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중력류 퇴적물의 기술과 분류에 관한 연구

A Study on Description and Classification of Subaqueous Sediment Gravity-Flow Deposits

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한 국 해 양 연 구 소

제출문

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본 보고서를 "중력류 퇴적물의 기술과 분류에 관한 연구"의 최종 보고서로 제출합니다.

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요 약 문

I. 제 목

중력류 퇴적물의 기술과 분류에 관한 연구

II. 연구 내용 및 결과

질량류 퇴적물의 기술과 분류를 위해 새로운 분석 방법을 제시하였다. 제시된 분류 방법은 입도(또는 암상)과 1차 퇴적 구조를 양 축으로 구성된 2원적인 시스템에 기초를 두고 있으며, 7개의 Facies Class와 22개의 퇴적상으로 구성된다. Facies Class는 암상에 의해 정의되며, 역암 (Class G), 역질 사암 (Class GS), 조립 사암 (Class CS), 중립 사암 (Class MS), 세립 사암 (Class FS), 이암 (Class M), 혼합층 (Class CD) 등으로 구성된다. 각각의 Facies Class는 1차 퇴적 구조에 의해 여러 단위 퇴적상으로 나뉘어지며, 퇴적 구조로는 1) 괴상, 2) (희미한) 층리, 3) 점이층, 4) 역점이층, 5) 사층리 등이 있다.

SUMMARY

I. Title of Study

A Study on Description and Classification of Subaqueous Sediment Gravity Flow Deposits

II. Abstract

A method for the description and classsification of subaqueous sediment gravity flow deposits is proposed. The scheme is based on a tier-tier system of grain size (or lithology) and primary sedimentary structures, which comprises 7 facies classes and 22 sedimentary facies. The facies class is defined based on lithology: Gravelstone (Class G), Gravelly Sandstone (Class GS), Coarse Sandstone (Class CS), Medium Sandstone (Class MS), Fine Sandstone (Class FS), Mudstone (Class M) and Chaotic Deposit (Class CD). Each facies class is furthur divided into individual sedimentary

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Chapter 1. INTRODUCTION

Since the term "facies" was first introduced by Gressly (1838) who used it to imply the sum total of the lithological and paleontological aspects of a stratigraphic unit, there have been many discussions and modified definitions (e.g. Reading, 1982; Walker, 1980; Stow, 1985). The term "facies" is now used to mean a body of sedimentary rock or sediment with specific physical, chemical and biological characteristics. The facies analysis and model will be ultimately used to interpret sediment transport and depositional processes and further to infer depositional environments, especially as compared with the informations from other well-studied ancient and modern sedimentary environments.

Recently a new classification scheme for modern and ancient deep-water deposits has been proposed in a review by Pickering et al. (1986). This scheme, and its slightly revised later version (Pickering et al., 1989), incorporate the previous classification schemes of Mutti and Ricci Lucchi (1972, 1975), Walker and Mutti (1973), Walker (1975, 1978) and corresponding classification scheme have been based chiefly on analysis of ancient turbiditic systems including the detailed bed-by-bed measuring of numerous outcrop sections in Miocene Pohang Basin, southeast Korea (For details, see Choe, 1986, 1990).

The description method and classification scheme for sediment gravity flow deposits proposed here can be used as a basis for both field studies and laboratory analytical work. Though this new classification pertains to subaqueous sediment gravity flow deposits in general, other facies associated with deep-water turbidites such as hemipelagic muds are also included.

characteristics such as size, shape, and content of clast, matrix content, fabric, sedimentary structures and lateral variation were made in detail on millimeter scale. Photographs were also made. Many columnar sections were made in an outcrop where lateral facies changes occur. Laterally extensive, continuous lithologic units were observed and described in several locations. Considering the altitude difference between the adjacent outcrops, the stratigraphic position of sections was rearranged in the columnar sections.

bedform and internal sequences (Miall, 1985).

The facies classification scheme used in this study is based on a two-tier system of grain size (or lithology) and primary sedimentary structures. The scheme comprises 22 facies, as outlined in Table 3-1 and Fig. 3-1. Seven facies classes are defined based on lithology: Gravelstone (Class G), Gravelly Sandstone (Class GS), Coarse Sandstone (Class CS), Medium Sandstone (Class MS), Fine Sandstone (Class FS), Mudstone (Class M) and Chaotic Deposit (Class CD). Each facies class is furthur divided into individual sedimentary facies in terms of primary sedimentary structures, which include 1) disorganized, massive or homogeneous; 2) (crudely) stratified or laminated; 3) normally graded; 4) inversely (inverse-to-normally) graded; and 5) cross-bedded or -stratified.

Single facies is defined as a unit bounded by sharp lower and upper boundaries, which is named as 'facies unit'. The sharp boundary is defined for the following characters: 1) scoured surface, 2) abrupt change in lithology (grain size) and 3)

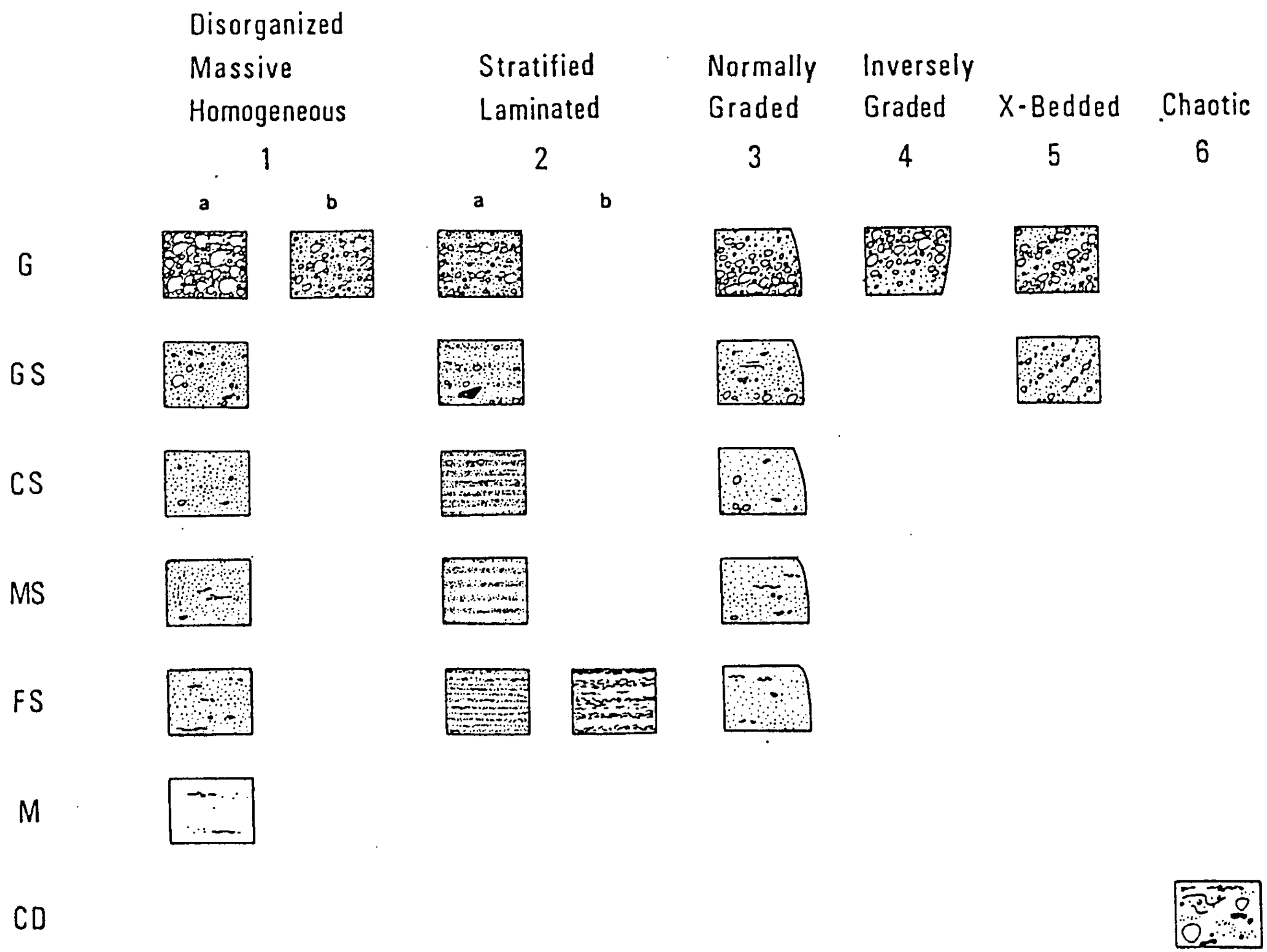

Fig. 3-1. Facies Classification Scheme

Chapter 4. FACIES CHARACTERISTICS

FACIES CLASS G: GRAVELSTONE

The class gravelstone contains more than 20% of gravels in fine to coarse sand matrix with minor amounts of mud. Gravels are commonly composed of (sub)rounded clasts of granite, sandstone, siltstone, basalt, quartzite and metasedimentary rocks. The gravelstone facies is of six types based on clasts' fabric and primary sedimentary structures: disorganized and clast-supported (facies G-1a), disorganized and matrix-supported (facies G-1b), (crudely) stratified (facies G-2), normally graded (facies G-3), inversely graded (facies G-4) and cross-bedded (facies G-5) (Table 3-1; Fig. 3-1).

Facies G-1a: Disorganized and clast-supported gravelstone

The facies G-1a is represented by disorganized and clast-supported gravels with sand matrix (Fig. 3-1). Each facies unit ranges in thickness from a few centimeters (a few gravels thick) to several meters. The gravels mainly consist of poorly-sorted pebble- to cobble-size clasts with some boulder-size graded nature, and the presence of overlying sandstone unit indicate that this facies is not deposited by cohesionless debris flow but powerful, fully turbulent flow, which could could be termed "gravelly high-density turbidity current".

Facies G-1b: Disorganized and matrix-supported gravelstone

The facies G-1b is characterized by disorganized and matrix-supported fabric in muddy sand matrix (Fig. 3-1). This facies mainly consists of granule- to cobble-size clasts (up to boulder) and is variable in thickness from a few gravels up to 10 m. Rarely calcite-cemented blocks and mudstone chunks are contained. This facies sometimes shows localized inverse grading of gravels and clast-supported gravel layers. The lower boundary of this facies is distinctive and flat but is rarely erosive. This facies is commonly encased in thick homogeneous mudstone (facies M).

The facies units are interpreted as debris flow deposits, based on disorganized fabric, floating large clasts in mud matrix, inverse grading and flat lower unit boundary (Johnson, 1970; Hampton, 1972, This facies is represented by horizontally stratified gravelstone unit (Fig. 3-1). Each facies unit ranges in thickness from 30 cm to 3 m. The facies consists of granule- to cobble-grade clasts with sandy matrix. The stratification is represented by either an alternation of gravel-rich and sand-rich layers (up to a few gravels thick) in clast-supported unit or strings of pebbles or granules in sand matrix. Mud clasts are commonly contained and range in diameter from a few centimeters up to 2 m. The lower facies boundary is flat or scoured. Each unit is commonly underlain by disorganized and clast-supported gravelstone (facies G-1a) and overlain by massive gravelly sandstone (facies GS-1).

The crude stratification of gravels, presence of rip-up mud clasts and the facies are indicative of tractional movement in high-density turbidity current. The coexistence of sands and gravels indicates that current velocity fluctuates (Davies and Walker, 1974; Walker, 1975, 1977). The sand-rich layers probably represent suspension density turbidity current deposit, based on normally graded nature, erosive lower boundary, its association with disorganized gravlestone and sandstone facies, and the presence of rip-up mud clasts (Lowe, 1982; Massari, 1984; Surlyk, 1984; Ineson, 1989). This facies unit is similar to R3 division (normally graded gravel) of Lowe (1982) and R2 division (normally graded gravel) of Massari (1984).

Facies G-4: Inversely graded gravelstone

The facies G-4 is characterized by gradual inverse grading of gravels and is either clast- or matrix-supported (Fig. 3-1). Each facies unit is variable in thickness from 10 cm up to 1 meter and mainly consist of well-rounded pebbles and cobbles. The units are commonly wedged within the outcrop. The lower and upper facies boundaries are flat and distinctive. This facies is overlain by disorganized/clast-supported gravelstone (facies G-1a) and sandstone facies.

Inverse grading is caused by dispersive

clasts and lignite fragments are commonly contained. The lower facies boundary is erosive showing channel geometry, whereas the upper boundary is gradational and flat. Each facies is commonly overlain by disorganized/clast-supported (facies G-1a) and normally graded (facies G-3) gravelstone units.

This facies is interpreted as high-density turbidity current deposit based on erosive lower boundary, presence of rip-up mud clasts, its association with disorganized/clast-supported and normally graded gravelstone facies (Winn and Dott, 1977, 1978, 1979; Lowe, 1982). Powerful current would erode muddy substratum. The high-density gravel dispersions in the basal part would continue to move laterally and fill the scour. The dispersions would exhibit different concentration of clasts and contain large amounts of sands. The turbidity current deccelerates with slight fluctuation of its velocity. This fluctuation results in change of gravel deposition mode. Under higher velocity condition, the gravel-rich dispersions fill the scour, whereas under slower (facies G-1a), crudely stratified (facies G-2) gravelstone and overlain by massive, graded coarse sandstone facies (CS-1, -3).

It is interpreted as sandy high-density turbidity current deposit based on its massive nature, the presence of outsize clasts and rip-up mud clasts and its association with the undelying gravelstone and the overlying coarse sandstone facies units (Hiscott and Middleton, 1979; Lowe, 1982; Massari, 1984; Surlyk, 1984; Postma et al., 1988). In sandy high-density turbidity current, the bulk of suspended load consists of clay-, silt- and sand-sized materials with small amounts of gravels. Increasing of flow unsteadiness would result in collapse of high-density suspended sediment cloud and thus the bulk of sand sediment would be rapidly deposited. This facies unit is similar to Lowe's (1982) S3 division (massive gravelly sand) or Massari's (1984) S2 division (massive gravelly sand).

Facies GS-2: Laminated gravelly sandstone

turbulent suspension of sands with a small amount of gravels. Slower settling and subsequent tractive movement as beadload cause to form parallel lamination. This facies unit is analogous to S1 (parallel-laminated) division of Lowe (1982).

Facies GS-3: Normally Graded gravelly sandstone

This facies is characterized by an upward decreases in size and in concentration of dispersed gravels (Fig. 3-1). Each facies unit consists of poorly sorted fine to coarse sand with scattered gravels. Individual units are laterally continuous within the outcrop, although some units are limited in lateral extension due to erosion of the overlying deposits. This facies unit ranges in thickness from a few centimeters up to 3 m. The gravels are generally rounded, granule- to boulder-size. Rip-up mud clasts and lignite fragments are commonly contained. The lower and upper facies boundaries are flat and smooth. The disorganized or normally graded gravelstone (facies G-1a, -3) and massive gravellly sandstone (facies GS-1) underlie this facies unit, whereas massive fine and medium of Lowe (1982) which is indicative of traction sedimentation at the base of high-density turbidity current. Close association with the cross-bedded gravelstone unit also indicates that it was deposited by high-density dispersion of gravels and sands developed at the base of high-density turbidity current (Winn and Dott, 1977; 1979; Lowe, 1982).

CLASS CS: COARSE SANDSTONE

The class coarse sandstone consists of coarse sand (> 80%) with some dispersed outsize gravels (< 5%); it includes massive (facies CS-1), laminated (facies CS-2) and normally graded (facies CS-3) units (Table 3-1; Fig. 3-1).

Facies CS-1: Massive coarse sandstone

The facies CS-1 is represented by massive coarse sandstone with some dispersed gravels (Fig. 3-1). Each facies unit ranges in thickness from 20 cm to 1 m and consists of poorly sorted medium to coarse sands with granules and small pebbles (up to boulder clasts). The unit rarely contains laterally in thickness from 20 to 60 cm and consist of medium to coarse sand with some granules and small pebbles. The units are generally laterally continuous within the outcrop, but are commonly scoured by the overlying gravelstone facies. Rip-up mud clasts and lignite layers commonly occur. The upper and lower facies boundaries are generally flat and distinct. The facies unit is intimately underlain by massive gravelly sandstone (facies GS-1) and gravelstone units (facies G-1a, G-2).

The facies CS-2 is essentially similar to the tractional division of classical turbidites (Tb) deposited by high- or low-density turbidity currents under upper flow regime (Allen, 1964; Middleton, 1966a, 1966b, 1967a, 1967b; Bridge, 1981; Lowe, 1982; Eyles et al., 1987).

Facies CS-3: Normally Graded coarse sandstone

The facies CS-3 is represented by normally graded unit of coarse sand (Fig. 3-1). Each facies unit ranges in thickness from 20 to 50 cm and is laterally continuous within the outcrop. The units settling. Within the flows, size segregation of suspended sediments occurs vertically and laterally producing normal grading (Lowe, 1982, 1988; Massari, 1984).

CLASS MS: MEDIUM SANDSTONE

The class "medium sandstone" consists of moderately sorted medium sand (> 80%) and comprises four facies: massive (facies MS-1), laminated (facies MS-2) and normally graded (facies MS-3) units (Table 3-1; Fig. 3-1).

Facies MS-1: Massive medium sandstone

The facies MS-1 is represented by massive unit of medium to fine sand with some dispersed coarse sands (Fig. 3-1). Each facies unit ranges in thickness from several centimeters to 40 cm and is generally continuous within the outcrop. Rip-up mud clasts, plant debris and lignite fragments are commonly contained. Outsized gravels rarely occur floating in unit. The lower facies boundary is flat or irregular due to soft sediment deformation including microloading and pseudonodules of sands, medium to coarse sands and fine to medium sands laminae which are a few millimeters thick and are laterally continuous within the unit. The units are variable in thickness from a few centimeters to 30 cm ane are laterally continuous within the outcrop. Rip-up mud clasts and lignite fragments are commonly contained. The lower and upper facies boundaries are flat and smooth. This facies is intimately alternated with other medium sandstone (MS-1, -3), fine sandstone (FS-1) and coarse sandstone (CS-1) facies.

Each facies unit is interpreted as low-density turbidity current deposit similar to the Bouma's B division (Tb). A variety of theories for the origin of parallel lamination of sand have been proposed. Parallel lamination of sand with considerable lateral extension is formed by shear stress fluctuations associated with coherent, large scale eddies advected with the main flow (Allen, 1984).

Facies MS-3: Normally Graded medium sandstone

This facies is characterized by normally graded

FS-2b) and normally graded (facies FS-3) facies (Table 3-1; Fig. 3-1).

Facies FS-1: Massive fine sandstone

The facies FS-1 is characterized by massive unit of fine sand with some medium to coarse sands (Fig. 3-1). Each facies unit is variable in thickness from less than 1 cm to 30 cm (up to a few meters in case of amalgamated unit). Each unit is laterally continuous within the outcrop (a few tens of meters long), although some are lenticular and limited in lateral extension exhibiting cross-cutting geometry. The lower facies boundary is commonly irregular showing loading and pseudonodules of sands and mud flames. Each unit commonly contains rip-up mud clasts (balls) usually less than 20 mm in diameter forming layers. Lignite and plant fragments are abundant. Each unit is frequently self-repeated and is commonly associated with the mudstone (M) and other sandstone facies (CS-1, CS-3, MS-1, and FS-2a, FS-2b, FS-3).

This facies unit is similar to the massive unit fluctuations are associated with large-scale eddies advected with the main flow. Parallel lamination may be produced by the migration of very low-amplitude bedforms (Smith, 1971, McBride et al., 1975; Miall, 1977; Bridge, 1981; Allen, 1984; Bridge and Best, 1988; Paola et al., 1989). Bridge (1978) and Cheel and Middleton (1986) proposed a model for the formation of horizontal laminae on upper flow regime plane beds as a reponse of the bed material to the bursting process on smooth or transitional rough beds. The laminated fine sandstone unit generally shows flat lower and upper boundaries and considerable lateral continuity within outcrop (up to over 30 m) which are indicative of unchannelized sheet flow. Within the facies FS-2a each lamina is laterally continuous, well sorted and shows discontinuous medium-to-coarse sand trains. These are suggestive of shear sorting in turbulent boundary layer. This facies unit is essentially similar to the tractional division of classical turbidites (Tb) deposited by low-concentration turbidity currents under upper flow regime (Bouma, clasts and lignite fragments are commonly contained. The lower and upper facies boundaries are generally irregualr showing sand injection, mud flames and sand loading. Each facies unit is associated with homogeneous mudstone (M) and sandstone (FS-1, FS-2a, MS-1, CS-1 and GS-1) facies.

This facies unit is similar to the Bouma's A division of classical turbidite. Most workers agree that it is deposited from turbulent suspension of low-density turbidity current (Surlyk, 1984; Eyles et al., 1987; Marzo and Anadon, 1988). As compared with the massive fine sandstone unit (facies FS-1), the normally graded sandstone unit would be deposited from turbulent flows which show rather slow suspension settling and relatively low sediment concentration.

CLASS M: MUDSTONE

Facies M: Homegeneous mudstone

The facies M is represented by light (or dark) olive gray, homogeneous mudstone ranging in thickness from 10 mm to several meters (Fig. 3-1).

(G-1a).

This facies unit is interpreted as slide/slump deposits, based on chaotic nature of disrupted sandstone and mudstone layers, the presence of large clasts, and flat and smooth lower boundary. The chaotic deposits are of two types on the basis of internal structure and relationship of the deposits to adjacent bed or layers (Choe, 1986; Pickering et al., 1986; Choe and Chough, 1988). These include 1) exotic clasts; and 2) contorted/disturbed strata showing gravity controlled wet-sediment deformation. The former most likely resulted from either submarine rockfall or slide/slump. They were deposited by gravity-induced sediment sliding and slumping.

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