CHAPTER 2
THE GEOLOGY OF THE SOUTH SULAWESI BASEMENT COMPLEXES

The basement complexes in south Sulawesi consist of two separate blocks, the Bantimala and Barru blocks, located in the western part of the peninsula (Fig. 2.1). The petrology, structure and tectonic evolution of these basement complexes has been discussed by numerous workers, particularly (Hamilton, 1979), (Sukamto, 1982), (van Leeuwen, 1981), (Wakita et al., 1996), (Miyazaki et al., 1996), (Parkinson & Katayama, 1999) and (Parkinson, 1998).

Sukamto (1975, 1982) and van Leeuwen (1981) proposed the name “Bantimala Tectonic Complex” to include the basement rocks of both the Bantimala and Barru areas, whereas Parkinson (1998) distinguished these two blocks as the Bantimala and Barru Complexes. In this thesis, the terms ‘Bantimala block’ and ‘Barru block’ will be used to refer to the basement rocks of these respective areas. Since it will become apparent that the two blocks are quite different in their geological characteristics, the plural “South Sulawesi Basement Complexes” will be used to refer to them collectively.

The Bantimala block is approximately 68.5 km^2 in area, whereas the Barru block is about 27.5 km^2 in area and lies to the north of the Bantimala block. Both are bounded to the west by complex associations of east-dipping thrusts and NNW-striking wrench faults and to the north and south by NW-SE trending sinistral wrench fault zones (Fig. 2.1) (Berry & Grady, 1987). The two blocks are separated by a gap of approximately 30 km, filled with Tertiary sediments and volcanic products but with no basement exposure.

2.1 PREVIOUS WORK
2.1.1 Bantimala Block

The first systematic mapping of the Bantimala block was conducted by Sukamto (1975). He noted the occurrence of pre-Tertiary assemblages including metamorphic rocks, ultramafics and fragments of mélange in Bantimala village and the surrounding area. He later proposed that this block was resulted from collision between the
Sundaland continental margin and the Pacific oceanic plate, prior to spreading of the Makassar Strait.

Fig. 2.1. Map of south Sulawesi showing the regional distribution of the basement complexes (Bantimala and Barru blocks) and principle study area as well as structural pattern. The basements complexes is sheared by fault and bounded by Tertiary sediments and volcanic product.
Hamilton (1979) reported that the basement of south Sulawesi crops out in two areas; one of which is the Bantimala area. The basement complex was described as consisting of ultramafic and metamorphic rocks striking northeastward. Based on the physical characteristics of the ultramafic and metamorphic rocks, he concluded that the basement complex originated in Cretaceous subduction at the eastern margin of Sundaland.

Berry and Grady (1987) showed the Bantimala block is characterised by the occurrence of cataclasite developed in fault zones, with a strong anastomosing cleavage. They reported that most of the clasts have been strongly deformed and rotated due to intensive faulting, the schistosity strike direction being consistently to the NW, roughly parallel to the faults.

The detailed stratigraphy of the Bantimala block was discussed by Wakita et al. (1996) (Figs. 2.2 and 2.3). They reported that the block is characterised by an assemblage of northeast-dipping, tectonically stacked slices which included metamorphic, sedimentary and ultramafic rocks, intruded locally by intermediate – basic igneous intrusions. The metamorphic rocks ranged mainly from greenschist to amphibolite facies, increasing in grade toward the northeast, although the observations of the current study suggest that the amphibolites are in fact part of the Barru block. Wakita et al. also recorded greenschists, glaucophane schists and blocks of eclogite. The sedimentary rocks include sandstone, shale, conglomerate, radiolarian chert, siliceous shale and mélangé. The ultramafic rocks were chiefly serpentinized peridotite, with local chromite lenses and basalt layers. They noted that the Bantimala block is distinguished by the occurrence of a mélange which includes rock types such as sandstone, shale, siliceous shale, chert, basalt, schist and felsic igneous rock in a sheared matrix of shale, as well as schist breccia. The block is bounded to the north and south by the Balangbaru Formation and the Tonasa Limestone respectively, to the west by Paleogene volcanics, and to the east by the Camba Formation. However, the similarities of radiolarians contained in the Balangbaru Formation and those in chert in the Bantimala Complex led them to suggest that the Balangbaru Formation is in fact part of Bantimala Complex.

Age determination on this complex was derived by several workers. K-Ar radiometric ages of 111 Ma were reported by Obradovich in Hamilton (1979) and 113 – 115 ±6 Ma from muscovite in schist by Wakita et al. (1996), whereas 111± 3 Ma were

Fig. 2.2. Geological map of the Bantimala block (after Sukamto, 1982; Wakita et al., 1996).
2.1.2 Barru Block

In contrast to the Bantimala block, little has been written concerning the geology of the Barru block in its own right. Generally, any discussion of the geology of this block has been included with that of the Bantimala block.

Hamilton (1979) and Sukamto (1982) described metamorphic and ultramafic as well as sedimentary rock units in the Barru area as the analogues of those in the Bantimala area, and deduced them to be part of the same basement complex. Van Leuween (1981) reported that the Barru block is quite similar to the Bantimala block, being composed of schist, gneiss, radiolarian chert, silicified shale and ultramafic rocks. He also noted that the block was locally intruded by dacitic – andesitic lava.

Berry & Grady (1987) described the Barru block as consisting of a series of low-pressure metamorphic rocks and ultramafics. Their lowest exposed unit is serpentinite, overlain by quartz-mica schist, then quartzite and chloritic phyllite. In contrast to the Bantimala block, the rock assemblages in Barru block have a SE-dipping foliation and a S to SW-trending lineation.

Syafrie et al. (1995) studied metamorphic rocks from the Barru block and reported the occurrence of some high-pressure metamorphic assemblages. However, he did not indicate the specific locations of these rocks, and later investigation suggests that it is very likely that the high-pressure assemblages were actually found in the Bantimala region (Syafrie, pers. comm. 2008).
Wakita et al. (1996) carried out K-Ar radiometric dating technique on mica from schists in the Barru block. Results from this investigation indicated that the metamorphic rocks of the Barru block were younger than those in the Bantimala block, with an age of 106 ± 5 Ma.

Wilson and Bosence (1996) studied the redeposited carbonate sequences of the Tonasa Limestone from some sections in the Barru area to configure the Tertiary evolution of south Sulawesi. They reported that the main control on sedimentation in this area was tectonic processes. In addition, they divided the redeposited facies into two groups; the Bantimala and the Barru redeposited facies which have different characteristics.

Based on these previous investigations and the field observations of the current study, a geological map of the Barru block is shown in Figure 2.4.
2.2 TECTONIC MODELS

Several tectonic models have been proposed to provide the understanding of the origin and the evolution of the South Sulawesi Basement Complexes. Most of the models indicate that this area was a part of east Kalimantan prior to the opening of the Makassar Strait in the Eocene as a pull-apart basin along the NW-SE trending Paternoster fault (Hall, 2002). Thus, Mesozoic rocks in this area would have formed at the southeastern margin of the Sundaland continent. Haile (1978) and Sasajima (1980) used paleomagnetic data from a Jurassic radiolarian chert in the Bantimala Complex to show that the region experienced an anticlockwise rotation of 35-50° since the late Mesozoic, rotating as a rigid block with the Malay Peninsula and West Kalimantan.

Wakita et al. (1996) proposed a model which focused on the west-dipping subduction of a slab of microcontinent under the Sundaland margin (Fig. 2.4). According to them, there was subduction east of Sundaland from the Jurassic to early Cretaceous, bringing various sized continental fragments which drifted from the south and accreted onto the Sundaland margin. These continental fragments were interpreted as former parts of the Gondwanaland, which broke up during the Mesozoic (Wakita et al., 1996) and interpreted as the sources for the Jurassic shallow marine sediments which are distributed in some parts of Sulawesi, including the Bantimala area. This was then followed by another phase of subduction of oceanic plate, which ultimately produced high-pressure metamorphic rocks and also formed the “Bantimala Trench” (Wakita et al., 1996) which contains shallow marine sediments. Another microcontinent was partly subducted and partly incorporated into the accretionary wedge. Due to the density differences, this continental fragment underthrusted and caused rapid uplift and exhumation of the high pressure metamorphic rocks onto the surface, forming the basement complexes of South Sulawesi.

Katili (1978) linked the exhumation of the South Sulawesi Basement Complexes with the opening of the Makassar Strait, and correlated the Cretaceous mélange in this complex with the Meratus Complex in east Kalimantan, of which he proposed they were detached portions.

Parkinson et al. (1998) concluded that the high-pressure metamorphic assemblages in the Bantimala area have some similarities with those from other metamorphic terranes in east Java, southeast Kalimantan and central Sulawesi. These complexes were interpreted to have been generated in the same tectonic environment, at
the margin of the Sundaland Craton. The exhumation of these high pressure assemblages was probably triggered by the collision of the Gondwana continental fragments with the Sundaland margin, which was a west-dipping subduction zone in the Early Cretaceous (120 – 115 Ma).

Guntoro (1999) proposed that the Bantimala Complex resulted from the collision between the south Sulawesi microcontinent with southeast Kalimantan in the Late Cretaceous due to west-dipping subduction below the Sundaland (Fig.2.5). Note that this implies some separation of south Sulawesi, possibly by a short-lived marginal basin, before then. The continuing motion of the Pacific Plate to the west formed a new subduction zone to the east of South Sulawesi, and resulted in the uplift of the Meratus Mountains and the emplacement of the Bantimala Complex. In the Paleocene, the Banggai–Sula microcontinent was approaching from the east, and rollback of the subducting plate produced back-arc spreading and the opening of the Makassar Strait, which separates the southeast part of Kalimantan from the southwest of Sulawesi.

Fig.2.4 Cartoon of tectonic evolution of the Bantimala Complex (after Wakita et al., 1996). Black shaded block represents oceanic crust.
2.3 HIGH PRESSURE METAMORPHIC ROCKS

T’hoen & Ziegler (1917) in van Leeuwen (1981) were the first workers to provide the information on the occurrence of the high-pressure (HP) metamorphic rocks, particularly eclogites, in the Bantimala area. However, it was not until the 1990’s that the high-pressure rocks in this area were studied in detail by workers such as Miyazaki et al., (1996), Wakita et al., (1996), Parkinson, (1998), Parkinson et al., (1998), Parkinson and Katayama, (1999), Maulana et al., (2008). The occurrence of the high-pressure metamorphic rocks in this basement complex has constrained the interpretation of the origin and evolution of South Sulawesi region.

Syafrie et al. (1995) reported the occurrence of lawsonite eclogite and retrograde blueschist from the Barru areas. The pressure and temperature conditions for the eclogite were estimated to be 21 kbar and 520°C, while the blueschist ranged from 8 kbar and 360°C to 13 kbar and 520°C. However, it has since been confirmed that the eclogites were found in the Bantimala block rather than Barru (Syafrie, pers. comm. 2008).

Wakita et al. (1996) described HP rocks from the Bantimala block (considered to include the Barru block), including glaucophane schist and eclogite showing respectively greenschist and amphibolite facies retrograde overprints. They interpreted
these HP assemblages to represent tectonic slices along major faults within this complex.

Miyazaki et al. (1996) described HP rocks from the Bantimala block including eclogite, garnet-bearing glaucophane rock and glaucophane-free schists. Using the garnet–clinopyroxene thermometer, they estimated that the peak temperature of eclogites, garnet-glaucophane rocks and glaucophane-free schists in the Bantimala area ranged from 580–630°C at 18 kbar to 590–640°C at 24 kbar. These $P$-$T$ conditions indicate that these rocks have experienced subduction to c. 65-85 km depth, at a low geothermal gradient (approximately 8°C/km) consistent with a cold oceanic plate subducting at a high rate and remaining cool during exhumation. They also reported that the mineral parageneses show that the HP metamorphic rocks experienced varying degrees of retrograde metamorphism. Generally, retrograde metamorphism was more widespread in garnet-glaucophane schists than the other rock types.

Parkinson et al. (1998) reported imbricated slices of metamorphic rock in this area which consist of three main types of blueschist: very fine-grained lawsonite-glaucophane schist, hematite-glaucophane schist, and garnet-glaucophane schist, interlayered with garnet-glaucophane-ferrochloritoid schist, albite-actinolite-chlorite schist and chlorite-mica schist. They concluded that these rocks are similar in petrology to other Mesozoic accretionary complexes in central and eastern Indonesia, particularly the Pompangeo Metamorphic Complex, in central Sulawesi.

Evidence of ultrahigh pressure (UHP) metamorphism (> 30 kbar) in the Bantimala complex was reported by Parkinson & Katayama (1999). They found coesite included in zircon from an eclogite (Parkinson and Katayama, 1999), coesite stability is diagnostic of such UHP conditions.

The most recent study on HP rocks in these complexes was presented by Maulana et al. (2008) who reported the petrology and mineralogy as well as calculated pressure and temperature conditions for eclogites from the Bantimala block. They came to the conclusion that the Bantimala eclogite equilibrated under UHP conditions ($28 \pm 2$ kbar and $650\pm50^\circ$C), consistent with Parkinson and Katayama (1999) but more extreme than reported by previous workers. In addition, they also showed that the Bantimala eclogites are quite distinct in term of mineralogy and petrology from the eclogites found in the Karangsambung area, Central Java (Kadarusman et al., 2007) and in the Palu region, Central Sulawesi (Kadarusman et al., 2002). Hence, there is little evidence for
the idea that the Bantimala block is part of a single cohesive Central Indonesia Collision Complex along with these other basement blocks, as has been supposed by previous workers (Wakita et al., 1996, Parkinson, 1998, Kadarusman et al., 2007).

The literature to date provides a broad understanding of the geologic context of the Bantimala and Barru blocks. However, questions still remain regarding the origin and the evolution of these two blocks, which will be addressed in this thesis. These questions include:

a. The high-pressure metamorphic assemblages in these two areas are different in type. High-pressure metamorphic rocks such as eclogite appear to be absent from the Barru block despite being abundant in the Bantimala block. Whether this is so, and the significance of this difference, remains an issue.

b. The treatment of these basement complexes as a single tectonic unit is questionable. The Bantimala and Barru blocks are separated at the surface by about 30 km of Tertiary sediments cover. The nature of the connection or disconnection between the two blocks needs to be discussed, particularly in the light of their different metamorphic and structural trends.

c. The origin and ages of the ophiolite suites in these two blocks are still not clearly defined. Some regard the ophiolites as dismembered parts of a larger Sulawesi ophiolite (Parkinson et al., 1998) but others consider them as local features, obducted on collision of a microcontinent (Wakita et al., 1996).

d. The structural pattern is more complex and the metamorphic rocks more varied in the Bantimala block than in the Barru block, which requires further discussion.

e. Data on the timing of emplacement and exhumation of the basement rocks in these two blocks is not complete, and the sequence of events is still subject to debate.