



Geology of Southern Leyte: Contribution to the Understanding of the Evolution of Central Philippines

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ABSTRACT

Geologic mapping was carried out in Southern Leyte which led to the recognition of a complete ophiolite sequence, the Malitbog Ophiolite Complex. A Late Cretaceous conglomerate unit containing clasts of basalt, gabbro and chert caps the ophiolite sequence. This suggests that the ophiolite was emplaced, exposed and eroded by Late Cretaceous. Pre-Late Oligocene to Quaternary sedimentary sequences also cap the ophiolite complex in some localities. The sedimentary deposits were formed in fluvial to shallow marine environments. The characterization of the lithologic units in Southern Leyte as presented here offer clues on the processes in the evolution of Southern Leyte and the environments where the different rock units formed. This, in return, helps in deciphering the geologic history of Central Philippines.

Keywords: ophiolite, crust-mantle sequence, geologic evolution, Central Philippines

INTRODUCTION

Geological mapping was conducted in Southern Leyte in April 2003 encompassing the areas of Liloan-Libagon, Sogod-Malitbog-Maasin along the western side of the Sogod Bay and in Panaon Island, (Figure 1). Previous studies done on the area include reconnaissance mapping for palinspastic reconstruction and tectonic interpretation (e.g. Florendo, 1987), geological survey with accompanying sediment and soil geochemical survey for metallic deposit exploration (e.g. Korean International Cooperation Agency [KOICA], 1993; Japan International Cooperation Agency Metal Mining Agency of Japan [JICA-MMAJ], 1990) and engineering geological investigation and geohazard assessment of some portions of Southern Leyte.

This study is part of the investigation into the crust – mantle sequences (ophiolites) which comprise some islands in Central Philippines. These oceanic crust – mantle sequences were part of land-bounded oceanic basins that existed a long time ago. Determining whether these different ophiolites were derived from the same marginal basin or from several oceanic basins is something that is being looked into as this is critical in deciphering the tectonic setting of an area (e.g. Gawlick *et al.*, 2008; Queaño *et al.*, 2008; Escuder-Virueze *et al.*, 2009). In order to do this, the scarcity of comprehensive geological data on the ophiolite complexes found in Leyte needs to be addressed. It is for this reason that geochemical investigation and field geological mapping were carried out in Leyte island to determine the characteristics and features of the ophiolite complexes in the island.

In this paper, field observations will be presented about an ophiolite complex, the Malitbog Ophiolite Complex, which was mapped in Southern Leyte. Characterization of the sedimentary rock cover as presented here gives an idea on the post-ophiolite emplacement history as it relates to the evolution of Southern Leyte. This subsequently contributes to the interpretation of the geologic and tectonic history of Central Philippines.

Methodology

Mapping and traverses were done along trails, roads, creeks or rivers, and ridges using the 1:50,000 scale topographic maps from the National Mapping and Resource Information Authority (NAMRIA). Location was obtained through triangulation and hand-held GPS units. Representative rock samples were collected from outcrops for petrographic and paleontological analyses. From the field observations, a geologic map was produced and geologic cross sections were drawn in order to fully understand the stratigraphic relationship of the different lithologic units. Remotely-sensed imageries and aerial photos were examined to delineate geologic structures such as faults or fractures.

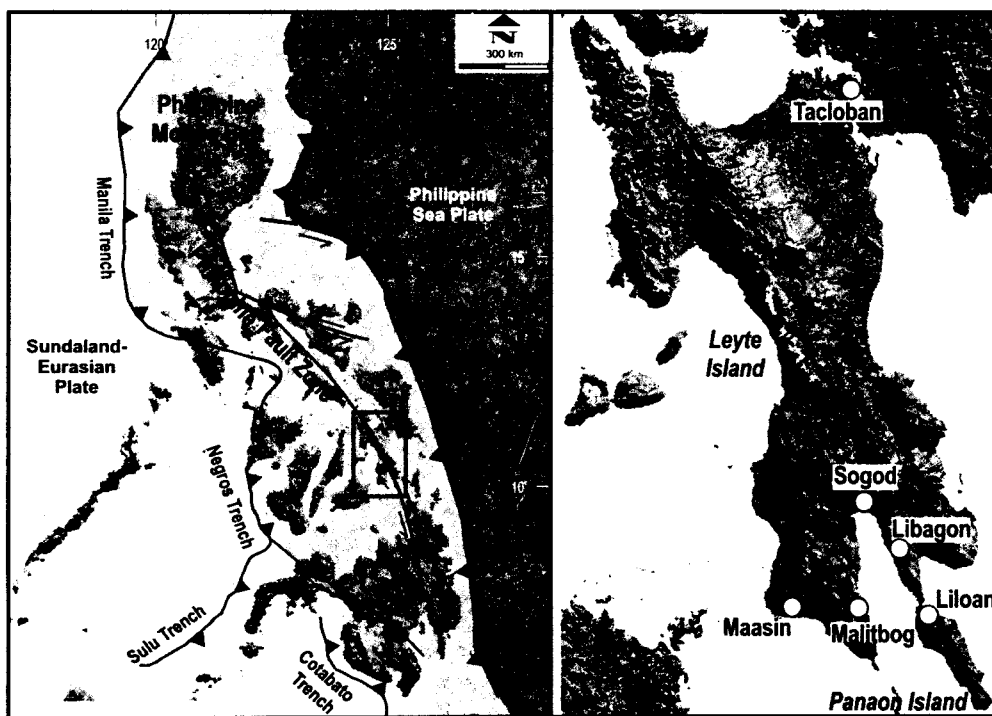


Figure 1. (Left) The Philippine island arc system was produced by the convergence between the Philippine Sea Plate (dark gray) and the Sundaland-Eurasian Plate (unshaded area). Leyte island by the boxed region. (Right) The areas in Southern Leyte which were mapped during this survey are Maasin, Malitbog, Sogod, Libagon, Liloan and Panaon island (images from the Shuttle Radar Topography Mission (SRTM) of the United States Geological Survey EROS Data Center).

Stratigraphy of Southern Leyte

Malitbog Ophiolite Complex

The Malitbog Ophiolite Complex (MOC) is widely distributed in Southern Leyte with the complete sequence (ultramafic rocks, layered gabbros, isotropic gabbros, dike swarm and pillow basalts and flow deposits) exposed in the eastern part of Maasin Peninsula in Biliran River (Figure 2). An ultramafic rock outcrop is also seen near Maasin City, whereas layered ultramafic rock exposures are noted in Liloan. The Tigbauan Formation is the conglomerate unit overlying the MOC. It contains clasts of basalt, gabbro and chert. The other sedimentary sequences overlying the ophiolite complex and its associated sedimentary carapace include the Laboon Formation, Panan-awan Formation, Dacao Formation, Calian Formation and Matalom Formation. Several volcanic deposits found in the area are represented by the Central Highlands Igneous Complex and the Quaternary Volcanics (Figures 2 and 3). A Late Cretaceous age assigned to the Tigbauan Formation was established based on the foraminiferal assemblage in the unit (Florendo, 1987). This is taken as the minimum age of emplacement of the MOC considering that ophiolite-derived clasts are found in the Tigbauan Formation.

Lherzolite - harzburgite

Mantle peridotites are observed in the northern part of Panaon Island, in the southern part of the Liloan-Lubigon area and in the Malitbog-Maasin area (Figure 4). The samples are variably serpentinized. Olivine converted to serpentine and magnetite, whereas orthopyroxene transformed to bastite are common occurrences. The peridotites are massive to extensively faulted. The latter peridotites range from blocky to almost broken formation. Highly sheared peridotites are found along thrust fault contacts. In one outcrop in Malitbog, a broken formation is overthrust on massive peridotites. Diabase, gabbro and aplitic dikes cut the peridotites similar to what has been observed elsewhere (e.g. Yumul et al., 1998; Celik and Chiaradia, 2008).

The peridotites, in some outcrops, are thrust on top of massive to layered gabbros as observed in Barangay Bugo, Maasin (Location: 10°09.25' N Lat.; 124°51.34' E Long.) (Figure 4a) and on top of tuffaceous sediments as encountered in Barangay Mahayahay, St. Bernard (Location: 10°14.45' N Lat.; 125°07.44' E Long.). The peridotites range in composition from dunites through harzburgites to lherzolites. The dunites found associated with the harzburgites and lherzolites may correspond to the transition zone dunite of an ophiolite sequence (e.g. Yumul, 2004, 2007). Magnesite veinlets fill the fractures and joints in the peridotites. Initial microprobe analysis of the peridotite spinels, previously collected from exposures along the Liloan Road, shows that most of these spinels are aluminous and that the peridotites are fertile lherzolites (Suerte, 2005).

Layered ultramafic cumulate rocks

A layered ultramafic cumulate sequence is exposed along the road going to Liloan, specifically in Ilag (Location: around 500 m from 10°12.13' N Lat.; 125°05.86' E Long.) (Figure 4b). The attitude of the layering is N25°W; 10°SW. Megascopic analysis of the layered sequence shows the presence of dunites, pyroxenites and harzburgites. The sequence encountered is intensely serpentinized (>75%). The layering structure, in spite of serpentinization, is still preserved. Layering is defined by phase and ratio contacts as shown by the varying percentage of olivine and orthopyroxene.

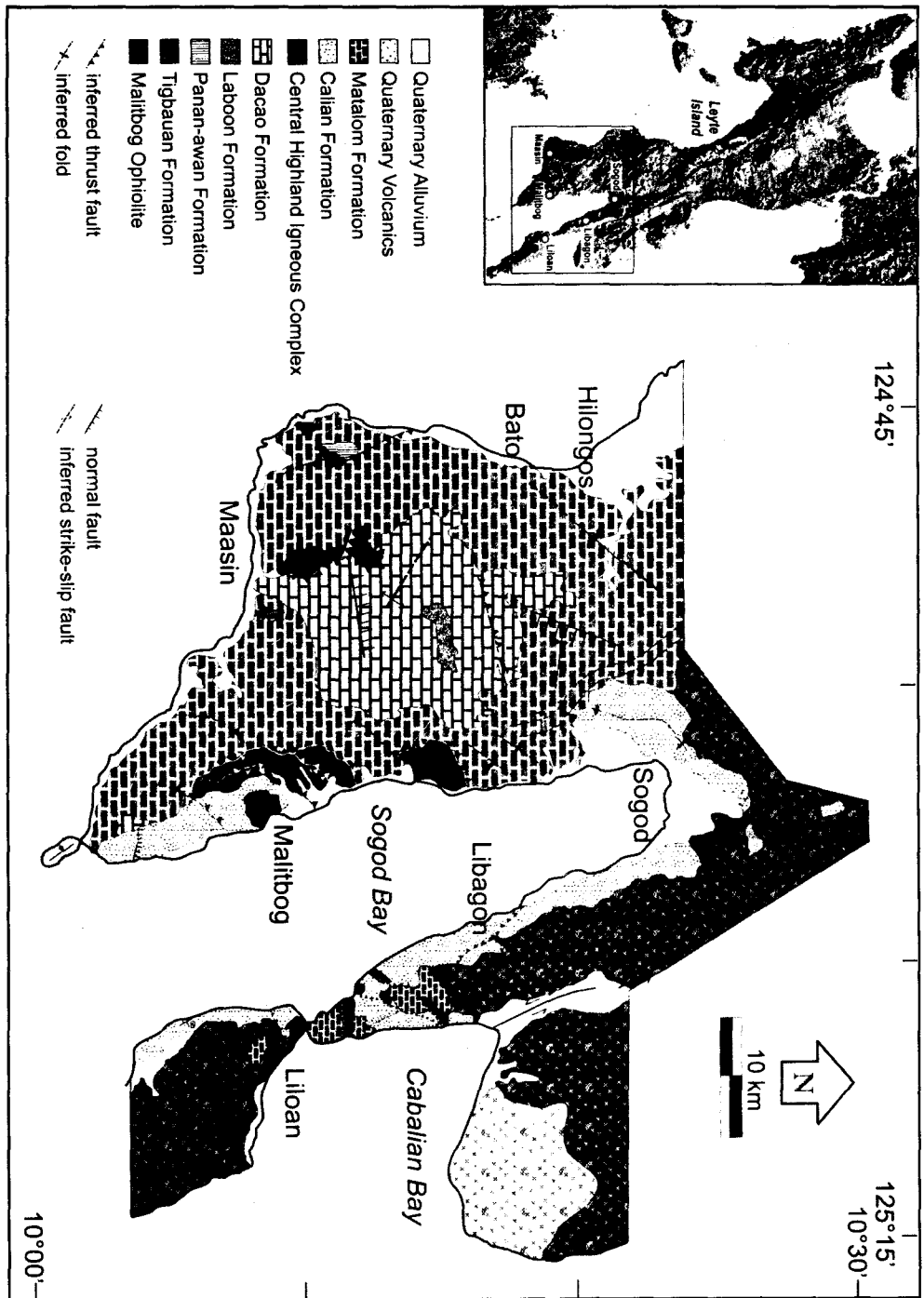


Figure 2. Geologic map of Southern Leyte and northern Panaon Island.

AGE		SOUTHERN LEYTE	PALEOENVIRONMENT
Recent	Late	Quaternary Alluvium	
	Early		
Pleistocene	Late	Matalom Formation	Shallow marine
	Early		
Pliocene	Late	CHIC	Terrestrial to shallow marine
	Early		
Miocene	Late	Calian Formation	
	Middle		
	Early		
Oligocene	Late	Dacao Formation	Shallow marine
	Early		
Eocene	Late	Laboon Formation	Fluvatile
	Early		
Paleocene	Late	Panan-awan Formation	Fore-arc
	Early		
Cretaceous	Late	Tigbauan Formation	Neritic to bathyal
	Early		
	Middle		
	Early		
	Late	Malitbog Ophiolite Complex	Subduction-related marginal basin
	Early		

Figure 3. Stratigraphic column of Southern Leyte. The paleoenvironments of the different sedimentary sequences are deduced from recognized fossil assemblages. CHIC = Central Highlands Igneous Complex.

Layered mafic cumulate rocks high level gabbro

Layered mafic cumulate rocks ranging from gabbro to anorthosite have been mapped in Lambunao River (Location: 10°08.18' N Lat.; 124°58.34' E Long.) in Biliran, Malitbog and in Barangay Bugo, Maasin (Location: 10°09.25' N Lat.; 124°51.34' E Long.) (Figure 4c). Layering attitude ranges from N62°W; 45°NE in Lambunao to N70°W; 73°NE in Maasin as exposed in outcrops. Almost all of the massive gabbros are found along the Lambunao River. The massive gabbros are fresh although some have been slightly chloritized. The gabbros show a phaneritic texture that consists of medium- to coarse-grained olivine, orthopyroxene, plagioclase and, in some samples, hornblende, along with minor amounts of opaque minerals. Diabase dikes cut some of the massive gabbros as noted in some floats.

Dike swarm

A dike swarm has been encountered in the Bgy. Abgao, Malitbog (Location: 10°10.19' N Lat.; 124°58.10' E Long.). The exposure consists wholly of diabase dikes with no country rock. The attitude of the dikes is N62°W; 40°NE.

Pillow to massive lavas

Pillow to massive lava deposits are well exposed near the headwaters of the Lambunao River (Location: 10°08.66' N Lat.; 124°58.27' E Long.) (Figure 4d). Most of the lavas are greenish-gray in color suggesting metamorphism. This can be related to ocean-floor metamorphism. Stretched pillows, which are ferruginous and with associated chert, have also been encountered (Location: around 400 m from 10°07.97' N Lat.; 124°58.44' E Long.). The exposure encountered in Lambunao River shows the basalts to be juxtaposed with massive gabbros. This part of the river is structurally disturbed. As observed, gabbros occur near the dunites, which are overthrust by harzburgites.

Panan-awan Formation

Our study led to the recognition of a new formational unit we call the Panan-awan Formation. This is a tectonic mélange observed in Malitbog and in the northwest portion of Maasin City. Its type locality is found west of Maasin City where it is observed in thrust contact with the Central Highlands Igneous Complex. The 1978 Penrose Conference defined a mélange as a mappable ($\leq 1:25,000$ scale), internally fragmented and mixed rock body containing a variety of blocks of pervasively deformed matrix (Silver and Beutner, 1980). The observed exposure consists of three units: mud(clay)-matrix portion, serpentinite-matrix portion and sheared basalt. These units are separated from each other by NW- and NE-trending thrust faults. The mud-matrix portion contains pebble- to boulder-sized, angular to sub-angular clasts of lithic wacke, chert, gabbro, basalts and harzburgite. On the other hand, the serpentinite-matrix portion is made up of ophiolite-derived, pebble- to boulder-sized clasts of harzburgite, lherzolite and dunite.

Sedimentary Sequences

Tigbauan Formation

Basalt, gabbro and chert clasts set in a sandy to tuffaceous matrix define the conglomerate unit atop the MOC as exposed in Lambunao River (Location: 10°08.32' N Lat.; 124°58.37' E Long). This is believed to be part of the Late Cretaceous Tigbauan Formation named by Florendo (1987). The type locality of this formation is found along the headwaters of Tigbauan River in Malitbog. It is made up of pelagic sedimentary units which include chert, shale, limestone and sandstone. A planktic foraminifer, *Helvetoglobotruncana Helvetica*, extracted from a limestone sample constrains the age of this unit to Late Cretaceous (Florendo, 1987). This age can be taken to be the minimum age of emplacement of the ophiolite with its age of generation being slightly older. The MOC during pre- to syn-Late Cretaceous would have been emplaced, exposed and eroded. The eroded ophiolite-derived materials were subsequently deposited as clasts in the sedimentary unit of the Tigbauan Formation. The MOC and Tigbauan Formation have an unconformable relationship.

Laboon Formation

Florendo (1987) first introduced the term Laboon Conglomerate as part of the Kanturing Group. This pre-Late Oligocene formation unconformably overlying the Tigbauan Formation is exposed in the Kanturing and Maigang Rivers. It consists of interbeds of polymictic conglomerates and sandstones. The polymictic conglomerates contain poorly-sorted, pebble to cobble-sized clasts of basalt, trachyte, diorite, andesite, chert, sandstone and limestone in a calcareous sandstone matrix. The calcareous sandstone beds are well-indurated with fine to coarse lithic and calcareous fragments (Figure 5a). The observed bedding trends N50°E, 45°NW. This formation is believed to have been formed in a fluvial environment (Florendo, 1987).

Dacao Formation

The Laboon Formation is unconformably overlain by the Dacao Formation. This is best exposed in Bgy. San Rafael, Danilo Moralde, Monte Alegre and Kanturing River (Florendo, 1987). The Dacao Formation is made up of interbeds of calcareous to lithic sandstone, siltstone, mudstone and fossiliferous to crystalline limestone (Figure 5b). The beds dip steeply (~80°) to the SW. The Late Oligocene to Early Miocene fossil assemblage found in this formation suggests a shallow marine environment (Porth *et al.*, 1989) (Figure 3).

Calian Formation

Unconformably overlying the Dacao Formation is the Calian Formation. This was first named by Domasig *et al.*, (1991) and pertains to a clastic sequence divided into a lower and upper unit. This unit is best observed along the periphery of Sogod Bay up to the northwestern fringe of Panaon Island. Sandstone-siltstone-mudstone interbeds comprise the lower unit of this formation (Figure 5c). The composition of this clastic sequence varies from calcareous to tuffaceous and sometimes bentonitic. A coralline, marly to crystalline limestone sub-unit has also been noted to occur together with the sandstone-siltstone-mudstone interbeds. The upper monomictic conglomerate unit shows an unconformable relationship with the lower unit. It is characterized by angular to subrounded, pebble- to cobble-sized andesitic clasts set in an andesitic matrix. The Calian Formation had been previously assigned a Late Pliocene to Early Pleistocene age (Domasig *et al.*, 1991). This present work, however, assigns a Middle Miocene to Late Pliocene age based on the fossil assemblage from the sandstone and siltstone samples (e.g. *Amphistegina* sp., *Lepidocyclina* sp., *N. humerosa*, *G. menardii*) and its stratigraphic relationship with the other units (Figure 3). This age is consistent with the age obtained from a sandstone unit by Domasig *et al.* (1991). The fossil assemblage obtained in this study also indicates a shallow marine environment.

Matalom Formation

The youngest bioclastic to coralline limestone unit is called the Matalom Formation (Figure 5d). A significant portion of Maasin Peninsula is underlain by this unit. The limestones are classified as mudstone, wackestone and boundstone using Dunham's classification (1962). The limestone beds dip gently ($\sim 10 - 30^\circ$) to the SE and SW. Corals, brachiopods, gastropods and foraminifera comprise the observed fossil assemblage. Paleontological dating done on limestone samples from this study constrains the age of the unit to Early Pliocene to Late Pleistocene.

Quaternary Alluvium

Alluvial deposits consisting of poorly consolidated terrace gravel were derived from the older rock units. These blanket the older formations and commonly occur in the fringes of the study area and along the coasts, rivers and floodplains.

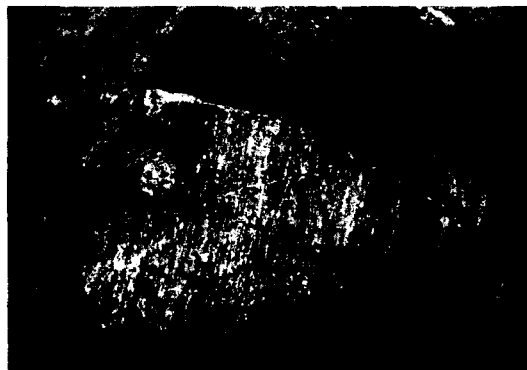


Figure 4. Some of the units of the Malitbog Ophiolite Complex exposed in Malitbog River and in Liloan. Photos by C.B. Dimalanta and 2003 Geology 170 and 215 classes.

a. Harzburgite is thrust on top of gabbro in this outcrop in Malitbog. The thrust fault (dashed line) which serves as the contact between the two lithologies trends $N10^\circ W, 80^\circ SW$.



b. Layered ultramafic cumulate rock outcrop in Ilagan, Liloan, Southern Leyte.



c. The thickness of layers in the layered gabbros range from 4 to 6cm.



d. Massive to pillow lavas make up the volcanic sequence of the Malitbog Ophiolite Complex as seen in one of the waterfalls of Lambunao River.

Central Highlands Igneous Complex

The Central Highlands Igneous Complex (CHIC) is first used in this work to collectively refer to the volcanic-related deposits found in Southern Leyte. This formation is proposed to include the Central Highland Volcanics, Pinut-an Andesite, Sogod Andesite and other intrusive bodies in the area. The Central Highland Volcanics refers to the mountain range in Central Leyte made up of hornblende-pyroxene andesite, basalt, dacite and pyroclastic deposits (JICA, 1990). Domasig *et al.*, (1991) referred to the Pinut-an Andesite in Panaon Island as the counterpart of the Central Highland Volcanics. The Central Highland Volcanics and Pinut-an Andesite are believed to be products of Early to Middle Miocene volcanism (JICA, 1990; KOICA, 1993). The Sogod Andesite, on the other hand, pertains to the younger andesite flows. Whole rock K-Ar dating of this unit yielded a Late Pliocene age (2.4 ± 0.12 Ma) (JICA, 1985).

In this study, CHIC is made up of pyroclastic flow deposits, andesitic to basaltic lava flows and includes dacitic to dioritic bodies. These deposits are found mostly in the eastern portion of Southern Leyte. The pyroclastic flow deposits are made up of sub-angular to angular, cobble- to boulder-sized clasts of basalt and andesite set in an andesitic matrix. The lava flows are massive; some exposures are porphyritic whereas some outcrops in Barangay Taa, Salog, along the Agas-Agas road exhibit columnar jointing. The andesitic lava flows exposed in Liloan and Subang-Daku show pervasive argillic alteration and silicification.

Quaternary Volcanics

This refers to the younger volcanic deposits related to Mount Cabalian which is located in the eastern portion of Southern Leyte. These deposits consist of andesitic lava flows and pyroclastic breccias. Age dating done by JICA-MMAJ (1990) using whole rock K-Ar method yielded a 1.5 Ma age.

DISCUSSION

1. Malitbog Ophiolite Complex: a product of intermediate- to fast-spreading center

Our field mapping in Southern Leyte confirmed the presence of an ocean lithospheric fragment which we have called the MOC. Most of the units comprising the MOC are distributed in a nearly north-south trend along the Biliran River near Malitbog. Some units of the ophiolite are also found near Maasin and in Liloan. The mantle section of the MOC, the ultramafic rocks, is widely distributed in the northern part of Panaon island, in the southern part of the Liloan-Libagon area and in the Malitbog-Maasin area (Figure 2). The gabbros are of limited distribution with the massive varieties being observed only in the Lambunao River. Layered gabbros are found in both the Lambunao River and in Barangay Bugo. The occurrence of both the layered and massive varieties of gabbro suggests the presence of a magma chamber. The MOC, based on the presence of ultramafic-mafic suites including a dike swarm and pillow lavas, is believed to have formed in an intermediate- to fast-spreading ridge (e.g. Yumul, 2003; Yumul *et al.*, 2008). This oceanic lithospheric fragment could have come from a proto-Philippine Sea oceanic basin (e.g. Tamayo *et al.*, 2004; Suerte *et al.*, 2005; Dimalanta *et al.*, 2006).

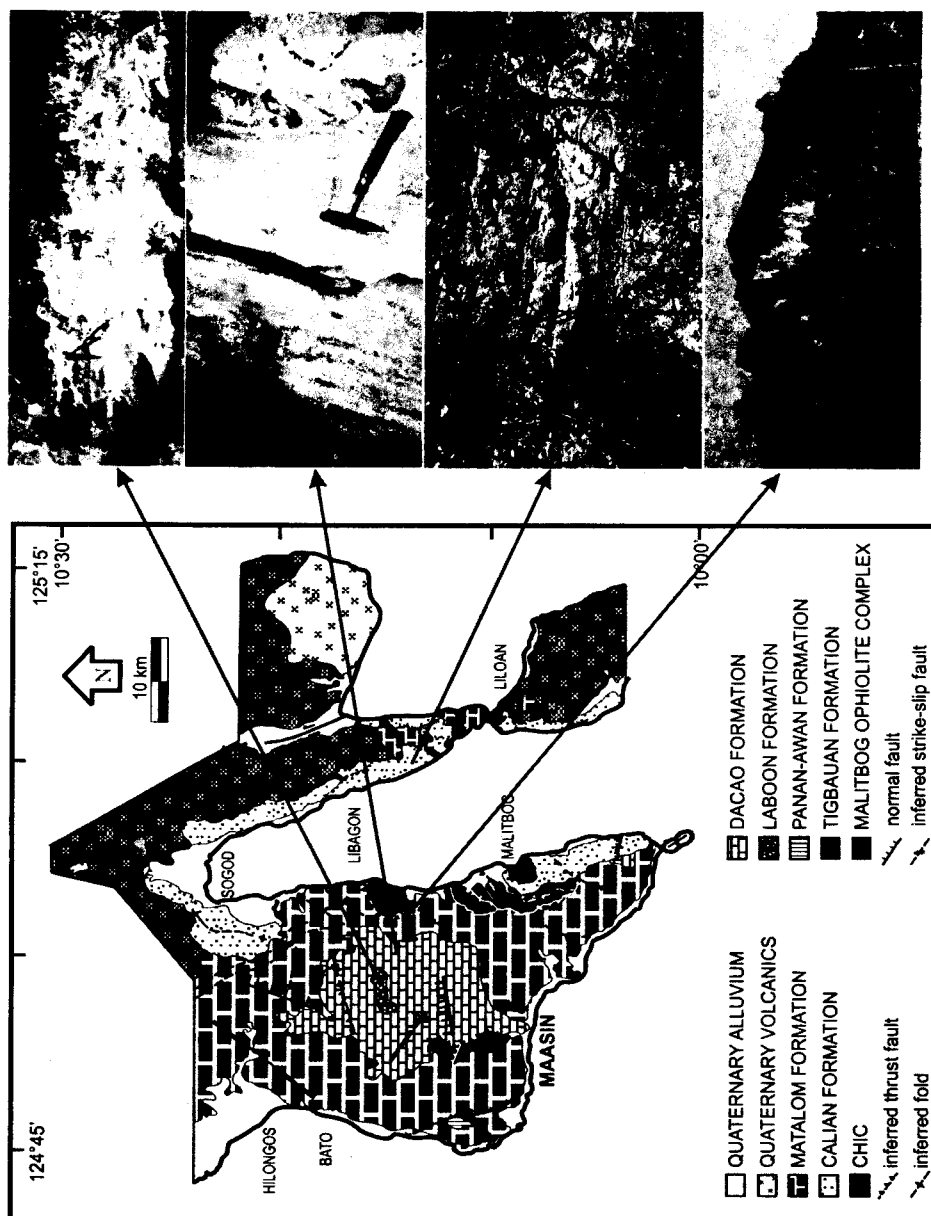


Figure 5. a. Photo of the Laboon Formation observed in Maigang River in the Maasin Peninsula. b. The Dacao Formation is made up of the oldest carbonate rocks in Southern Leyte. c. Interbeds of sandstone-siltstone-mudstone comprise the Calian Formation. d. Limestone of the Matalom Formation unconformably overlies the ultramafic rocks of the Malitbog Ophiolite Complex. Photos by C.B. Dimalanta and 2003 Geology 170 and 215 classes.

2. Implications on the evolution of Central Philippines

The lithologic units which were mapped in Southern Leyte offer various clues that contribute to the understanding of the evolution of Southern Leyte, in particular, and Central Philippines, in general.

Southern Leyte is floored by the MOC, a fragment of an oceanic lithosphere that was emplaced onland by Late Cretaceous. This is constrained by the age of the Tigbauan Formation which contains clasts of the ophiolite complex. This means that prior to or during the Late Cretaceous, the MOC had been exposed resulting into its erosion. The erosion provided the ophiolite clasts incorporated in the conglomerate unit of the Tigbauan Formation.

Another significant result from this study is the recognition of the Panan-awan Formation. The *mélange* is interpreted to comprise of three units - a mud-matrix portion, serpentinite-matrix portion and sheared basalt separated from each other by thrust faults. However, one might also consider interpreting these units as representing the different facies of a *mélange*. The Panan-awan Formation may represent a spectrum from a broken formation all the way to a *mélange* (Raymond, 1984). This formation is interpreted to be a tectonic *mélange* with its formation associated with the emplacement of the MOC (e.g. Dimalanta and Yumul, 2003).

At a later time, during the Oligocene, the presence of an arc is suggested by clasts of volcanic rocks in the Laboon Formation. What could possibly be the source of these volcanic rocks? There is a well-defined volcanic arc from Bicol extending to Leyte but the Philippine Trench to which the volcanism can be attributed is considered to be young (<5 m.y. or much younger than Oligocene) (e.g. Andal *et al.*, 2005). Therefore, the presence of the volcanic clasts in the Oligocene Laboon Formation cannot be due to subduction along the present-day Philippine Trench. One possibility to account for the volcanic activity that produced the volcanic clasts is through subduction along the paleo-Southeast Bohol Trench (e.g. Faustino *et al.*, 2006). The andesite clasts in the conglomerate unit of the Calian Formation also call for pre-Middle Miocene magmatism from a volcanic arc. Magmatic activity during Early to Middle Miocene is also postulated to account for the andesite, basalt, dacite and pyroclastic deposits that characterize the CHIC. These recent field data from Southern Leyte are all consistent with the model of a paleo-Southeast Bohol Trench. The presence of this feature had also been suggested previously by other workers to account for the Cretaceous volcanic rocks in Cebu as well as the location and distribution of the Southeast Bohol Ophiolite Complex and the associated Cansiwang *Mélange* (e.g. Barretto *et al.*, 2000; Yumul *et al.*, 2000).

Lastly, the Middle Miocene unconformity reflected in the stratigraphic section of Southern Leyte may be a regional signature of the Miocene collision event (e.g. Yumul *et al.*, 2005; Dimalanta and Yumul, 2006). This coincides with the time when the Palawan Microcontinental Block is postulated to have collided with the Philippine Mobile Belt. The shallow marine environment that characterized the Calian Formation may even be an offshoot of the collision event.

CONCLUSIONS

The geology of Southern Leyte reveals the progressive shallowing of the environment of deposition of the different formations: from the Tigbauan Formation deposited in a neritic to bathyal environment to shallow marine, fluvial and terrestrial settings. The Cretaceous is characterized by basin opening and closing resulting into the emplacement of the MOC. The Oligocene – Miocene formations containing volcanic clasts suggest the existence of a subduction zone which is taken here as equivalent to the paleo-Southeast Bohol Trench.

The observed continuous shallowing of the environment of deposition from the Miocene to the present can be an effect of the collision of the Palawan Microcontinental Block with the Philippine Mobile Belt. The collision resulted into this part of Central Philippines being uplifted.

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