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Depositional Environment of the Cambrian Machari Formation in the Yeongweol Area, Gangweon Province, Korea

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Abstract: The Middle to Late Cambrian Machari Formation in the Machari area, Yeongweol, Korea consists of 7 lithofacies and 3 facies associations, which are thought to be deposits of carbonate ramp (mid to outer ramp) to basin environment. These lithofacies are bedded lime mudstone, laminated lime mudstone, bioclastic/peloidal packstone to grainstone, peloidal/bioclastic wackestone, conglomerate, mottled lime mudstone, and shale. Bedded lime mudstone facies, a few cm thick lime mudstone alternating with shale layer, is believed to have been deposited by intermittent dilute turbidity currents. Laminated lime mudstone facies, alternating lime mudstone with laminated shale, is interpreted to have been formed by fine-grained turbidity currents. Bioclastic/peloidal packstone to grainstone facies was deposited by turbidity current and peloidal/bioclastic wackestone faceis was deposited by debris flow. Conglomerate facies is thought to be deposits of storm activities. Mottled lime mudstone facies is interpreted to have been formed by bioturbation. Shale facies is interpreted to have been formed by suspension settling. Seven lithofacies of the Machari Formation are divided into three facies associations. Facies association I consisted of bedded lime mudstone facies, mottled lime mudstone facies, conglomerate facies, and bioclastic/peloidal packstone to grainstone facies, is interpreted to have been deposited on the mid ramp. Facies assocaition II consisted of bedded lime mudstone facies, laminated lime mudstone facies, bioclastic/peloidal packstone to grainstone facies, and peloidal/bioclastic wackestone facies is thought to be deposits of the outer ramp. Facies association III consisted of laminated lime mudstone facies and shale facies is interpreted to have been formed on the basin environment.

Key words: Machari Formation, Cambrian, facies, carbonate ramp

INTRODUCTION

The study on depositional environment of carbonate platform is essential to understand facies distribution, diagenesis, sequence stratigraphy, and evolution of carbonate platform. The carbonate platform can be either carbonate rimmed shelf or ramp depending on slope angle and presence of rim. The carbonate platform with carbonate slope is characterized by slope angle higher than 1° whereas the carbonate ramp is characterized by slope angle less than 1° (Burchette and Wright, 1992). The carbonate slope is in turn controlled by presence of rim of carbonate platform and the presence of rim of carbonate platform results in development of carbonate slope. Carbonate ramp can be evolved to rimmed shelf as progradation results in the formation of rim at shallow depths of carbonate platform (Read, 1985; Barnaby and Read, 1990). The carbonate slope is characterized by features associated with high angle of slope such as slump, slide scar, debris flow whereas the ramp lacks such features. The ramp can be divided into three subenvironments; innner ramp which is above fair weather wave base (FWWB), mid ramp which is located below FWWB and above storm wave base (SWB), and outer ramp which is below SWB (Wright and Burchette, 1996). Lithofacies of carbonate ramp environment has recently been studied by Proust *et al.* (1998), Bachtel and Dorobek (1998), and Chen *et al.* (2001). Betzler *et al.* (1999) reported that Neogene Bahamian outer carbonate ramp sediments are characterized by cyclic alternations of light- and dark-gray wackestone/packstone with interbedded calciturbidite packages and minor slumps.

The Machari Formation is a part of the Yeongweol Group which consists of the Sambangsan, Machari, Wagok, Mungok, and Yeongheung formations in ascending order ranging in age from Middle Cam-

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Table 1. Stratigraphic classification of the lower Paleozoic Joseon Supergroup in Yeongweol area.

Geologic Age		Choi (1998)
Ordovician	Caradoc Llanvirn Arenig	Yeongheung Fm.
	Tremadoc	Mungok Fm.
Cambrian	Late	Wagok Fm.
		Machari Fm.
	Middle	Sambangsan Fm.

brian to Late Ordovician (Table 1). The Yeongweol Group is a part of the Joseon Supergroup, Cambro-Orodovician carbonate sequences in Korea distributed mainly in the Taebaek Mountains and adjacent areas, Gangweon Province, Korea. The Machari Formation is late Middle Cambrian to middle Late Cambrian in age (Lee, 1995). Previously the Machari Formation was reported to have been deposited on the carbonate slope (Lee, 1993). However, recent investigation on the Machari Formation revealed that slump features turn out to be fold structures and the angle of slope where the Machari Formation was deposited might be lower than the carbonate slope. Sedimentary features of the Machari Foramtion will provide the depositional setting which can be revealed by facies analysis. The purpose of this study is to reveal the depositional environment of the Machari Formation based on facies analysis.

GEOLOGIC SETTING

The Machari Formation is distributed in the Yeongweol area as north-south trending bands with other Cambro-Ordovician sequences because of thrust faulting (Fig. 1). The formation overlies the Middle Cambrian siliciclatic Sambangsan Formation which consists of laminated argillite, micaceous sandstone and sandy shale (Reinemund, 1957). It is overlain by the Late Cambrian Wagok Formation which consists of massive dolomite (Koo, 1992; Woo and Moore, 1996). The Wagok Formation is overlain by the Ordovician Mungok Formation which is interpreted to have been deposited on tidal flat (Paik *et al.*, 1991) or subtidal ramp (Choi and Lee, 2000). The Mungok Formation is in turn overlain by the Yeongheung Formation which was deposited on tidal flat (Choi and Woo, 1993; Yoo and Lee, 1997).

METHODS

Lithofacies were classified based on allochemical particles, color, structures, abundance of argillaceous components, lateral continuity, and boundary characteristics. Stratigraphic sections were measured in the field and lithofacies was observed macroscopically and microscopically. Rock slabs were prepared to investigate sedimentary features. Lithofacies were grouped into facies associations based on lithology and occurrence pattern.

LITHOFACIES AND SEDIMENTARY PROCESSES

The Machari Formation consists of 7 lithofacies. They are bedded lime mudstone facies, laminated lime mudstone facies, bioclastic/peloidal packstone to grainstone facies, pelodial/bioclastic wackestone facies, conglomerate facies, mottled lime mudstone facies, and shale facies. Description of each facies and its sedimentary processes are as follows.

Bedded Lime Mudstone Facies

Description: This facies is the most common facies in the Machari Formation and consists of ribbon limestone, parted limestone and nodular limestone. The ribbon limestone consists of 2 to 5 cm thick lime mudstone bed alternating with same thick shale or dolomitic shale. Parted limestone consists of 3.5 to 10 cm thick lime mudstone bed alternating with a few mm to 2 cm thick shale layer (Fig. 2A). Nodular limestone consists of 2 to 45 cm long and 2 to 7 cm thick lime mudstone nodules alternating with same thick but continuous layers of relatively dark shale or dolomitic shale (Fig. 2B). Limestone layers are commonly massive but some show millimeter thick laminations. Sometimes low angle cross-

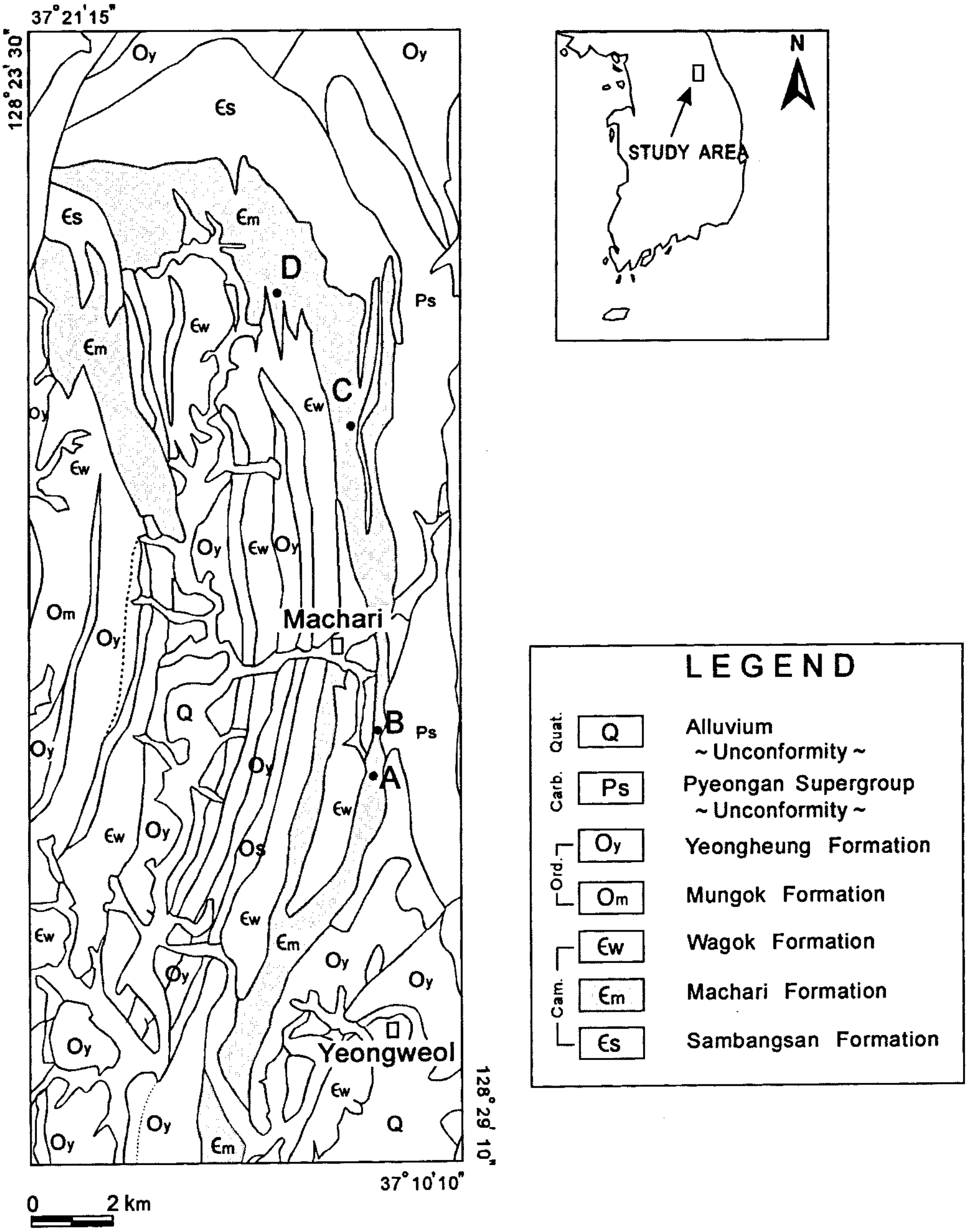


Fig. 1. Geologic map showing distribution of the Machari Formation in the Yeongweol area (GICTR, 1962; Choi, 1998). Four localities (A and B, Deogwoo; C, Solchee; and D, Gonggiri) were investigated in detail.

laminations and sinusoidal ripple laminations are developed (Fig. 2C). Ribbon and parted limestone show relatively good horizontal continuity. Lower contact of the facies is relatively abrupt whereas the upper contact is gradual. The wheathered surface of dolomitic shale in nodular limestone is protruded compared to nodule-shaped limestone. Under the microscope limestone layer consists of micrite, microspar, and spar with a few peloids and bioclasts (Figs. 2D and E). Some dolomites are in limestone layer but more dolomites are in shale layer. Pressure solution features such as wispy and solution

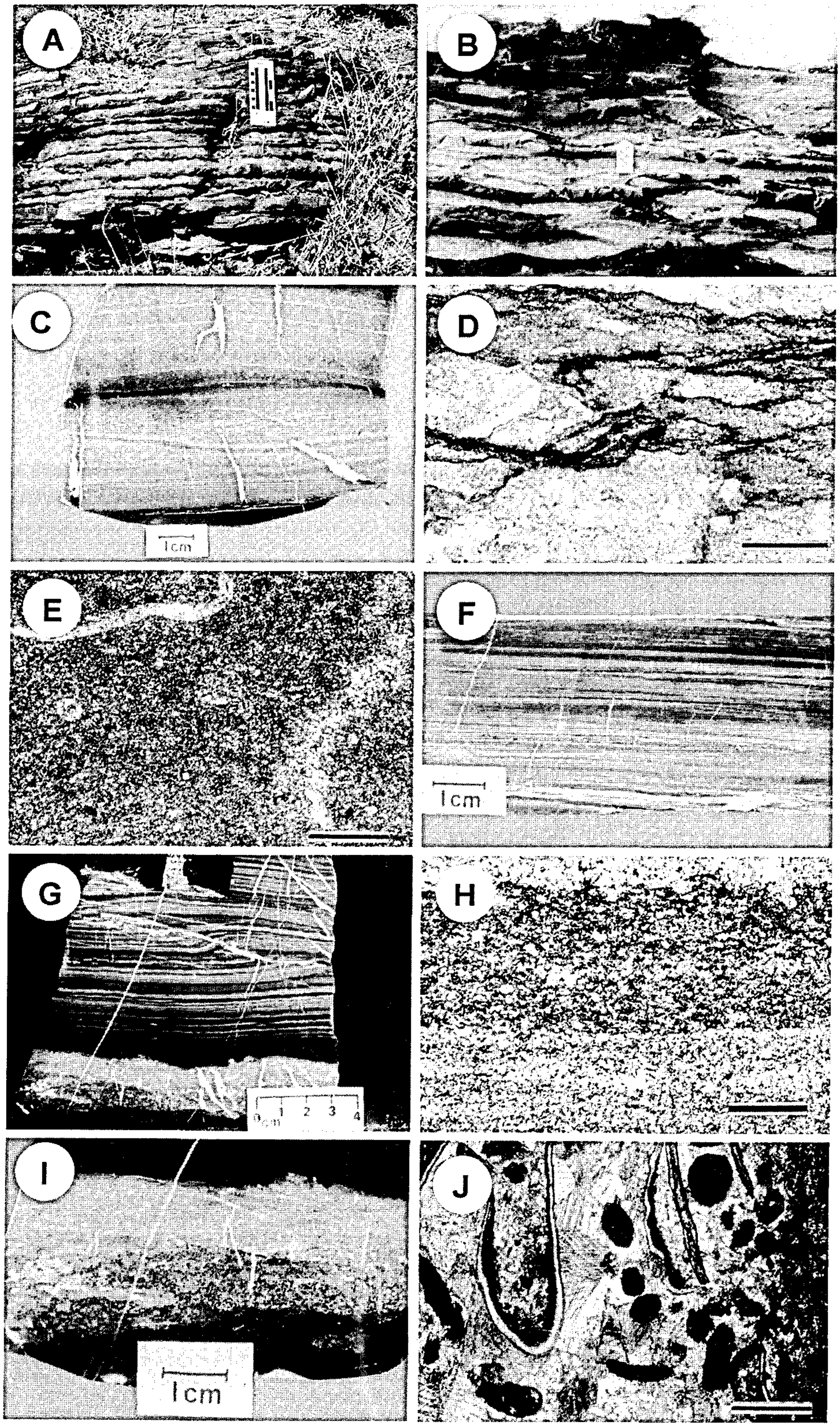


Fig. 2.

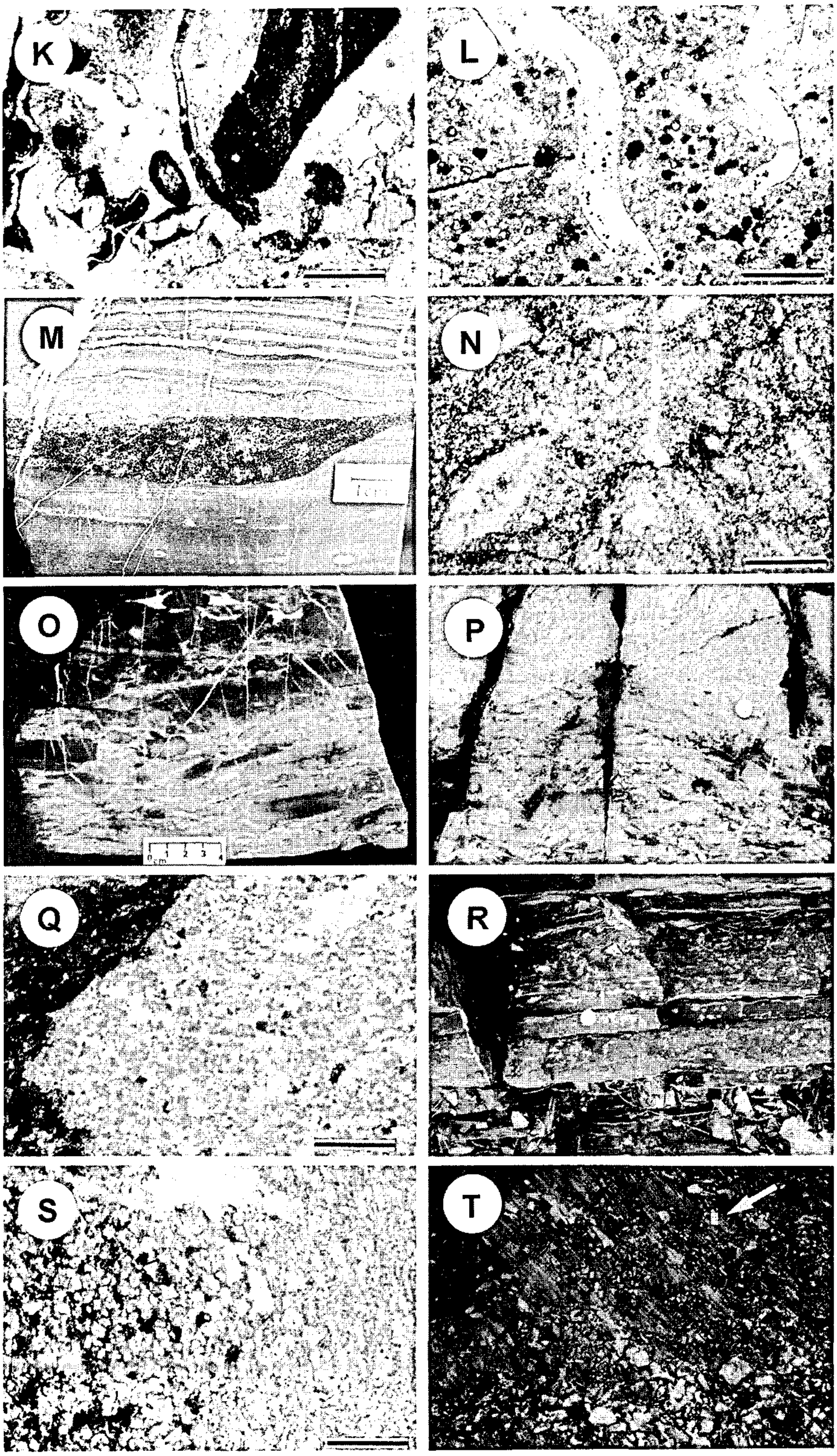


Fig. 2. Continued.

Fig. 2. Features of lithofacies. All scale bars in photomicrographs are 400 μm. A. Field photograph of bedded lime mudstone (parted limestone) facies characterized by relatively thick lime mudstone bed alternating with relatively thin argillaceous laminae. B. Field photograph of bedded lime mudstone (nodular lime mudstone) facies. Scale bar is about 5 cm. C. Rock slab photograph showing low-angle cross-lamination within lime mudstone. D. Photomicrograph of bedded lime mudstone characterized by micritic to sparry limestone alternating with clayey laminae. Wispy seams formed by pressure solution are in clayey laminae. In plane-polarized light. E. Photomicrograph of limestone bed of bedded lime mudstone facies with a few bioclasts. F. Rock slab photograph of laminated lime mudstone facies characterized by alternation of limestone laminae alternating with argillaceous limestone laminae. G. Rock slab photograph of laminated lime mudstone facies overlying bioclastic/peloidal packstone (2 cm thick gray bed at bottom). Laminae are faulted by thrust. H. Photomicrograph of laminated lime mudstone facies showing limestone laminae (at bottom) alternating with argillaceous lime mudstone laminae. Note micro-load casts along the top boundary of the argillaceous limestone laminae. I. Rock slab photograph of bioclastic/peloidal limestone facies (middle bed of about 1 cm thick). J. Photomicrograph of bioclastic/peloidal limestone facies showing bioclasts and peloids. In cross-polarized light. K. Photomicrograph of bioclastic/peloidal packstone to grainstone facies showing bioclasts including *Girvanella* (dark and relatively large clast in upper right). In cross-polarized light. L. Photomicrograph of bioclastic/peloidal limestone facies showing trilobite and peloids. In cross-polarized light. M. Rock slab photograph of peloidal/bioclastic wackestone facies showing lens-shaped bed and sharp lower contact. N. Photomicrograph of peloidal/bioclastic wackestone facies consisted of bioclasts in micrite to spar matrix. In cross-polarized light. O and P. Rock slab photographs of conglomerate facies. Limestone clasts occur in argillaceous matrix (O); planar to elongate clasts are oriented parallel to subparallel to the bedding surface. Q. Photomicrograph of conglomerate facies. Limestone clast is composed of peloidal packstone; matrix is composed of argillaceous mud. In cross-polarized light. R. Field photograph of mottled lime mudstone facies. Mottles are yellowish on weathered surface and protruded compared to limestone. S. Photomicrograph of mottled lime mudstone facies characterized by dolomitization of mottle and gradual boundary between dolomitized mottle and limestone. T. Field photograph of shale facies. Scale bar (arrow) is 5 cm.

seams are distributed (Fig. 2D).

Interpretation: Parallel bedding and laminations, and relatively good horizontal continuity of fine sediments suggest relatively deep environment. Lime mud is interpreted to have derived from shallow depths such as inner shelf similar to carbonate periplatform ooze (McIlreath and James, 1984; Schlager *et al.*, 1994; Clari and Martire, 1996) and it was transported and deposited as turbidite on the deeper part of slope where clays were settling at constant rate. The slope angle where calciturbidites and pelagic muds were deposited was thought to be less than 1° as there are lack of slumps and slide scars in the Machari Formation. Nodules in nodular limestone is reported to be formed at shallow burial depths by early diagenesis (Mullins *et al.*, 1980; Moller and Kvingan, 1988; and Clari and Martire, 1996). Dissolution of fine grained lime mud and bioclastic particles supplies calcium carbonate to precipitate carbonate cements in lime mudstone layer and the lime mudstone layer tend to be cemented effectively compared to adjacent shale-rich layer (Moller and Kvingan, 1988). As the sediments bury compaction occurs preferentially at the shale-rich layer compared to already lithified limestone layer. Consequently nodular bedding is thought to be formed and layering is enhanced.

Laminated Lime Mudstone Facies

Description: This facies consists of 1 to 3 mm thick gray laminated lime mudstone laminae alternating with less than 1 mm thick dark gray to black laminated shale (Fig. 2F). Laminations are horizontal and show good lateral continuity. Lower contact is abrupt (Fig. 2G) and sometimes load and flame structures are developed along the lower contact. The facies is a few cm to 60 cm thick and occurs with shale facies. Under the microscope limestone consists of micrite and microspar (Fig. 2H) with minor amount of peloids. In shale layer minor calcite spar is present.

Interpretation: Fine grain size, dark color, lack of bioturbation, and a few mm thick parallel laminations suggest deep water deposition (Barnaby and Read, 1990). Lime mudstone with good horizontal continuity is similar to pelagic deposits (Scholle *et al.*, 1983) and this facies is suggested to have been deposited by fine-grained turbidity currents below storm wave base.

Bioclastic/Peloidal Packstone to Grainstone Facies

Description: This facies consists of 1 to 10 cm thick gray to dark gray bioclastic and peloidal packstone to grainstone (Fig. 2I). Lateral continuity is not good and poorly developed reverse grading is shown. The lower contact is abrupt and irregular with scour surface (Fig. 2I), and load and flame structures. Overlying this facies is laminated lime mudstone and shale facies. The upper boundary is relatively parallel and sharp contact. Laminated packstone consists of a few mm thick laminae to 25 mm thick bed. The thickness of laminated packstone is 1 to 10 cm. Allochems are medium to coarse sand sizes of bioclasts with minor amount of peloids. The laminated packstone shows mostly parallel lamination but some of it shows cross-lamination. Lateral continuity of lamination is relatively good. Bioclasts show parallel orientation to bedding surface and grading in some parts. The lower contact is sharp or gradational. Under the microscope allochems are mainly bioclasts and peloids with some oncoids, cortoids, and intraclasts (Fig. 2J); they are very fine sand to coarse sand, and aggregated grains showing moderate to poor sorting. Some bioclasts are *Girvanella* fragments (Fig. 2K). Some intraclasts consist of 0.5 to 30 mm subangular to rounded algal aggregates. Oncoids consist of circular to elliptic-shaped algal or micritic laminae. Cortoids consist of peloids or bioclastic cores surrounded by micritic envelopes. Peloids consist of brownish micrite and they are circular to elliptic shape. Bioclasts are mainly trilobite and brachiopod fragments with some micritic envelopes (Fig. 2L). Some bioclasts show geopetal structure.

Interpretation: Occurrence of *Girvanella* intraclasts suggests origin of sediment from algal bioherm in photic zone (Coniglio and James, 1985). Occurrence of bioclasts originated in shallow water depth in association with deep water facies such as laminated lime mudstone and shale facies suggests transportation of shallow water bioclasts to relatively deep water environment. Shallow water bioclasts and peloids are thought to have been transported by turbidity currents to deep water presumably below fair weather wave base. Massvie grains with scour and grading suggest turbidite deposits (Ta, b).

Peloidal/Bioclastic Wackestone Facies

Description: This facies occurs as 1 to 4 cm thick planar to lenticular bed in lime mudstone facies (Fig. 2M). The lower contact is relatively sharp and the upper contact is either sharp or gradational. Sometimes load casts are developed along the lower contact. Under the microscope bioclasts and peloids are distributed in micrite and microspar matrix. Bioclasts are often fragmented (Fig. 2N); peloids are 50 to 250 μm in size and dark colored.

Interpretation: Lenticular bed, occurrence in lime mudstone facies, sharp lower contact and presence of load structure suggest debris flow deposits (Enos and Moore, 1983). Playford (1980) indicated that debris flow deposits are characterized by planar to lenticular channel-form sediment body with load cast. Mudler and Alexander (2001) indicated that debris flow has sufficient cohesive material (mud) to allow pseudoplastic nature and particles tend to hold together. Occurrence of peloidal wackestone facies as relatively thin sediment body in the Machari Formation suggests relatively small debris flow.

Conglomerate Facies

Description: This facies consists mostly of pebble sized clasts of lime mudstone, dolomitized lime mudstone or peloidal packstone, but clasts range in size from coarse sand to cobble. Conglomerate is either grain supported or matrix supported and matrix is lime mud or shaley dolomite (Fig. 2O). Grains are planar to elongate shape, angular to subrounded, and poorly sorted; they are oriented randomly or subparallel to the bedding surface (Fig. 2P). In some area they show reverse grading followed by normal grading. The thickness of facies is 30 to 50 cm but varies laterally; in some parts it reaches up to

200 cm. The lower contact is relatively sharp. Along the lower contact scour mark and deformed underlying bed are observed. The upper and lower boundaries are sharp. Under the microscope lime mudstone clasts consist of micrite and microspar. Dolomitized clasts consist of interlocking dolomite. Peloidal packstone clasts consist of silt-sized peloids (Fig. 2Q). Matrix between clasts consists of argillaceous lime mud with peloidal and bioclasts.

Interpretation: Sharp upper and lower boundaries and random to subparallel orientation of clasts suggest event deposit. Conglomerates in the Machari Formation consist mainly of lime mudstone clasts although they consist minorly of peloidal packstone. Partially lithified lime mudstone and peloidal packstone are thought to have been broken by storm activities and transported nearby. High-energy storm waves were capable of breaking the semilithified carbonate layers into clasts, which were then deposited nearby forming lime conglomertes (Glumac and Walker, 2000; Seguret *et al.*, 2001).

Mottled Lime Mudstone Facies

Description: This facies consists of bioturbated mottles which occur in homogeneous lime mudstone. This facies occur as 30 to 100 cm thick bed intercalated in bedded lime mudstone. Mottles are several mm to 4 cm in size and their shapes are irregular to circular (Fig. 2R). Mottles are dark gray on fresh surface and brown on weathered surface. Boundaries with underlying bedded facies are gradational; degree of bioturation decreases downward and irregularly disturbed layers gradually change into bedded facies. The thickness of gradational zone is 15 cm. Under the microscope mottles consist of subhedral to anhedral interlocking dolomite (Fig. 2S) and lime mudstone consists of micrite and microspar. The boundary between dolomitized mottles and micrite or microspar is gradational. Irregularly disturbed bed contain minor amount of bioclasts.

Interpretation: Mottles are interpreted to have been formed by bioturbation. This facies might be formed in oxygenated depths where organisms can live (Elrick, 1996; Holland and Patzkowsky, 1998). However, lack of shallow depth indicator such as scour mark by wave action suggests that the mottled lime mudstone facies was formed below fair weather wave base. Some mottled facies occurring in association with black shale facies suggest bioturbation could occur even below storm wave base.

Shale Facies

Description: Shale facies consists of dark gray to black shale (Fig. 2T). Laminations and fissilities are developed. Laminations show good horizontal continuity. The thickness of shale facies is several cm to 1.5 m. This facies occurs in association with laminated lime mudstone facies.

Interpretation: Lack of shallow water features such as scour mark, mud crack, and ripple cross laminations (Demicco and Hardie, 1994) suggests relatively deep water deposition below storm wave base. Laminations with good horizontal continuity suggest pelagic settling (Gomez-Perez *et al.*, 1999). Dark gray to black color suggests dysaerobic environment presumably in oxygen minimum layer.

FACIES ASSOCIATIONS AND DEPOSITIONAL SETTINGS

Description and depositional processes for each facies is given in Table 2. Fig. 3 shows stratigraphic sections of the Machari Formation. Occurrence pattern of facies in the Machari Formation can be grouped into 3 facies associations (Fig. 4). Interpreted depositional environment is presented in Fig. 4. The angle of slope where the Machari Formation was deposited might be less than 1° as there are lack of sedimentary features associated with carbonate slope such as slumps and slide scars.

Facies association I consists of bedded lime mudstone facies, mottled lime mudstone facies, conglomerate facies, bioclastic/peloidal packstone to grainstone facies and peloidal/bioclastic wackestone facies. Occurrence of mottles formed by activities of organisms suggests oxygenated depth (Proust *et al.*, 1998).

Table 2. Description of lithofacies, depositional processes, and associated references.

Lithofacies	Description	Depositional Processes	References
Bedded Lime Mudstone Facies	Alternating layers or nodules of dark gray lime mudstone (or gray dolomite) with black shale (or argillaceous dolomite); 1 ~ 10 cm thick; mostly massive micrite, microspar and spar; some parallel laminated or locally low-angle cross-laminated; sharp lower boundaries and gradational upper boundaries	Dilute turbidity currents (Tc) and suspension settling	Mullins and Cook, 1986; Coniglio and James, 1990; Lehrmann *et al.*, 1998
Laminated Lime Mudstone Facies	Alternating layers of lime mudstone with black shale; a few mm thick; gray to black; composed of micrite and microspar and argillaceous mineral; mostly parallel laminated; some low-angle cross lamination, convolution and flame structure	Fine grained turbidity current (Tde) and suspension settling	Cook and Taylor, 1977; Keith and Friedman, 1977; Scholle *et al.*, 1983; Barnaby and Read, 1990
Bioclastic/Peloidal Packstone Facies	Massive or laminated; 1 ~ 10 cm thick; light to dark gray; bioclasts (trilobite, brachiopod, *Girvanella*) and peloids; some oncoids, cortoids and intraclasts; very fine to coarse sand sized grains with some intraclasts (lime mudstone and algal clasts) of 2 to 30 mm in size; moderate to poorly sorted; some inverse grading; erosional to sharp basal contacts, loading structure	Turbidity current (Tab)	Middleton and Hampton, 1976; Enos and Morre, 1983; Coniglio and James, 1985, Foreman *et al.*, 1991; Mutti *et al.*, 1996
Peloidal/Bioclastic Wackestone Facies	Planar to lenticular form in lime mudstone bed; silt to fine sand size; micritic matrix; sharp upper conact, and sharp or gradational basal contact; loading stucture	Debris flow	Enos and Moore, 1983; Mulder and Alexander, 2001
Conglomerate Facies	A few cm to 110 cm thick; mostly lime mudstone clasts, some shale and peloidal limestone clasts; sand to pebble size; poorly sorted; angular to rounded; clast- to matrix-supported; massive to graded; sharp upper contacts and sharp to erosional lower contacts	Storm activities	Glumac and Walker, 2000; Sami and Descrochers, 1992; Seguret *et al.*, 2001
Mottled Lime Mudstone Facies	Irregular mottles in lime mudstone; 10 to 100 cm thick; light gray to gray micritic matrix; minor bioclasts; dolomitized mottles	Bioturbation of lime mudstone	Elrick, 1996; Holland and Patzkowsky, 1998
Shale Facies	Thinly laminated dark gray to black shale; fissile and good lateral continuity of laminations	Suspension settling	Elrick, 1996; Gomez-Perez *et al.*, 1999; Srinivasan and Walker, 1993

Relatively common occurrence of allochems in bioclastic/peloidal packstone to grainstone and conglomerates suggests relatively shallow water depth which is close to the source of carbonates. Relatively thick lime mudstone layer compared to laminated lime mudstone suggests shallow water depths close to source area of carbonate mud, inner ramp. Agitation in shallow water depths churns bottom sediments and suspended lime muds were transported offshore direction. These muds were deposited by turbidity currents on the mid ramp where argillaceous muds were settling from water column; consequently bedded lime mudstone was formed. Occurrence of limestone conglomerates suggests a depositional setting above the storm wave base (Sami and Desbrochers, 1992). High-energy storm waves were capable of breaking the semilithified carbonate layers into clasts, which were then deposited nearby forming lime conglomerates (Glumac and Walker, 2000; Seguret *et al.*, 2001). Lack of indicator of wave action such as scour mark and ripple suggests depositional setting below fair weather wave base. Therefore the depositional environment for facies association I is interpreted to be mid ramp, which is below fair

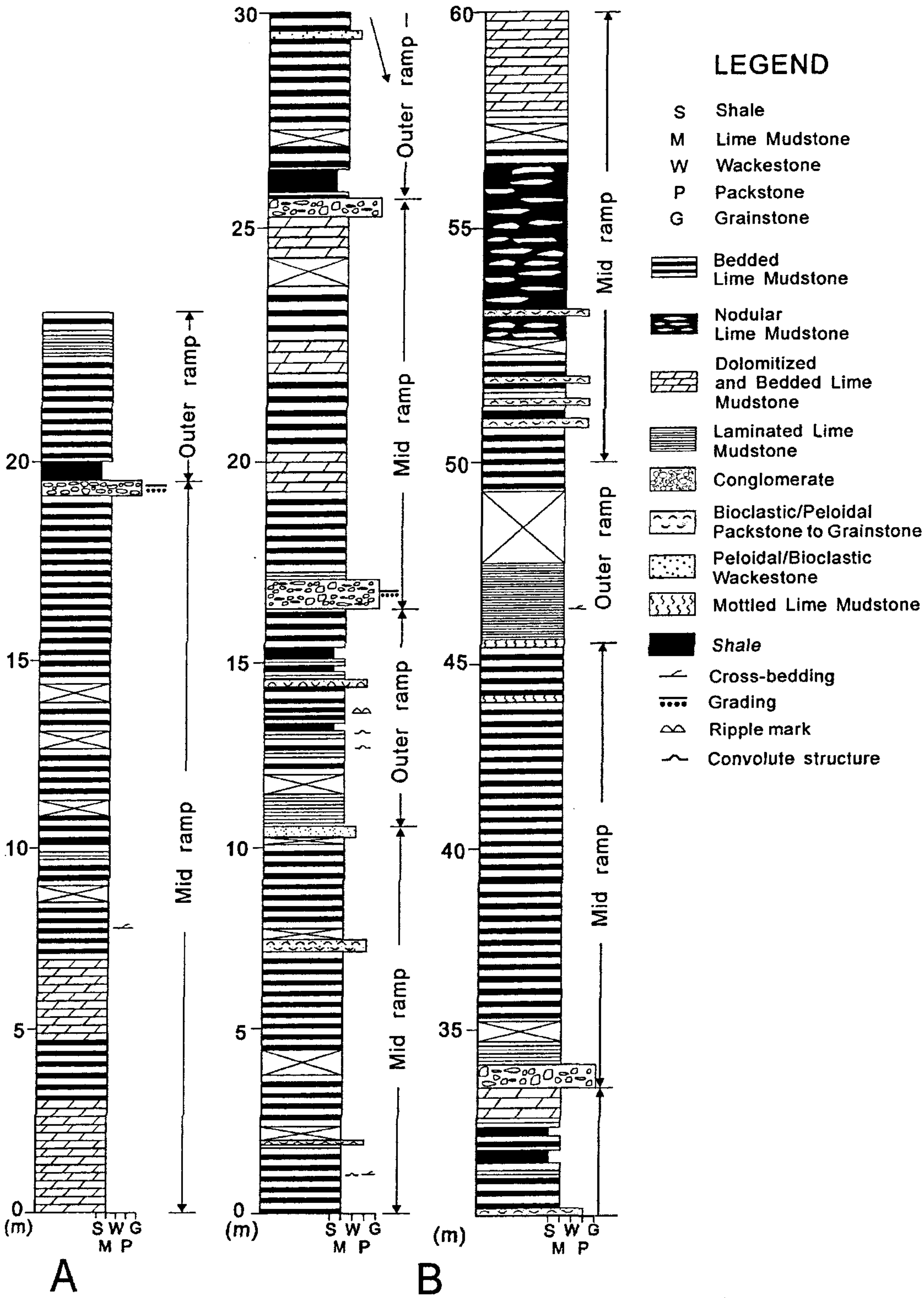
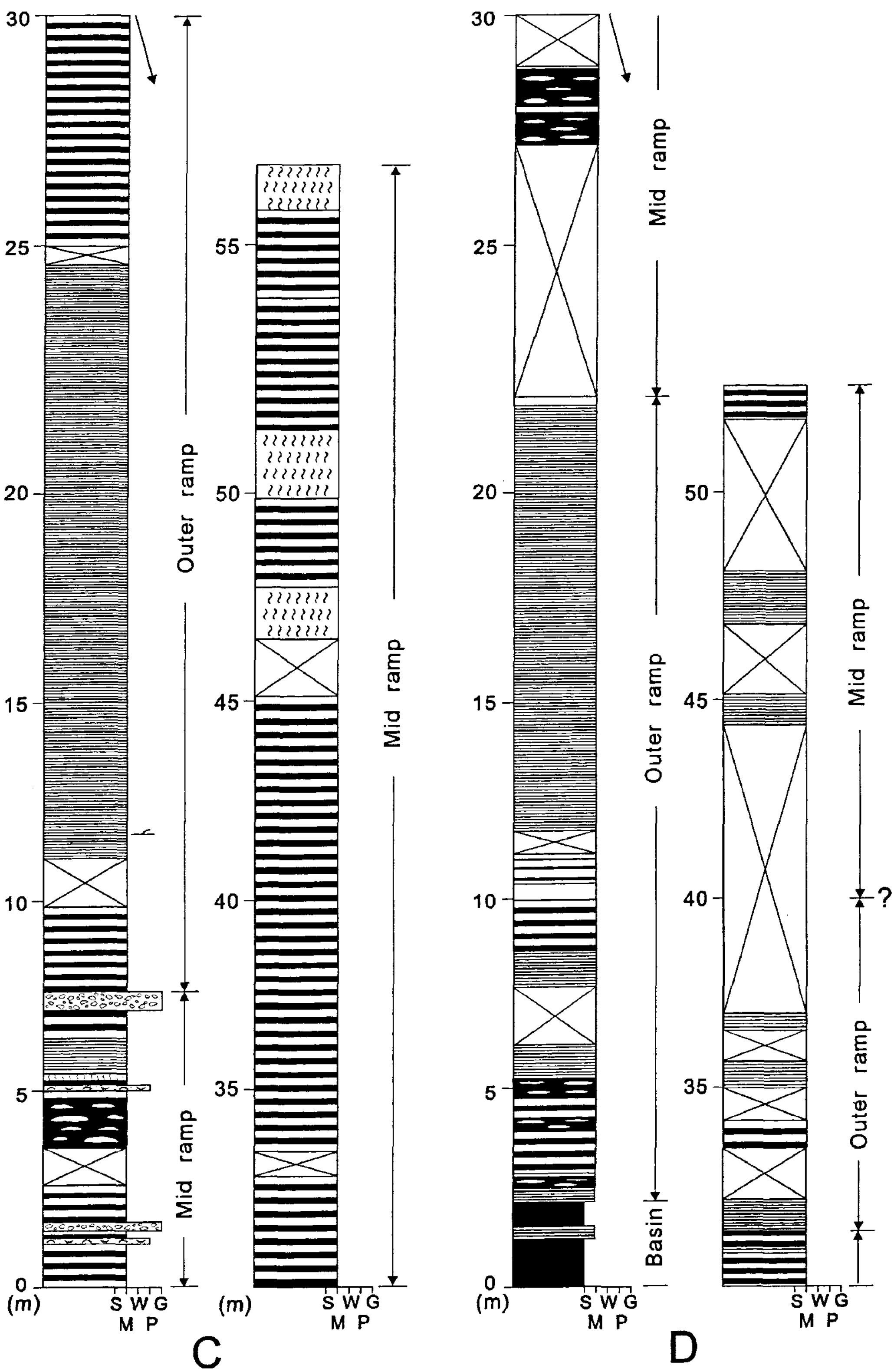


Fig. 3. Stratigraphic sections measured at four localities. A and B Deogwoo, C Solchee, and D Gonggiri. Depositional settings based on facies associations are shown in the right of the measured sections. Abbreviations at the bottom of the sections stand for as follows. S, shale; M, lime mudstone; W, wackestone; P, packstone; and G, grainstone.



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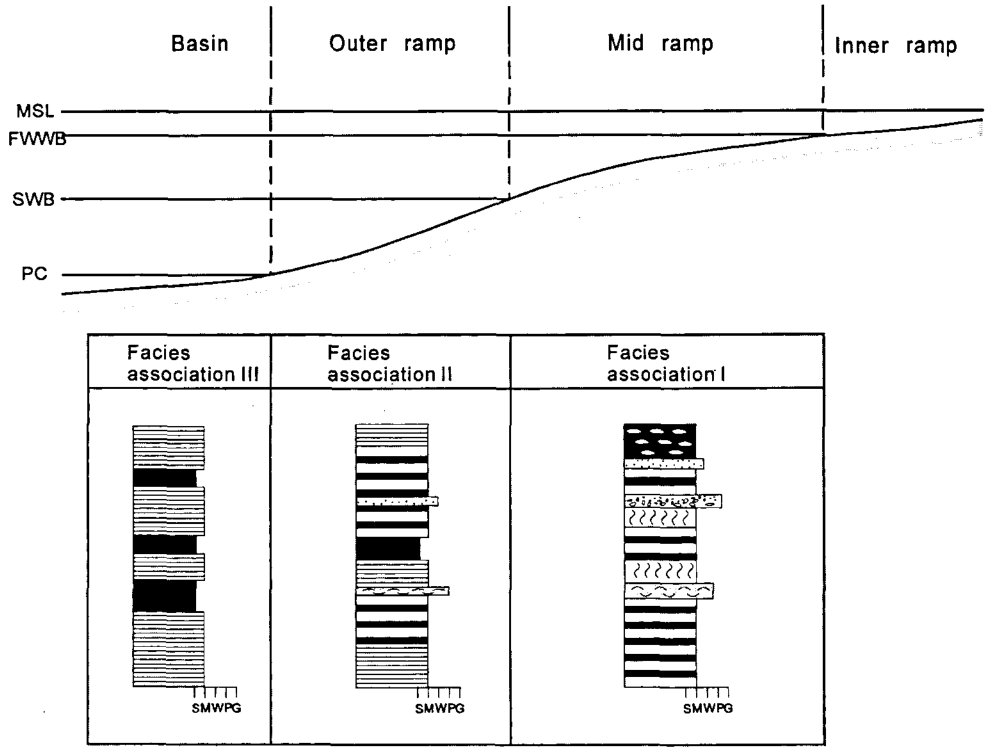

Fig. 4. Schematic diagram of the depositional environment of the Machari Formation. Carbonate mid ramp to basin with corresponding facies associations are presented. Abbreviations are follows. MSL, mean sea level; FWWB, fair weather wave base; SWB, strom wave base; and PC, pycnocline.

weather wave base but above storm wave base (Burchette and Wright, 1992).

Facies association II consists of bedded lime mudstone facies, laminated lime mudstone facies. bioclastic/peloidal packstone to grainstone facies, and peloidal/bioclastic wackestone facies. Lack of features associated with shallow water carbonates such as scour marks, mud cracks, and ripple cross laminations (Demicco and Hardie, 1994) suggests this facies association was deposited below storm wave base. Lack of slump and slide features which are commonly associated with carbonate slope suggests carbonate ramp environment (Burchette and Wright, 1992). Lamination and bedding in this facies association are interpreted to have been formed by intermittent influx of shallow water lime mud as turbitity currents on the carbonate ramp where calcareous muds were settling at relatively constant rate as pelagic muds. Sometimes peloidal /bioclastic wackestone was introduced by debris flow and packstone to grainstone was introduced by turbidity currents. Dark gray and black calcareous shale suggests quiet dysaerobic waters below storm wave base (Elrick, 1996). In the ocean low oxygen concentration occurs at 120 to 800 m depth (Duxbury and Duxbury, 1996). Facies II, therefore, is interpreted to have been deposited on outer carbonate ramp below storm wave base.

Facies association III consists of laminated lime mudstone facies and shale facies. Good horizontal continuity of laminations suggests homogeneous environment. Dark gray and gray color of sediments indicates dysaerobic condition. Thin laminations consisted of lime mud alternating with argillaceous mud suggest influx of sediments by fine-grained turbidite (Scholle *et al.*, 1983). Lack of lime mudstone bed and coarse-grained carbonates suggests remote distance from source area (shallow subtidal flat).

Table 3. Facies associations, description, and depositional settings of the Machari Formation.

Facies associations	Description	Depositional settings	References
FA I	Bedded lime mudstone facies, mottled lime mudstone facies, conglomerate facies, bioclastic/peloidal packstone to grainstone facies, peloidal/bioclastic wackestone facies	Mid ramp	Burchette and Wright, 1992; Proust *et al.*, 1998; Glumac and Walker, 2000; Saltzman, 1999
FA II	Bedded lime mudstone facies, laminated lime mudstone, bioclastic/peloidal packstone to grainstone facies, peloidal/bioclastic wackestone facies	Outer ramp	Burchette and Wright, 1992; Glumac and Walker, 2000
FA III	Laminated lime mudstone, shale facies	Basin	Burchette and Wright, 1992; Elrick, 1996; Glumac and Walker, 2000; Proust *et al.*, 1998

Increase of shale bed thickness suggests deposition of argillaceous sediments from water column by pelagic settling. Consequently the depositional setting of facies association III might be a basin.

CONCLUSIONS

Facies analysis on the Middle to Late Cambrian Machari Formation in the Machari area, Yeongweol, Korea reveals that the formation was deposited on the carbonate ramp to basin. The Machari Formation consists of 7 lithofacies and 3 facies associations. Lithofacies are bedded lime mudstone facies, laminated lime mudstone facies, bioclastic/peloidal packstone to grainstone facies, pelodial/bioclastic wackestone facies, conglomerate facies, mottled lime mudstone facies, and shale facies. Bedded lime mudstone facies, the most common facies and consisting of few cm thick lime mudstone alternating with shale layer is believed to have been formed by intermittent deposition of lime mud as dilute turbidity currents below fairweather wave base where clays were settling from water column at relatively constant rate. Laminated lime mudstone facies, alternating lime mudstone laminae with shale laminae, is interpreted to have been formed by deposition of fine-grained turbidity currents. Bioclastic/peloidal packstone to grainstone is interpreted to have been deposited by turbidity current. Peloidal/bioclastic wackestone facies is thought to have been deposited by debris flow. Conglomerate facies might have been deposited by storm activities. Mottled lime mudstone facies is interpreted to have been formed by bioturbation. Shale facies was deposited by suspension settling.

Three facies associations characterized by lack of sedimentary features associated with carbonate slope such as slumps and slide scars suggest the depositional environment of the Machari Formation was carbonate ramp (mid to outer ramp) to basin environment. Facies association I consisted of bedded lime mudstone facies, mottled lime mudstone facies, conglomerate facies, bioclastic/peloidal packstone to grainstone facies, and peloidal/bioclastic wackestone facies is interpreted to have been deposited on the mid ramp. Facies association II consisted of bedded lime mudstone facies, laminated lime mudstone facies, bioclastic/peloidal packstone to grainstone facies, and peloidal/bioclastic wackestone facies might have been deposited on the outer ramp. Facies association III consisted of laminated lime mudstone and shale facies is thought to have been deposited on the basin environment.

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