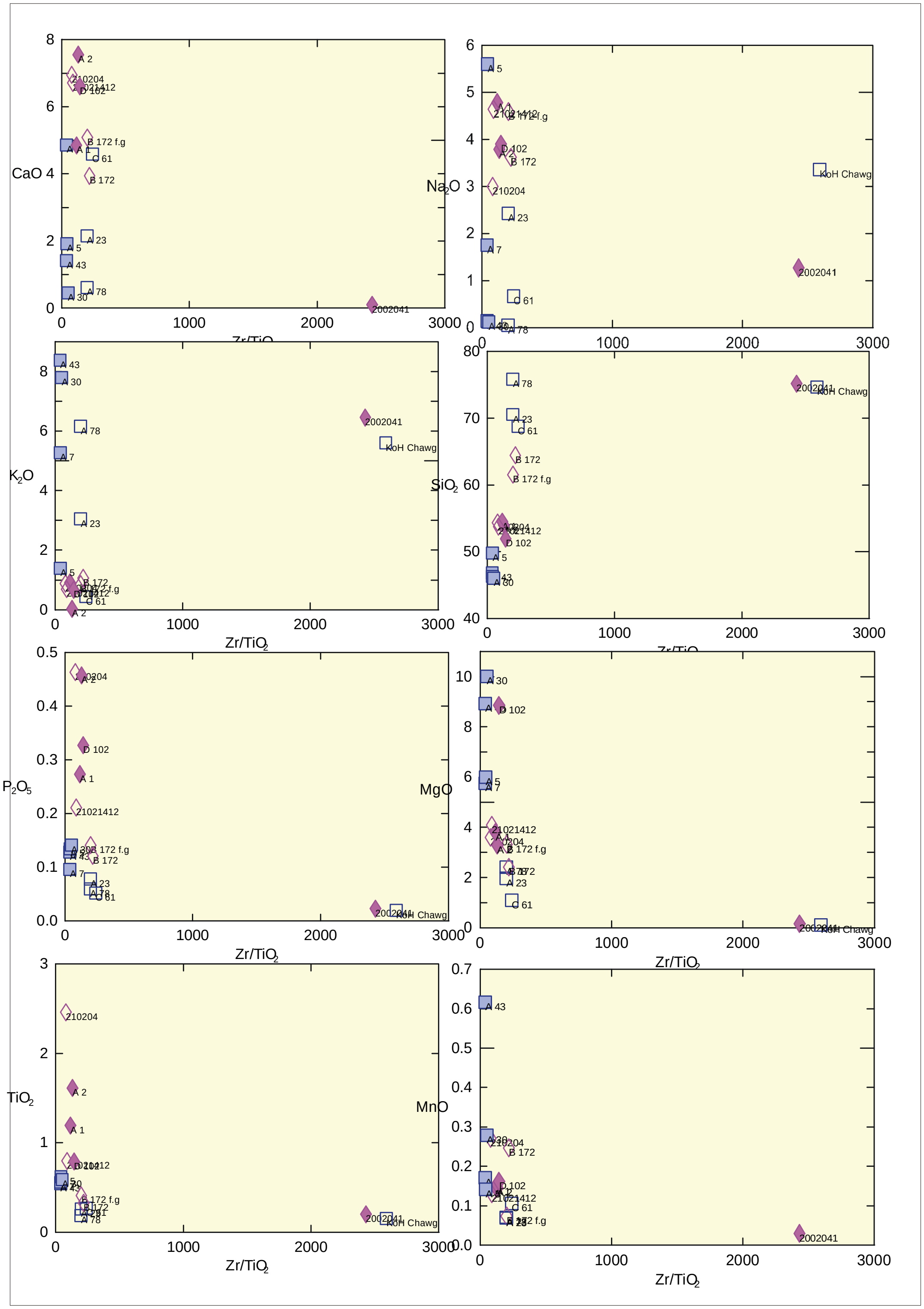

Figure 5…. Major element composition vs Zr/TiO2ppm values. Numbers next to the symbols indicate sample numbers

Trace element discrimination diagrams

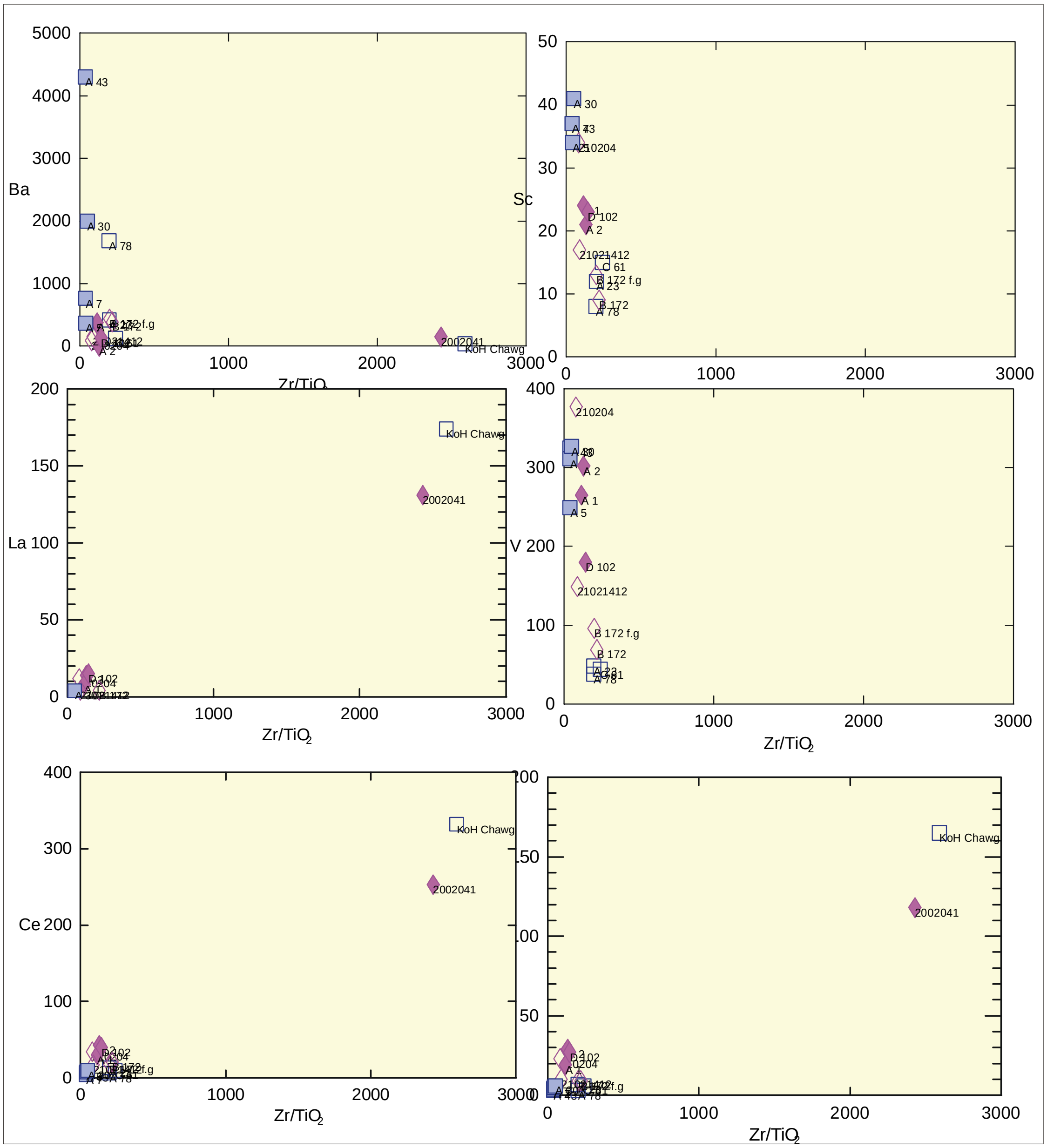

Figure 5.7 *Trace element composition vs Zr/TiO2ppm values. Numbers next to the symbols indicate sample numbers (refer to table 5.1)*

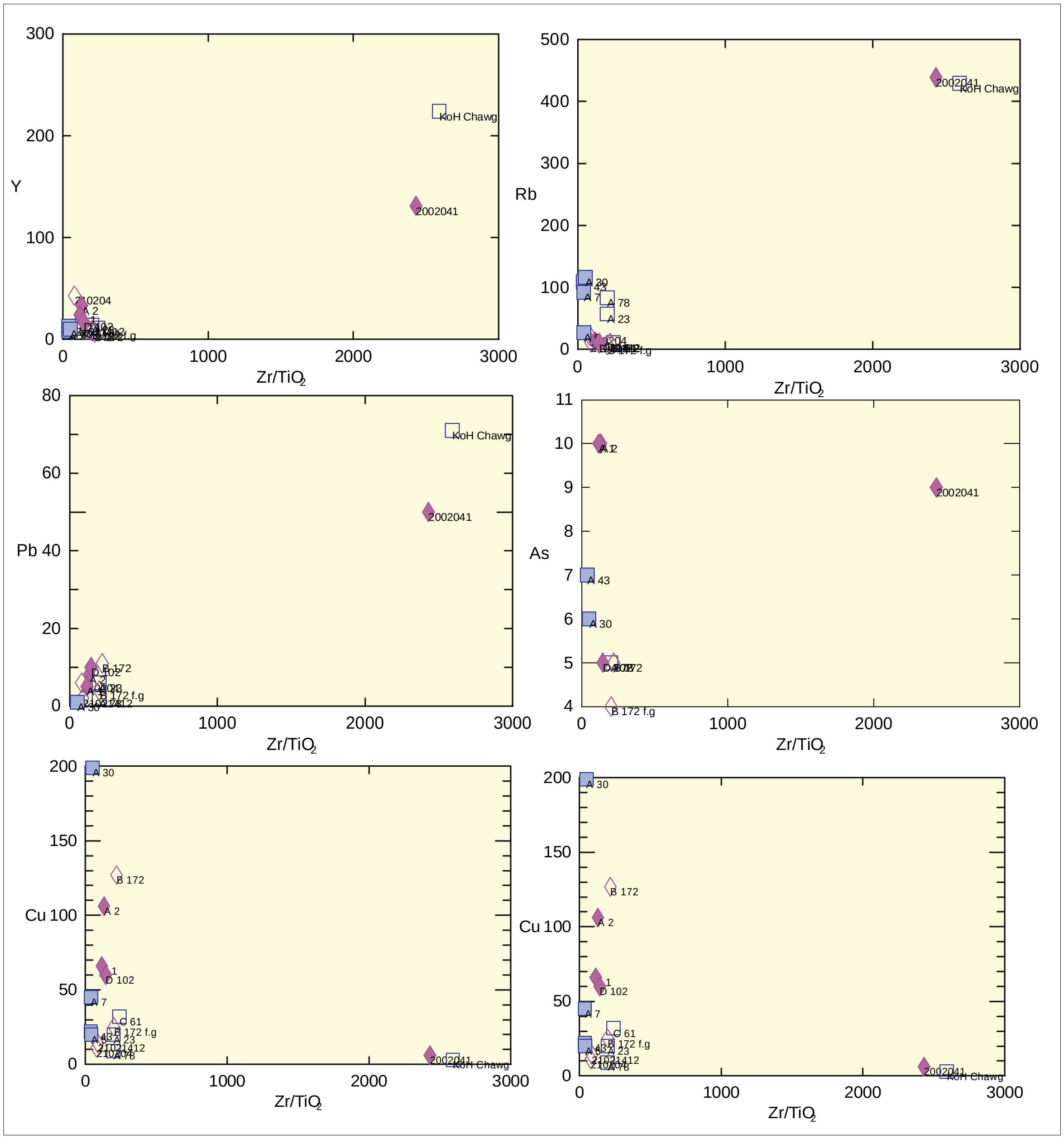

Figure 5.7 *Trace element composition vs Zr/TiO2ppm values. Numbers next to the symbols indicate sample numbers (refer to table 5.1)*

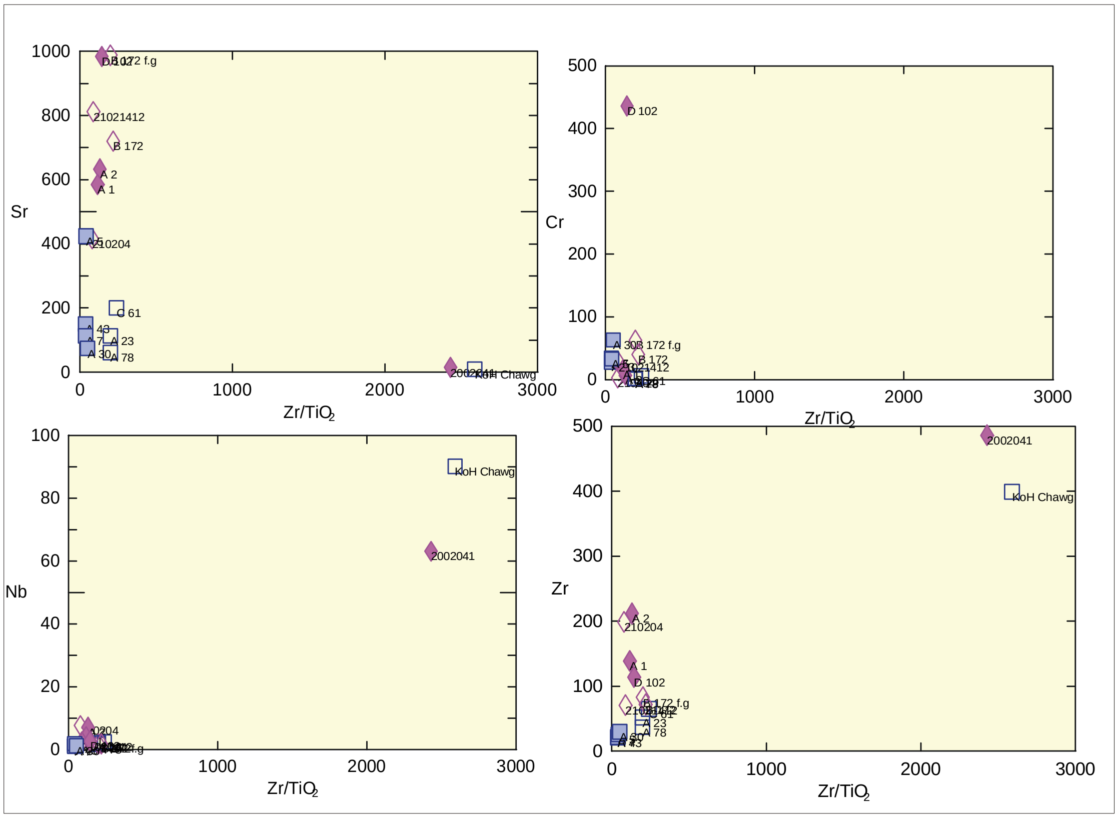

Figure 5.9 *Trace element composition vs Zr/TiO2ppm values. Numbers next to the symbols indicate sample numbers (refer to table 5.1)*

5 Petrology

Facies	Texture	Phenocryst and microphenocryst assemblages and lithic fragments	Groundmass
Flow banded spherulitic rhyolite (**Koh Chang**)	Moderately porphyritic rhyolite with well developed spherulites and lithophysae	Quartz: 60-70%, 1-3 mm subhedral K felspar (?): 10-15%, 2-3 mm subhedral to euhedral Spherulites and lithophysae: 0.5 mm arcuate to acicular radiating quartz crystals often containing a vug in their centre	Fine grained equigranula (2-5%) chlorite and seric
210201	Equigranular, holocrystalline andesite	Actinolite: 50-60% <0.5 mm acicular to whispy phenocrysts Titanomagnetite: 15-20% 1 mm laths Quartz/silica: 2% 1-2mm ragged margins Alteration: small 2-3mm veins containing white mica and sparce epidote	NA
B172	Moderately to coarsely porphyritic andesite	Plagioclase felspar: 3-5 mm tabular euhedral to subhedral phenocrysts containing pervasive silica alteration (possibly sanadine) Clinopyroxene: 5% 4-5 mm euhedral phenocrysts with interstitial Fe-Ti oxide laths Amphibole: 15% 3-4mm tabular phenocrysts Fe-Ti Oxides: 5% o.5mm ragged to blocky laths	Medium- coarse grained 1mm clinopyroxene and

2102042	Moderately porphyritic andesite	Amphibole: 10% 9mm tabular euhedral to subhedral tabular phenocrysts Sanadine: 5% 1-2mm subhedral and pervasively replaced by silica Clinopyroxene: 1% rare <1mm anhedral crystals Fe-Ti oxides: 20% <0.5 mm blocky euhedral crystals Alteration: Calcite, chlorite alteration	Holocrystalline actinolite oxides and magnetite
Facies	**Texture**	**Phenocryst and microphenocryst assemblages and lithic fragments**	**Groundmass**
A2 Plagioclase phyric variably chlorite altered andesite	Moderatey to coarsely porphyritic	Plagioclase felspar: 10-20% 0.5 101mm blocky to tabular phenocrysts containing inclusions of Fe-Ti Oxides Alteration: The plagioclase felspar has been wholly to partially replaced by chlorite, pyrite also occurs.	Fine to medium grained e comprised of 70% variab blocky plagioclase felspa magnetite and amphibole

A23 Quartz rich pumice breccia		Alteration: Highly silicified matrix and and crystal assemblage. The matrix is fine grained . The crystal phases include silica replaced alkali felspar, quartz crystals and plagioclase felspar crystals. No remnant pumice textures are distinguishable due to the high level of replacement.	NA
A32 Plagioclase phyric basaltic andesite	Equigranular	Plagioclase felspar: 60% <1mm tabular phenocrysts Olivine: 2% <0.5 mm subhedral phenocrysts Pyroxene: 14% subhedral <1mm subhedral to anhedral phenocrysts Titanomagnetite: 5 % <0.25mm blocky prismatic crystals Alteration: small component of chlorite alteration and silicification of crystal phases. Vugs infilled by quartz	NA

Facies	**Texture**	**Phenocryst and microphenocryst assemblages and lithic fragments**	**groundmass**
C62 Polymictic lithic rich pumiceous breccia	Polymictic andesitic lithic breccia	clast type (1) plagioclase phyric andesite: Plagioclase felspar : (20% - 30%) of 1 to 2 mm coarse blocky subhedral to euhedral plagioclase felspar crystals phenocrysts Pyroxene: (6%), 1 - 2.5 mm pyroxene phenocrysts altered to chlorite and clays. clast type (2) plagioclase felspar and hornblende phyric andesite: Plagioclase felspar: 15-20% subhedral 1 to 2mm Amphibole: 1-5% 1mm amphibole clast type (3): mudstone and siltstone consisting of a high proportion of plagioclase felspar and clast type (4) basaltic clast: composed of altered plagioclase felspar, pyroxenes, rare olivine and amphibole, magnetite, chalcopyrite and pyrite. The most widespread fragment has been wholly silicified composed of fine grained equigranular quarts crystals with larger quarts inclusions within it.	Clast type 1: evenly cryst plagioclase felspar and ra groundmassis altered to s and clay or calcite. Red d clasts is due to a dusting adularia. The amygdales rock volume and are infil and adularia. Clast type 2: < 0.5 mm ev composed of tabular plag Clast type 4: fine grained with 1 mm pyroxene anc tabular felspar crystals.

Facies	Texture	Phenocryst and microphenocryst assemblages and lithic	Groundmass
		Clast type (5): pumice, highly altered	
A10 Plagioclase phyric andesite	Moderately porphyritic	Plagioclase felspar: 15%-30%, 2-3mm euhedral and less abundant (5%) altered felspar phenocrysts. Alteration: plagioclase phenocrysts are dusted with hematite and overprinted by sericite, patchy carbonate and minor epidote. The rims are often altered to adularia. Amphibole: is altered to chlorite, sericite, carbonate and less commonly sphene. Xenoliths: 2-3 mm equigranular aphyric euhedral plagioclase felspar and amphibole. Amygdales: 2 mm, circular to ragged in shape infilled by adularia, silica, clays, chlorite and carbonate.	fine grained (0.5mm) equ containing K-feldspar, ap (5%) amphibole, and opa Oxides with minor pyrite

		fragments	
A7 plagioclase phyric andesite clast	Moderately porphyritic	Amygdale: infilledby calcite plagioclase felspar phenocrysts: Pervasive chlorite alteration.	groundmass consists of p titanomagnetite and oxid
A43 andesite clast	Moderately to coarsely porphyritic	Plagioclase felspar: 30-40 % 1-2 mm blocky to tabular euhedral phenocrysts Pyroxene: 5% 1-2 mm euhedral to subhedral wholly replaced by quartz Titanomagnetite: 5% <0.25 mm laths Vesicles: 5-10% 2-3 mm quartz infilled vugs with irregular curvey margins	Titanomagnetite, quarts, plagioclase felspar crysta replaced quarts crystals,
D105 Sparcely plagioclase phyric andesite	Moderately to porphyritic	pyroxenes: 5 -10% 1mm subhedral phenocryts plagioclase felspar: 30-40% 0.25 – 0.5 mm subhedral crystals wholly or partially replaced by fibrous chlorite. Xenolith: is equigranular, composed of large quarts, plagioclase felspar and titanomagnetite crystals.	The groundmass is equig is composed of plagiocla titanomagnetite crystals.

Geochemical Data - Major element Data

	Sample Identification:											
Oxides	C 61	A43	A78	A7	B172	200204	Koh Chang	A2	A23	A1	B172	

SiO_2	68.76	46.84	75.83	46.30	61.53	75.15	74.64	53.91	70.53	54.51	64.43	
TiO_2	0.27	0.54	0.19	0.56	0.41	0.20	0.15	1.61	0.26	1.19	0.33	
Al_2O_3	13.64	18.00	10.31	17.84	16.73	12.72	13.56	15.95	13.82	16.62	16.61	
Fe_2O_3	3.59	8.88	1.80	9.31	4.55	2.50	0.75	9.81	2.40	8.84	3.73	
MnO	0.11	0.62	0.07	0.17	0.07	0.03	<0.01	0.15	0.07	0.15	0.25	
MgO	1.09	8.92	2.41	5.75	3.32	0.16	0.11	3.29	1.97	3.80	2.41	
CaO	4.59	1.41	0.61	4.86	5.08	0.10	<0.01	7.55	2.15	4.85	3.94	
Na_2O	0.67	0.14	0.05	1.75	4.59	1.27	3.36	3.79	2.43	4.78	3.62	
K_2O	0.44	8.38	6.16	5.27	0.86	6.45	5.60	0.03	3.05	0.91	1.06	
P_2O_5	0.05	0.13	0.06	0.10	0.14	0.02	0.02	0.46	0.08	0.27	0.12	
Loss inc.S-	7.01	5.93	2.49	7.74	3.36	1.51	1.55	3.34	3.37	4.03	3.17	
Total	100	100	100	100	100	100	100	100	100.13	100	100	
S	0.10	0.18		0.04	<0.01	0.03	<0.01	0.06	0.07	0.02	0.15	

Trace element data

	GC1	GC2	GC3	GC4	GC5	GC6	GC7	GC8	GC9	GC10	GC11	GC12	GC13
ements	C 61	A43	A78	A7	210204	B172	200204	Koh Chang	A2	A23	A1	B172	21021412
	2.4	1.2	1.6	1.0	7.6	1.8	63.1	90.2	7.0	2.1	4.1	1.8	2.4

	65	21	37	22	199	83	486	399	212	52	139	72	71
	201	150	61	113	416	988	15	10	633	113	585	720	812
	6	28	1	34	3	63	<1	<1	7	2	16	40	27
	125	4300	1684	763	87	438	147	36	1	417	377	387	151
	15	37	8	37	34	13	<2	<2	21	12	24	9	17
	44	325	38	311	377	96	<1.5	<1.5	302	48	265	69	149
	<2	<2	12	<2	131	174	14	<2	8	4	<2	15	4
	10	7	6	4	34	18	253	332	43	13	30	21	17
	6	3	3	4	23	9	118	165	29	7	19	9	10

Identification:													
	GC1	**GC2**	**GC3**	**GC4**	**GC5**	**GC6**	**GC7**	**GC8**	**GC9**	**GC10**	**GC11**	**GC12**	**GC13**
e elements	**C 61**	**A43**	**A78**	**A7**	**210204**	**B172**	**200204**	**Koh Chang**	**A2**	**A23**	**A1**	**B172**	**21021412**
Y	11	11	7	8	43	9	131	224	33	14	24	7	12
U	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	10	14	<1.5	<1.5	<1.5	2	<1.5
Rb	11	109	83	92	22	7	439	429	<1	57	13	10	11
Th	<1.5	<1.5	<1.5	<1.5	2	<1.5	49	60	2	<1.5	<1.5	<1.5	<1.5
Pb	<1.5	<1.5	2	<1.5	6	4	50	71	8	6	5	11	2
As	<3	7	5	<3	<3	4	9	<3	10	<3	10	5	<3
Bi	<2	**<2**	<2	**<2**	<2	**<2**	<2	**<2**	<2	**<2**	<2	**<2**	<2
Zn	57	68	35	81	94	48	217	27	104	34	111	4200	71

Cu	32	22	9	45	11	25	6	3	106	20	66	127	14	
Ni	3	15	1	15	8	39	7	8	20	2	13	18	16	

APPENDIX 3: ROCK CATALOGUE

APPENDIX I: GEOCHEMICAL and PETROLOGICAL DATA

Sample Preparation

Samples of fresh rock were collected from drillcore and surface exposures throughout the study areas. Samples were prepared by crushing approximately 700-1000 gm in the steel jaw crusher. Approximately 50-100 gm of hand picked fragments up to 1cm across, free of oxidised or weathers rinds,veins or amygdales were blown free with a compressed air gun and ground in a tungsten carbide ring mill for 3 minutes to produce rock powder (<75µm). This powder was used for all XRF analysis.

SUMMARY OF XRF ANALYSIS (X-Ray Fluorescence Analysis)

School of Earth Sciences, University of Tasmania **Phil. Robinson 29/03/2000**

Instrument	Philips PW1480 X-Ray Spectrometer
X-Ray Tubes	3kW max. ScMo anode side window. Elements analysed: Majors, S and Y, Rb, U, Th, Cu, Pb, Zn, Ni, As, Bi, Co, Ga, Tl, Se, W, Br
	3kW max. Au anode side window. Elements analysed: Nb, Zr, Sr, Ba, Cr, V, Sc, La, Ce, Nd, Sb, Sn
	3kW max. Rh anode side window. Elements analysed: Mo, occasionally Nb
Crystals:	LiF 200, LiF 220, PX-1 (for Na and Mg), PE002, Ge111
Collimators:	Coarse (0.7mm) and fine (0.3mm) with auxiliary (0.14mm)
Detectors:	Gas flow proportional counter with P10 gas (10% methane in argon) and Scintillation Counter.
Sample Changer:	Philips 30 position sample holder

Sample Preparation

Major Elements:	Fusion discs prepared at 1100 degreesC in 5%Au/95%Pt crucibles 0.77g sample, 4.125g Norrish Flux (Lithium borates/La2O3 mix), 0.055g LiNO3 for silicates.Platinum/gold moulds used for cooling. Sulphide bearing samples have a mix with more LiNO3 as oxidising agent and the mix is preignited at 700 degreesC for 10 minutes. Ore samples and ironstones use 12/22 flux and a higher flux/sample ratio. Dolomites and limestones need pure lithium tetraborate as a flux.
Trace Elements	Pressed powder pills (3.5 tonnes/cm^{-2}) with 10 grams sample. Binder used is PVP-MC.

Corrections

Corrections for mass absorption are calculated using Philips X40 software with De Jongh's calibration model and Philips (or CSIRO) alpha coefficients. Compton scattering is also used for many trace elements.

Calibration

Pure element oxide mixes in pure silica, along with international and Tasmanian standard rocks are used. Numerous checks of standard rocks and pure silica blanks are run with each program.

Major element discrimination diagrams

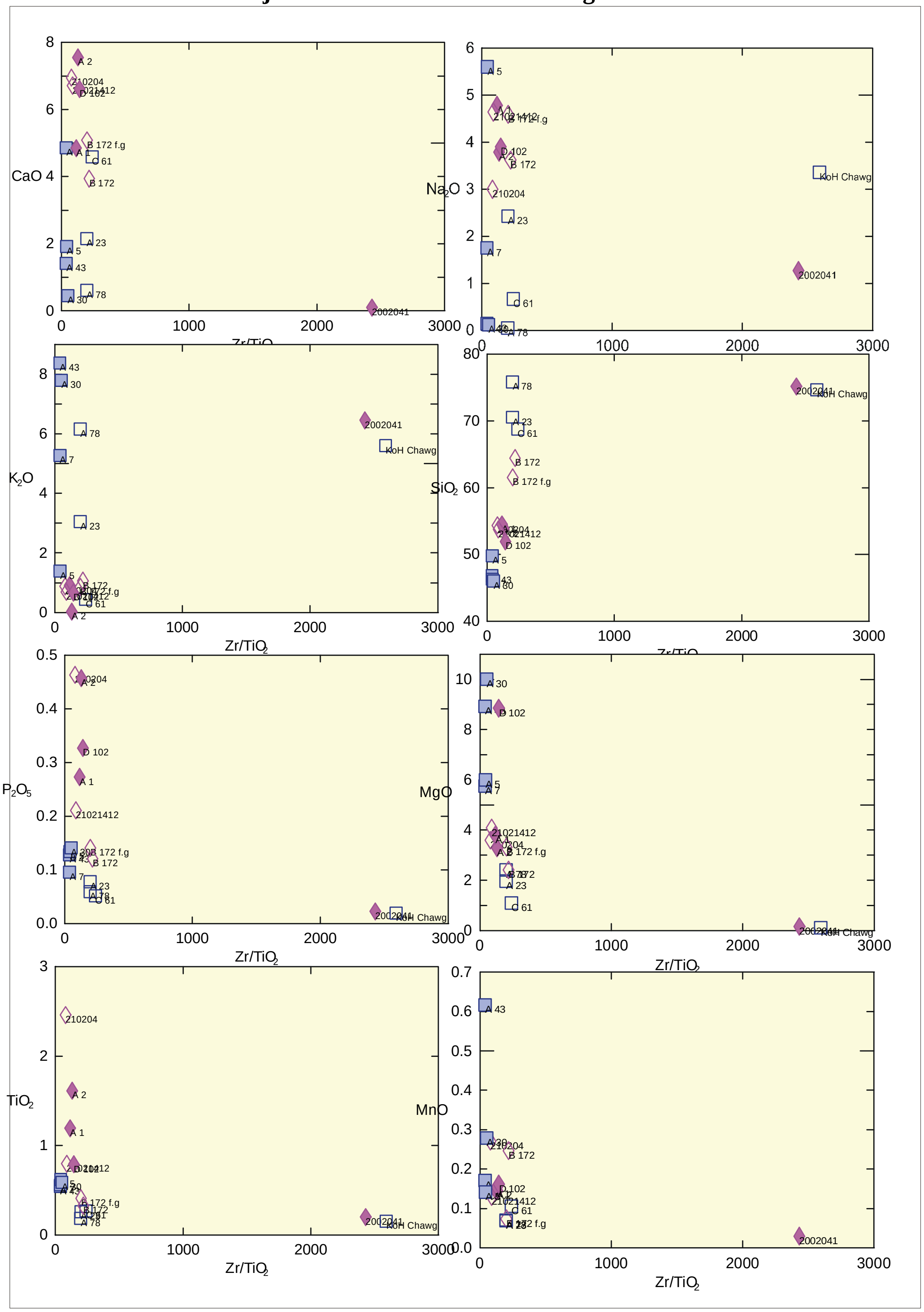

Figure I *Major element composition vs Zr/TiO2ppm values. Numbers next to the symbols indicate sample numbers*

Trace element discrimination diagrams

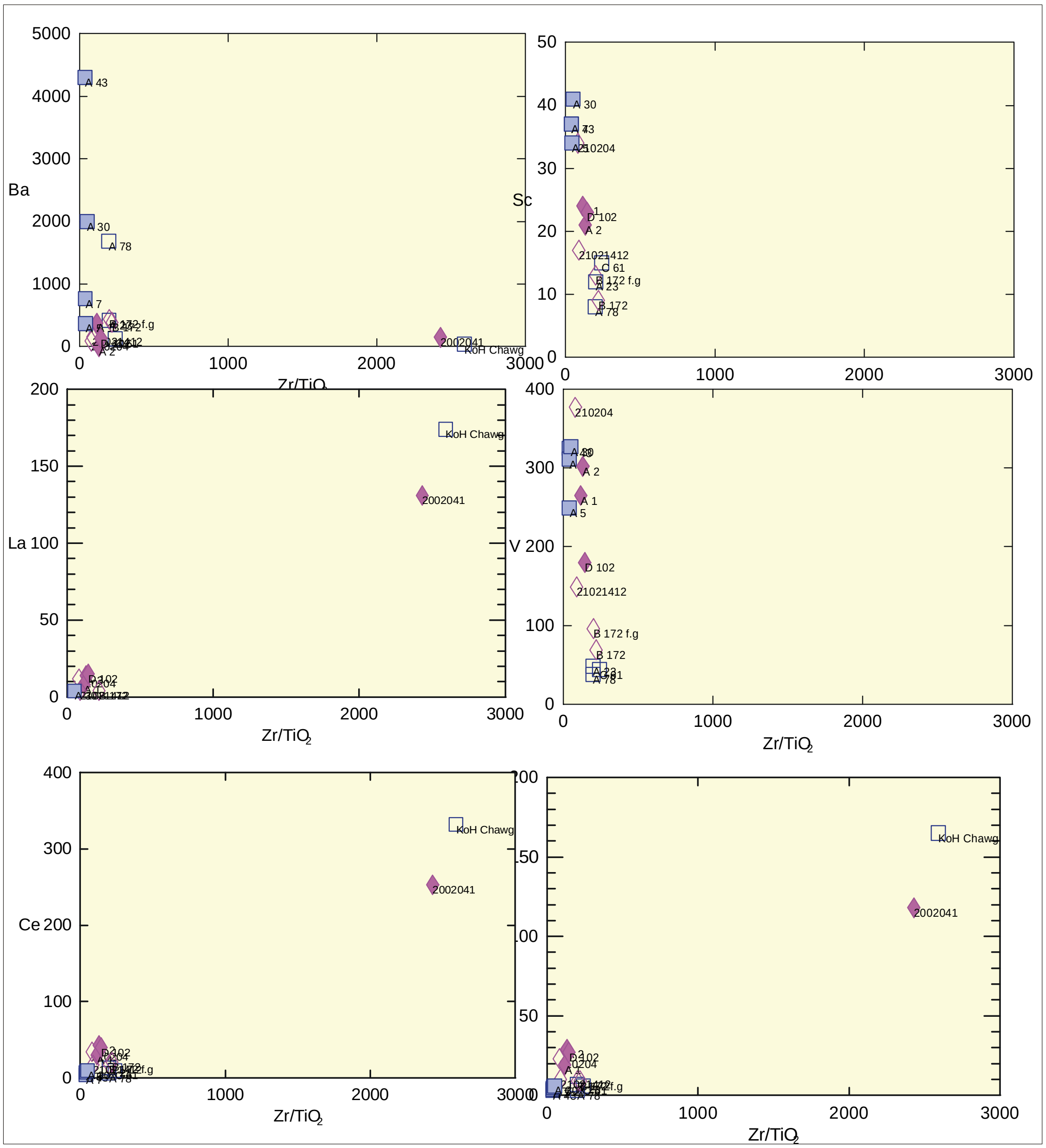

Figure II *Trace element composition vs Zr/TiO2ppm values. Numbers next to the symbols indicate sample numbers (refer to table 5.1)*

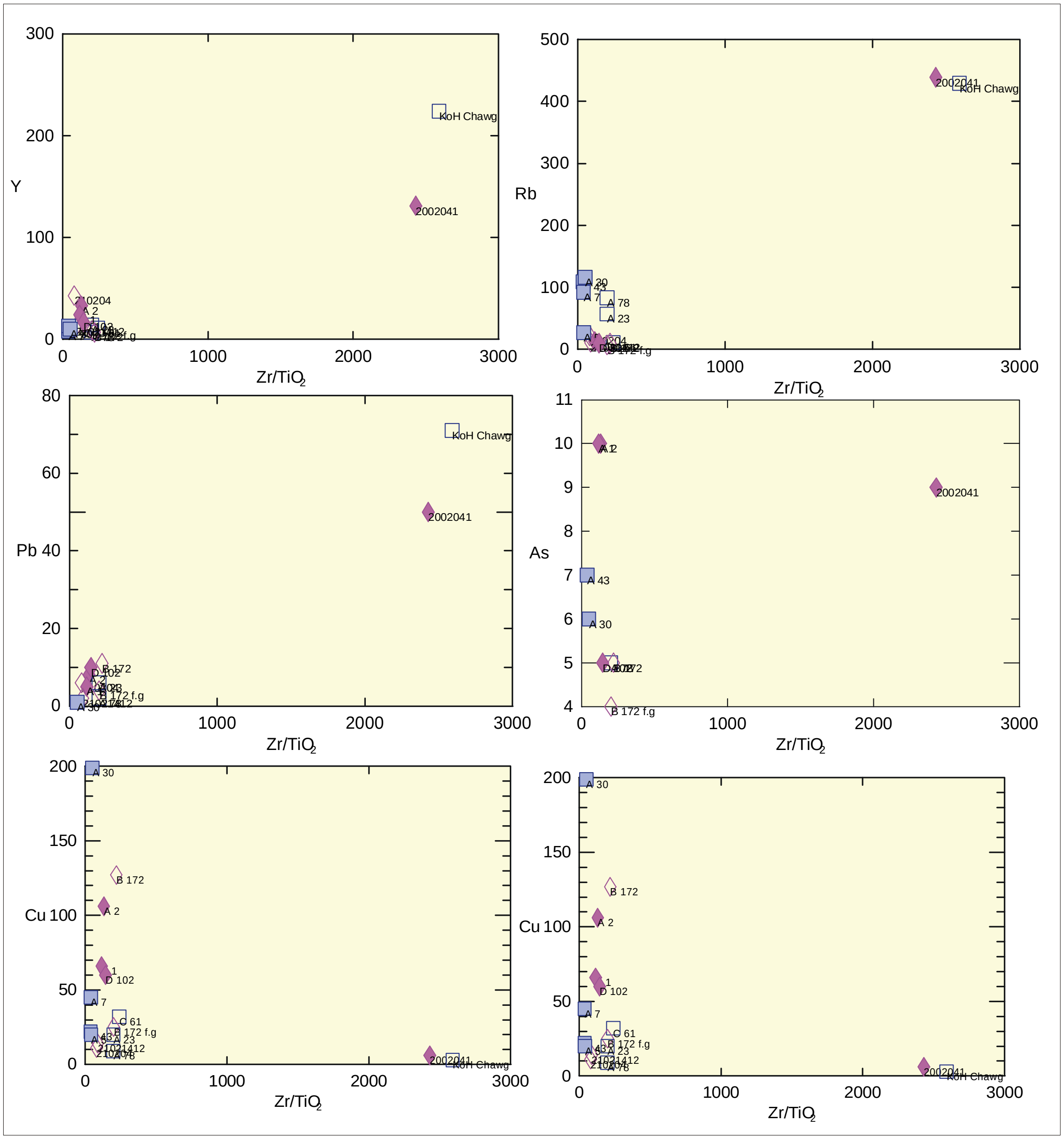

Figure III *Trace element composition vs Zr/TiO2ppm values. Numbers next to the symbols indicate sample numbers (refer to table 5.1)*

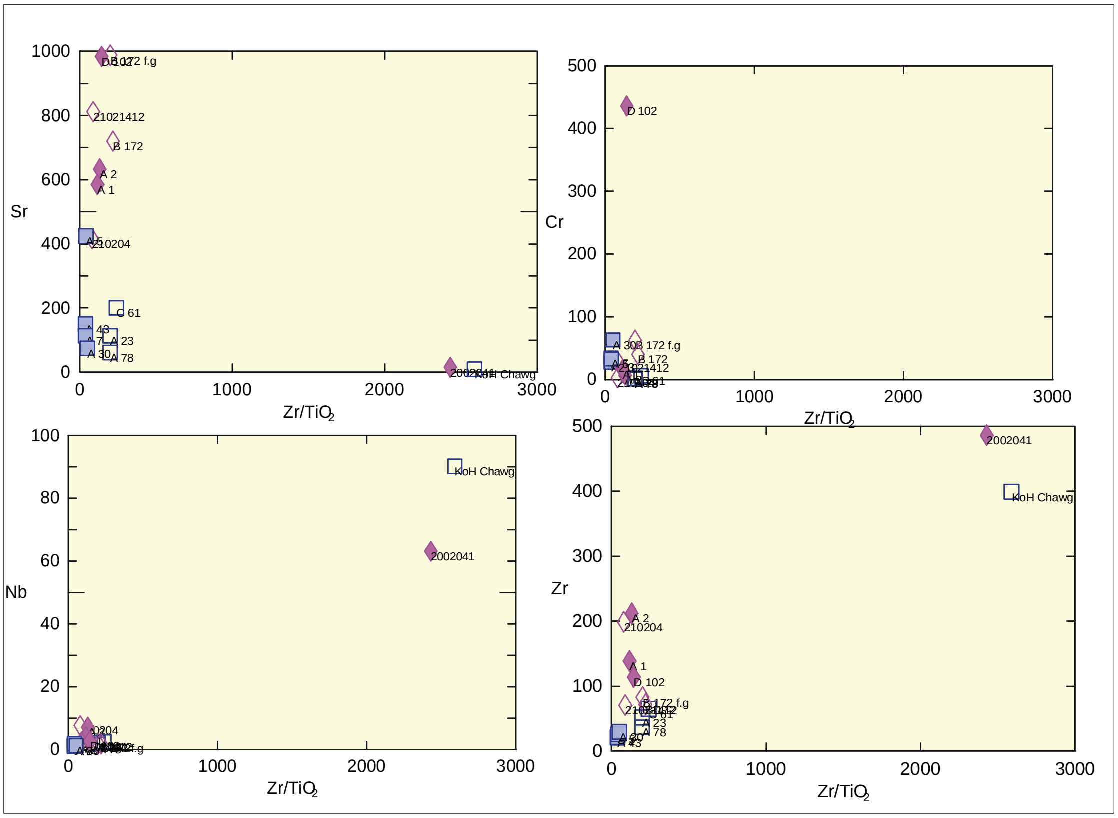

Figure IV *Trace element composition vs Zr/TiO2ppm values. Numbers next to the symbols indicate sample numbers (refer to table 5.1)*

Facies	**Texture**	**Phenocryst and microphenocryst assemblages and lithic fragments**	**Groundmass**
Flow banded spherulitic rhyolite (**Koh Chang**)	Moderately porphyritic rhyolite with well developed spherulites and lithophysae	Quartz: 60-70%, 1-3 mm subhedral K felspar (?): 10-15%, 2-3 mm subhedral to euhedral Spherulites and lithophysae: 0.5 mm arcuate to acicular radiating quartz crystals often containing a vug in their centre	Fine grained equigranular quartz rich with minor (2-5%) chlorite and sericite
210201	Equigranular, holocrystalline andesite	Actinolite: 50-60% <0.5 mm acicular to whispy phenocrysts Titanomagnetite: 15-20% 1 mm laths Quartz/silica: 2% 1-2mm ragged margins Alteration: small 2-3mm veins containing white mica and sparce epidote	NA
B172	Moderately to coarsely porphyritic andesite	Plagioclase felspar: 3-5 mm tabular euhedral to subhedral phenocrysts containing pervasive silica alteration (possibly sanadine) Clinopyroxene: 5% 4-5 mm euhedral phenocrysts with interstitial Fe-Ti oxide laths Amphibole: 15% 3-4mm tabular phenocrysts Fe-Ti Oxides: 5% o.5mm ragged to blocky laths	Medium- coarse grained felspar phyric with <3% 1mm clinopyroxene and 1 – 0.5 mm Fe-Ti oxide
2102042	Moderately porphyritic andesite	Amphibole: 10% 9mm tabular euhedral to subhedral tabular phenocrysts Sanadine: 5% 1-2mm subhedral and pervasively replaced by silica Clinopyroxene: 1% rare <1mm anhedral crystals Fe-Ti oxides: 20% <0.5 mm blocky euhedral crystals Alteration: Calcite, chlorite alteration	Holocrystalline actinolite rich with blocky Fe-Ti oxides and magnetite

Facies	**Texture**	**Phenocryst and microphenocryst assemblages and lithic fragments**	**Groundmass**
A2 Plagioclase phyric variably chlorite altered andesite	Moderatey to coarsely porphyritic	Plagioclase felspar: 10-20% 0.5 101mm blocky to tabular phenocrysts containing inclusions of Fe-Ti Oxides Alteration: The plagioclase felspar has been wholly to partially replaced by chlorite, pyrite also occurs.	Fine to medium grained equigranular crystals comprised of 70% variably altered tabular to blocky plagioclase felspar crystals, scattered magnetite and amphibole
A23 Quartz rich pumice breccia		Alteration: Highly silicified matrix and and crystal assemblage. The matrix is fine grained . The crystal phases include silica replaced alkali felspar, quartz crystals and plagioclase felspar crystals. No remnant pumice textures are distinguishable due to the high level of replacement.	NA
A32 Plagioclase phyric basaltic andesite	Equigranular	Plagioclase felspar: 60% <1mm tabular phenocrysts Olivine: 2% <0.5 mm subhedral phenocrysts Pyroxene: 14% subhedral <1mm subhedral to anhedral phenocrysts Titanomagnetite: 5 % <0.25mm blocky prismatic crystals Alteration: small component of chlorite alteration and silicification of crystal phases. Vugs infilled by quartz	NA

Facies	Texture	Phenocryst and microphenocryst assemblages and lithic fragments	Groundmass
C62 Polymictic lithic rich pumiceous breccia	Polymictic andesitic lithic breccia	clast type (1) plagioclase phyric andesite: Plagioclase felspar : (20% - 30%) of 1 to 2 mm coarse blocky subhedral to euhedral plagioclase felspar crystals phenocrysts Pyroxene: (6%), 1 - 2.5 mm pyroxene phenocrysts altered to chlorite and clays. clast type (2) plagioclase felspar and hornblende phyric andesite: Plagioclase felspar: 15-20% subhedral 1 to 2mm Amphibole: 1-5% 1mm amphibole clast type (3): mudstone and siltstone consisting of a high proportion of plagioclase felspar and clast type (4) basaltic clast: composed of altered plagioclase felspar, pyroxenes, rare olivine and amphibole, magnetite, chalcopyrite and pyrite. The most widespread fragment has been wholly silicified composed of fine grained equigranular quarts crystals with larger quarts inclusions within it. Clast type (5): pumice, highly altered	Clast type 1: evenly crystalline containing plagioclase felspar and rare amygdales, groundmassis altered to silica, adularia, chlorite and clay or calcite. Red discolouration of some clasts is due to a dusting of haematite and /or adularia. The amygdales constitute 5 to 7% of the rock volume and are infilled by silica, calcite, clay and adularia. Clast type 2: < 0.5 mm evenly crystalline, composed of tabular plagioclase felspar crystals Clast type 4: fine grained groundmass (<1 mm) with 1 mm pyroxene and 1.5mm acicular to tabular felspar crystals.
A10 Plagioclase phyric andesite	Moderately porphyritic	Plagioclase felspar: 15%-30%, 2-3mm euhedral and less abundant (5%) altered felspar phenocrysts. Alteration: plagioclase phenocrysts are dusted with hematite and overprinted by sericite, patchy carbonate and minor epidote. The rims are often altered to adularia.	fine grained (0.5mm) equigranular groundmass, containing K-feldspar, apatite, interstitial chlorite , (5%) amphibole, and opaques including Fe-Ti Oxides with minor pyrite.

		Amphibole: is altered to chlorite, sericite, carbonate and less commonly sphene. Xenoliths: 2-3 mm equigranular aphyric euhedral plagioclase felspar and amphibole. Amygdales: 2 mm, circular to ragged in shape infilled by adularia, silica, clays, chlorite and carbonate.	
Facies	**Texture**	**Phenocryst and microphenocryst assemblages and lithic fragments**	**Groundmass**
A7 plagioclase phyric andesite clast	Moderately porphyritic	Amygdale: infilledby calcite plagioclase felspar phenocrysts: Pervasive chlorite alteration.	groundmass consists of plagioclase felspar and titanomagnetite and oxide phases.
A43 andesite clast	Moderately to coarsely porphyritic	Plagioclase felspar: 30-40 % 1-2 mm blocky to tabular euhedral phenocrysts Pyroxene: 5% 1-2 mm euhedral to subhedral wholly replaced by quartz Titanomagnetite: 5% <0.25 mm laths Vesicles: 5-10% 2-3 mm quartz infilled vugs with irregular curvey margins	Titanomagnetite, quarts, partially altered plagioclase felspar crystals, chlorite altered replaced quarts crystals, plagioclase.
D105 Sparcely plagioclase phyric andesite	Moderately to porphyritic	pyroxenes: 5 -10% 1mm subhedral phenocryts plagioclase felspar: 30-40% 0.25 – 0.5 mm subhedral crystals wholly or partially replaced by fibrous chlorite. Xenolith: is equigranular, composed of large quarts, plagioclase felspar and titanomagnetite crystals.	The groundmass is equigranular The groundmass is composed of plagioclase felspar, blocky titanomagnetite crystals.

Major element data

	Sample Identification:														
Oxides	**C 61**	**A43**	**A78**	**A7**	**B172**	**200204**	**Koh Chang**	**A2**	**A23**	**A1**	**B172**	**21021412**	**A5**	**D102**	**A30**
SiO_2	68.76	46.84	75.83	46.30	61.53	75.15	74.64	53.91	70.53	54.51	64.43	53.77	49.81	51.95	46.02
TiO_2	0.27	0.54	0.19	0.56	0.41	0.20	0.15	1.61	0.26	1.19	0.33	0.80	0.62	0.79	0.59
Al_2O_3	13.64	18.00	10.31	17.84	16.73	12.72	13.56	15.95	13.82	16.62	16.61	18.58	19.99	15.20	18.96
Fe_2O_3	3.59	8.88	1.80	9.31	4.55	2.50	0.75	9.81	2.40	8.84	3.73	7.19	9.48	7.47	8.92
MnO	0.11	0.62	0.07	0.17	0.07	0.03	<0.01	0.15	0.07	0.15	0.25	0.13	0.14	0.16	0.28
MgO	1.09	8.92	2.41	5.75	3.32	0.16	0.11	3.29	1.97	3.80	2.41	4.08	5.99	8.85	10.01
CaO	4.59	1.41	0.61	4.86	5.08	0.10	<0.01	7.55	2.15	4.85	3.94	6.71	1.92	6.61	0.45
Na_2O	0.67	0.14	0.05	1.75	4.59	1.27	3.36	3.79	2.43	4.78	3.62	4.64	5.60	3.90	0.12
K_2O	0.44	8.38	6.16	5.27	0.86	6.45	5.60	0.03	3.05	0.91	1.06	0.69	1.39	0.67	7.79
P_2O_5	0.05	0.13	0.06	0.10	0.14	0.02	0.02	0.46	0.08	0.27	0.12	0.21	0.13	0.33	0.14
Loss inc.S-	7.01	5.93	2.49	7.74	3.36	1.51	1.55	3.34	3.37	4.03	3.17	3.66	4.79	3.83	6.18
Total	100	100	100	100	100	100	100	100	100.13	100	100	100	100	100	100
S	0.10	0.18		0.04	<0.01	0.03	<0.01	0.06	0.07	0.02	0.15	0.01	<0.01	0.36	0.28