2

Zavala, C., M. Arcuri, M. Di Meglio, H. Gamero Diaz, and C. Contreras, 2011, A genetic facies tract for the analysis of sustained hyperpycnal flow deposits, *in* R. M. Slatt and C. Zavala, eds., Sediment transfer from shelf to deep water—Revisiting the delivery system: AAPG Studies in Geology 61, p. 31–51.

# A Genetic Facies Tract for the Analysis of Sustained Hyperpycnal Flow Deposits

**Carlos Zavala and Mariano Arcuri**
*GCS Argentina, Universidad Nacional del Sur, Bahía Blanca, Argentina*

**Mariano Di Meglio**
*GCS Argentina, Bahía Blanca, Argentina*

**Helena Gamero Diaz and Carmen Contreras**
*Schlumberger Technology Corp., Addison, Texas, U.S.A.*

## ABSTRACT

Facies analysis performed for more than 10 yr in several lacustrine and marine basins allowed the distillation of a genetic and predictive facies tract of general application to the recognition of sustained turbulent (noninertial) hyperpycnal flow deposits. The facies tract is composed of three main genetic facies groups related to bed load (B), suspended load (S), and lofting (L) transport processes.

Facies B (bed load) is the coarsest grained and relates to shear and frictional drag forces provided by the overpassing long-lived turbulent (hyperpycnal) flow. Three main subcategories are recognized, termed B1 (massive or crudely bedded conglomerates), B2 (pebbly sandstones with low-angle asymptotic cross-stratification), and B3 (pebbly sandstones with diffuse planar lamination and aligned clasts).

Facies S is finer grained and relates to the gravitational collapse of suspended load transported by the hyperpycnal flow. Four subfacies types are recognized, termed S1 (massive sandstones), S2 (parallel laminated sandstones), S3 (sandstones with climbing ripples), and S4 (massive siltstones and mudstones).

Facies L (lofting) relates to the buoyancy reversal of the hyperpycnal flow provoked by lift of a less dense fluid (in this case, fresh water) typically found in marine and other saline-receiving basins. The finest materials suspended in the

Copyright ©2011 by The American Association of Petroleum Geologists.
DOI:10.1306/13271349St613438

flow (very fine–grained sand, silt, plant debris, and mica) are lifted from the substrate and settle down forming silt/sand couplets of great lateral extent. Facies L develops only in marine/saline environments, whereas facies S3 and S4 are more common in lacustrine environments.

Hyperpycnites are often very complex, showing internal erosional surfaces and gradual facies recurrences related to deposition from long-lived and highly dynamic (fluctuating) flows. This complex behavior results in the accumulation of composite beds having an internal facies arrangement that strongly departs from conventional facies models developed for surgelike flows. Facies B characterizes transfer zones, and its occurrence allows the prediction of sandstone deposits (facies S) basinward. Facies L is mostly developed in flow-margin areas. In marine settings, the reversing buoyancy effect (lofting) at the hyperpycnal flow margin will result in less lateral continuity of sandstone bodies compared with those related to resedimentation processes, with important consequences for hydrocarbon reservoirs.

## INTRODUCTION

Recent advances in the understanding of a new category of clastic depositional system, termed "hyperpycnal system," have provided a new frontier for the understanding of clastic facies in marine and lacustrine environments. A hyperpycnal system (Zavala et al., 2006a) is the subaqueous extension of the fluvial system (in the sense of Schumm, 1977, 1981). It originates when a river in flood directly discharges a sustained and relatively more dense turbulent mixture of fresh water and sediments (hyperpycnal flows; Bates, 1953) into a receiving standing body of water. To overcome the density contrast with marine waters, the plunging of a river flow will require a suspended-load concentration varying between 35 and 45 kg/m$^3$ (Mulder and Syvitski, 1995) according to latitudinal variations. As a consequence of its excess in density, the incoming flow plunges and moves basinward as a land-generated underflow (Figure 1). Increasing evidence shows that hyperpycnal systems can extend hundreds of kilometers basinward (Collins, 1986; Johnson et al., 2001; Nakajima, 2006; Zavala et al., 2006a; Gamero et al., 2007; Cheng-Shing and Ho-Shing, 2008; Bourget et al., 2010) and can explain the accumulation of very thick clastic successions in shelfal and deep-marine settings even during highstands of sea level (Mutti et al., 1996, 2003).

Observations made in 230 contemporaneous rivers (Mulder and Syvitski, 1995) revealed that more than 66% of the rivers produce periodic hyperpycnal discharges, allowing the basinward transfer of huge volumes of sediments. As an example, during a single hyperpycnal discharge (lasting 18 hr in November 1995) the Var river transferred a volume of sediments equivalent to that transported in 20 yr in nonflood conditions (Mulder et al., 2003). Although hyperpycnal discharge seems to be very common in contemporaneous rivers, only a few examples of deposits interpreted as fossil hyperpycnites can be found in the literature (Plink-Björklund and Steel, 2004; Pattison, 2005, 2008; Zavala et al., 2006a; Myrow et al., 2008; Soyinka and Slatt, 2008). Consequently, it is possible that many ancient hyperpycnal deposits were misinterpreted in the past as deposited in more conventional depositional systems (Mutti et al., 1996, 2003). Although present hyperpycnal discharges transport mostly very fine-grained sediments, increasing evidence from ancient strata (Mutti et al., 2003; Plink-Björklund and Steel, 2004; Saitoh, 2004; Gamero et al., 2005, 2007, 2008; Pattison, 2005, 2008; Hesse and Khodabakhsh, 2006; Olariu and Bhattacharya, 2006; Petter and Steel, 2006; Zavala et al., 2006a, b, c, 2007a, b, 2008b; Lamb et al., 2008; Myrow et al., 2008; Ponce et al., 2008a, b; Soyinka and Slatt, 2008; Zavala, 2008) strongly supports the idea that coarse-grained hyperpycnites could be much more common than expected.

Extensive field and core studies performed during more than 10 yr in several different sedimentary basins (Table 1) show that sedimentary facies related to hyperpycnal systems are very distinctive and could easily be differentiated from surgelike (classical) turbidites, tempestites, and other conventional facies types.

A hyperpycnite (Mulder et al., 2003) is a particular type of turbidite having distinctive and at present poorly known facies characteristics (Mulder and Alexander, 2001). Its origin is closely related to a direct fluvial discharge and results in facies types and depositional features that commonly resemble those

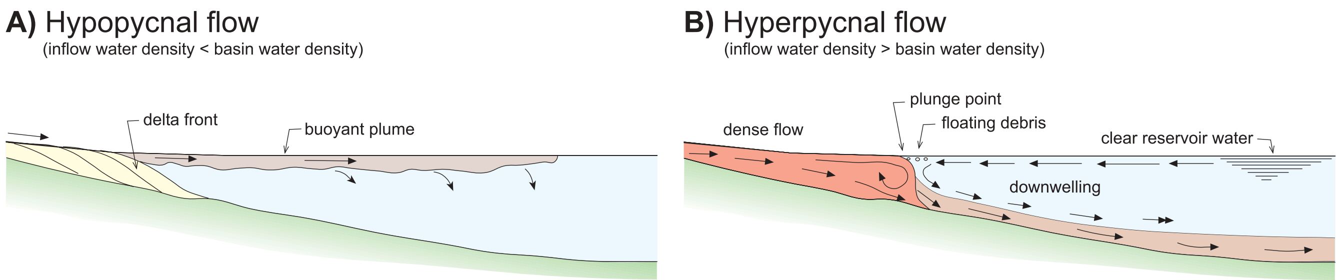



**FIGURE 1. Comparison between hypopycnal (A, inflow density < sea-water density) and hyperpycnal (B, inflow density > sea-water density) flows (original concept by Bates, 1953). Note that in the case of the hyperpycnal flow, the fluvial discharge sinks below the sea-water body, continuing its travel basinward as a quasi-steady underflow. Panel B was redrawn from the pioneer work of Knapp (1943). After Zavala et al. (2008a).**

considered as typical of fluvial environments (bed load, meandering, etc.) but are commonly associated with clear marine and lacustrine indicators. The transfer and accumulation of a huge volume of continental sediments during a single long-lived flood frequently results in confusing facies types from a conventional point of view. The resulting clastic sedimentary bodies could be biostratigraphically sterile or can display a wide range of water-depth indicators. Very thick hyperpycnites commonly lack or show rare and very specific trace fossils favoring the confusion of these strata with estuarine deposits. As for every sediment gravity flow, the location and thickness of coarse-grained hyperpycnal sedimentary bodies are very sensitive to the contemporaneous subaqueous topography, commonly resulting in the accumulation of very thick laminated or structureless sandstone bodies of difficult interpretation using nonhyperpycnal facies models.

The objective of this chapter is to introduce and to discuss a new approach to a genetic facies model constructed for the analysis and understanding of long-lived and fully turbulent hyperpycnal flows and their coarse-grained deposits illustrated with selected examples from different South American basins.

## A GENETIC FACIES MODEL FOR THE ANALYSIS OF HYPERPYCNAL DEPOSITS

Descriptive facies models focus on the careful description and classification of different types of

**Table 1.** Main units and sedimentary basins considered in this study.

| *Unit* | *Age* | *Basin* | *Country* | *References* |
|---|---|---|---|---|
| La Lola Fm | Ordovician | Ventania | Argentina | Zavala et al., 2000 |
| Los Molles Fm | Early Jurassic | Neuquén | Argentina | Zavala and Gonzalez, 2001 |
| Lajas Fm | Middle Jurassic | Neuquén | Argentina | Zavala and Gonzalez, 2001 |
| Lotena Fm | Middle Jurassic (Callovian) | Neuquén | Argentina | Zavala, 2005 |
| Mulichinco Fm | Early Cretaceous (Valanginian) | Neuquén | Argentina | Zavala, 2000a |
| Rayoso Fm | Barremian–Aptian | Neuquén | Argentina | Zavala et al., 2006a |
| Magallanes Fm | Late Cretaceous | Austral | Argentina | Saccavino et al., 2008 |
| Misoa Fm | Eocene | Maracaibo | Venezuela | Gamero et al., 2005 |
| Pampatar Fm | Eocene | Ensenada | Venezuela | Guzmán and Campos, 2008 |
| Merecure Fm | Oligocene | Maturin | Venezuela | Zavala et al., 2007b |
| Carapita Fm | Miocene | Maturin | Venezuela | Gamero et al., 2007 |
| Herrera Sst | Miocene | Columbus | Trinidad | Gamero et al., 2007 |
| Mayaro Fm | Pliocene | Columbus | Trinidad | Zavala et al., 2008b |
| Pliocene sandstones | Pliocene | Columbus | Trinidad | Gamero et al., 2008 |
| Catarozzo Gp | Late Pliocene | Sant'Arcangelo | Italy | Zavala, 2000b |
| Aliano Gp | Late Pliocene–Early Pleistocene | Sant'Arcangelo | Italy | Zavala, 2000b |
| Tursi Gp | Late Pliocene–Early Pleistocene | Sant'Arcangelo | Italy | Zavala, 2000b |

*Fm = Formation; Sst = Sandstone; Gp = Group.*

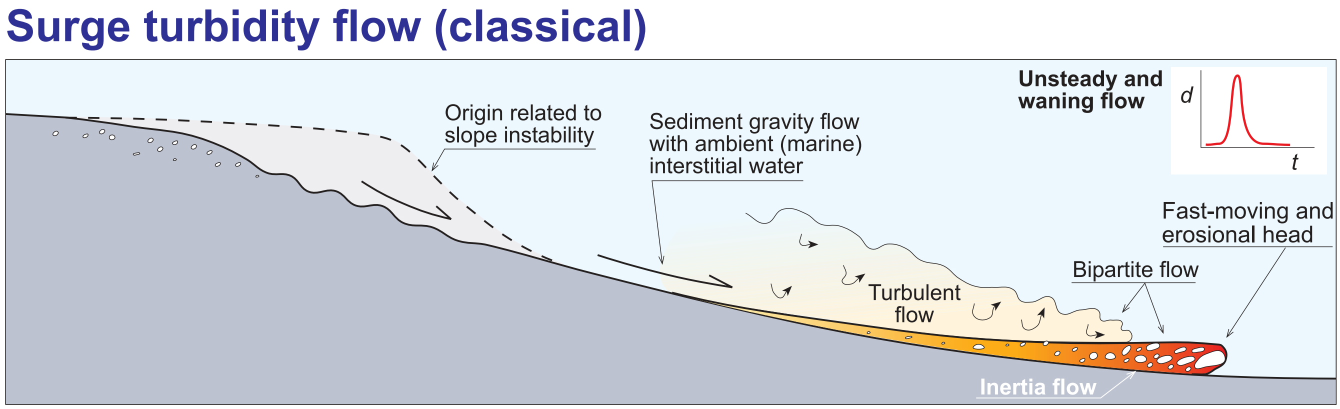



**FIGURE 2.** Main characteristics of surgelike turbidites originated by slope instability. Flow bipartition results in a fast-moving inertial flow followed by a slow-moving turbulent (gravitative) flow. Inspired by Mutti et al. (1999). *d* = discharge; *t* = time.

sedimentary rocks according to their macroscopic characteristics such as sedimentary structures, grain size, color, geometry, and types of bounding surfaces, among others (Walker, 1984). These descriptive facies are then commonly grouped into different categories according to some common characteristics (i.e., coarse-grained facies, cross-bedded facies, massive facies, etc). A descriptive facies analysis is an objective procedure because it is based on observable macroscopic physical characteristics. Therefore, different observers can arrive at similar conclusions. The main objective of a descriptive facies analysis is to determine the paleoenvironment of accumulation.

Genetic facies models and facies tracts represent a step ahead in facies analysis because they require a conceptual-based classification. A genetically oriented facies approach distinguishes facies according to the main sedimentary processes involved during their transport and deposition. As in fossil deposits sedimentary processes can only be inferred, the genetic approach strongly depends on the experience and the paradigm used by the observer. The use of a genetic approach requires an early understanding of the depositional environment, which should be determined using the descriptive facies approach previously described. The main goal of a genetic facies analysis is to determine the conceptual facies tract and to predict the expected facies types outside of the reference section under study. At present, genetic facies tracts are only available for turbidites related to ignitive surgelike processes, mainly associated with slope failures. The use of a genetic approach for the analysis of surgelike turbidites was introduced by Bouma (1962) in his milestone contribution. Bouma described a key facies sequence from the Oligocene Peira Cava flysch that allowed, for the first time, the analysis of the position along the depositional profile of a certain sandstone body and the prediction of landward and basinward directions and processes based on the possible characteristics of the genetically related sedimentary bodies.

A significant improvement to the genetic facies tract applied to the analysis of turbidite deposits was later made by Mutti and Ricci Lucchi (1972), which also incorporated very coarse-grained sedimentary populations. Lowe (1979, 1982) carefully described and discussed the origin of ancient fine- and coarse-grained turbidites based on their flow rheology and inferred particle support mechanisms. Lowe (1982) also emphasized the importance of bed load in coarse-grained turbidites.

In a series of more recent contributions, Mutti (1992) and Mutti et al. (1999, 2003) increased the predictive power of genetic facies tracts by adding a discussion on the importance of hydraulic jumps and flow transformation in controlling the characteristics of the resulting sedimentary facies. Mutti et al. (1999) improved the genetic interpretation by applying the concept of flow bipartition introduced by Sanders (1965). According to Mutti et al. (1999), a turbidity flow will therefore be composed of a fast-moving inertial (granular) flow followed by a slow-moving turbulent flow. Deposition of different facies types (F2–F9) occurs as a consequence of a series of hydraulic jumps as the flow wanes and dilutes basinward (Mutti et al., 1999). As the flow is driven by inertial forces related to the fast-moving granular flow, this kind of flow will therefore require an acceleration on a steep slope and will be very sensitive to slope breaks. In addition, if this turbidity flow originates from slope instability (ignitive classical turbidites), the density of interstitial flow waters will be similar to that of ambient waters, thus preventing the effect of lofting (Figure 2).

In recent years, the origin of turbidites has been also related to the direct supply of relatively dense mixtures of water and sediments by rivers in flood or hyperpycnal flow (Normark and Piper, 1991; Mutti et al., 1996; Bruhn and Walker, 1997; Mutti et al., 1999, 2009; Klaucke et al., 2000; Stow and Mayall, 2000; Mulder et al., 2001a, b; Deptuck et al., 2003; Mutti et al., 2003; Posamentier and Kolla, 2003; Joseph and Lomas, 2004; Migeon et al., 2004; Plink-Björklund and Steel, 2004; Pattison, 2005; Antobreh and Krastel, 2006; Gervais et al., 2006; Mansurbeg et al., 2006; Migeon et al., 2006; Ponce et al., 2008a, b). Mutti et al. (1996, 2003, 2009) emphasized the importance of catastrophic flooding in the accumulation of very thick clastic successions in shallow- to deep-marine settings, mainly associated with small and medium-size mountainous rivers characterized by relatively short- and high-gradient transfer zones. Mutti et al. (2003) recognized the flood-generated delta-front sandstone lobes as the main depositional element associated with hyperpycnal flows. This provides a broad spectrum of relatively small intergradational and coarse-grained fluvial-deltaic systems ranging between two end members, (1) fan deltas and (2) river deltas. According to Mutti et al. (2003), fan-delta systems accumulate in roughly tabular lobes extending from alluvial conglomerates to shelfal siltstone and mudstone. In these systems, flood-generated dense flows enter seawaters as catastrophic and inertia-dominated relatively unconfined flows. Coarser materials tend to collect at the front of the flow, giving way to a horizontally negative grain-size gradient. River-delta systems, however, could be dominated by two intergradational types of flow corresponding to sediment-laden streamflows (long-lived turbulent flows) and composite sediment-laden streamflows (inertial flows, with horizontally negative grain-size gradient). In river-delta systems, sedimentation occurs mainly in a mouth bar (characterized by sigmoidal bedding) and in associated flood-generated delta-front sandstone lobes. Mutti et al. (2003, p. 739) indicate that "in the case of higher outflow efficiency, coarse sediment collapsed at river mouths is transported as tractive bed load by sustained turbulent flows exiting river mouths as hyperpycnal flows. This process sets up the formation of tractional bed forms that are primarily controlled by water depth and the velocity and steadiness of the bypassing hyperpycnal flows."

The understanding of facies types related to sustained turbulent (noninertial) hyperpycnal flows represents a deep challenge for sedimentologists because long-lasting river discharges and their associated facies types could be very different from those expected in surgelike (inertia-dominated) turbidity flows (Mulder and Alexander, 2001; Zavala et al., 2006a; Zavala, 2008). To travel hundreds of kilometers (Nakajima, 2006), the hyperpycnal discharges have to be maintained for weeks or months and consequently they will be mostly associated with low-gradient medium- to large-size rivers.

In this chapter, we focus our analysis on the facies types related to sustained fully turbulent hyperpycnal flows with associated bed load. A sustained hyperpycnal flow has a distinctive behavior that will result in the accumulation of nonconventional beds from a classical point of view. Its origin related to a direct fluvial discharge results in a subaqueous flow having characteristics commonly considered as typical of alluvial sedimentation. A sustained hyperpycnal flow is a land-derived, relatively slow-moving, and fully turbulent sediment gravity flow (Mulder et al., 2003) having the ability to carry basinward interstitial fresh water (Hesse and Khodabakhsh, 1998; Johnson et al., 2001; Hesse et al., 2004; Mansurbeg et al., 2006; Warrick et al., 2008; Zavala, 2008). The diameter of the clastic suspended particles commonly ranges from silt to very fine sand (0.004–0.25 mm; Myrow et al., 2006). The particles are transported together with plant debris and micas (Zavala et al., 2006c, 2008b; Zavala, 2008). In contrast to surgelike (ignitive) turbidites, sustained hyperpycnal flows have a slow-moving and more diluted leading head (Kassem and Imran, 2001) that will be very sensitive to the preexisting subaqueous topography (Figure 3).

The moving of a sustained hyperpycnal flow will not necessarily require steep slopes (Zavala et al., 2006a) because the flow could be maintained as long as the high-density fluvial discharge continues (Prior et al., 1987). Therefore, the distance reached by a sustained hyperpycnal flow traveling along a gently dipping or near-flat sea bottom will depend mostly on the duration of the related flood event (Zavala et al., 2006a). In contrast with surgelike flows where deposition is dominated by the head, in sustained hyperpycnal flows, deposition is dominated by the body (De Rooij and Dalziel, 2001; Peakall et al., 2001). These characteristics allow the preservation in the hyperpycnal deposit of evidences of flow fluctuations that occurred during the overpassing discharge, resulting in the accumulation of composite

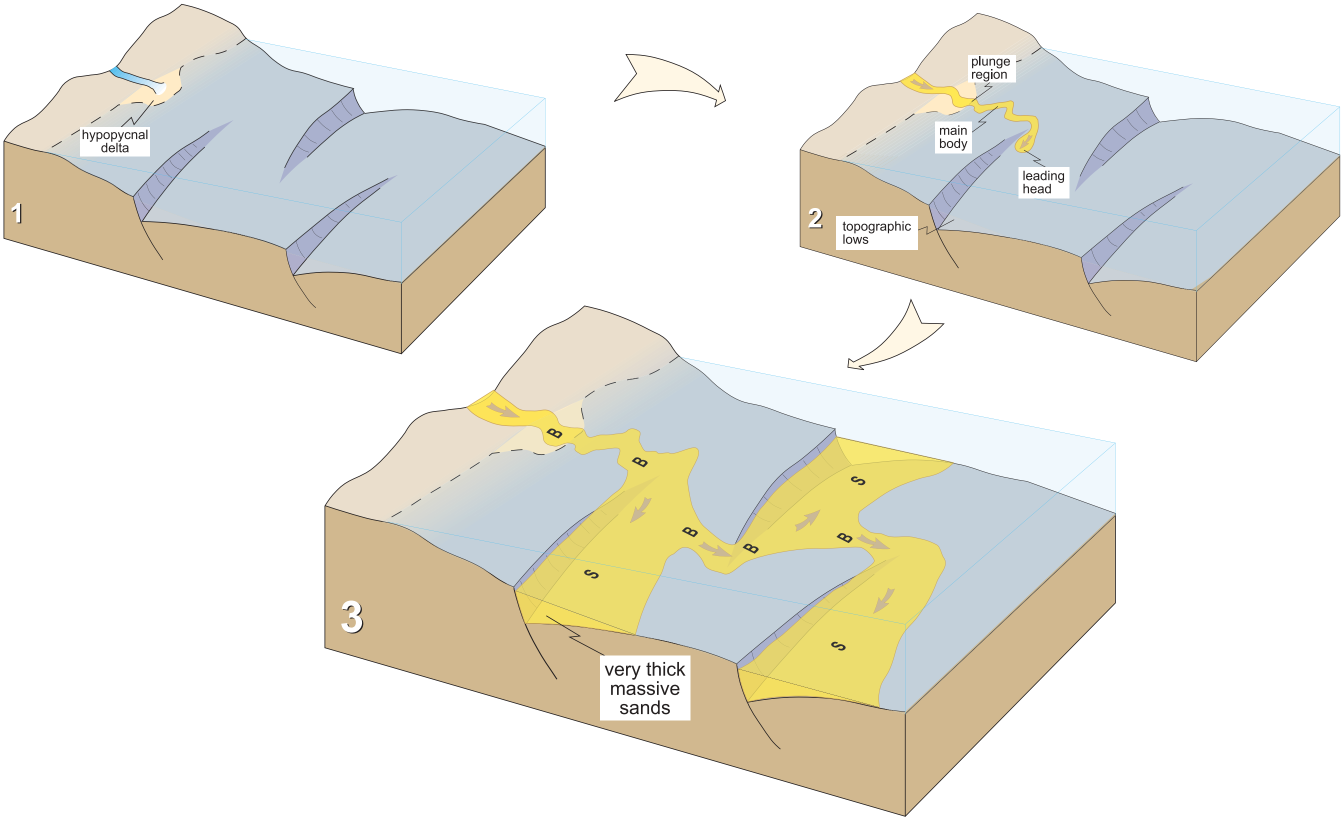



**FIGURE 3.** **Main steps in the triggering and evolution of a sustained hyperpycnal flow. (1) Normal hypopycnal delta. (2) The increase in the overall density of the fluvial discharge forces the flow to plunge and to produce a sustained hyperpycnal flow, with a leading head followed by the main body. The leading head will advance, trying to achieve the deepest part of the submarine landscape. (3) The submarine lows could be filled with very thick massive sands. Horizontal scale is tens of kilometers.**

beds (Zavala et al., 2007a). Contrary to classical models of turbidity sedimentation, coarse-grained materials are not transported at the flow head but are dragged at the flow bottom as bed load (Figure 4) related to shear forces provided by the overpassing long-lived turbulent flow (Plink-Björklund and Steel, 2004; Zavala et al., 2006b, 2008b). Bed load in sustained hyperpycnal flows is probably inherited from the original subaerial discharge that enters the receiving basin. Recognition of bed-load facies in hyperpycnal deposits is crucial for facies prediction because these facies give fundamental information about (1) the position in the facies tract with respect to the whole hyperpycnal system, (2) flood event magnitude and duration, and (3) expected related facies types in more proximal and distal areas.

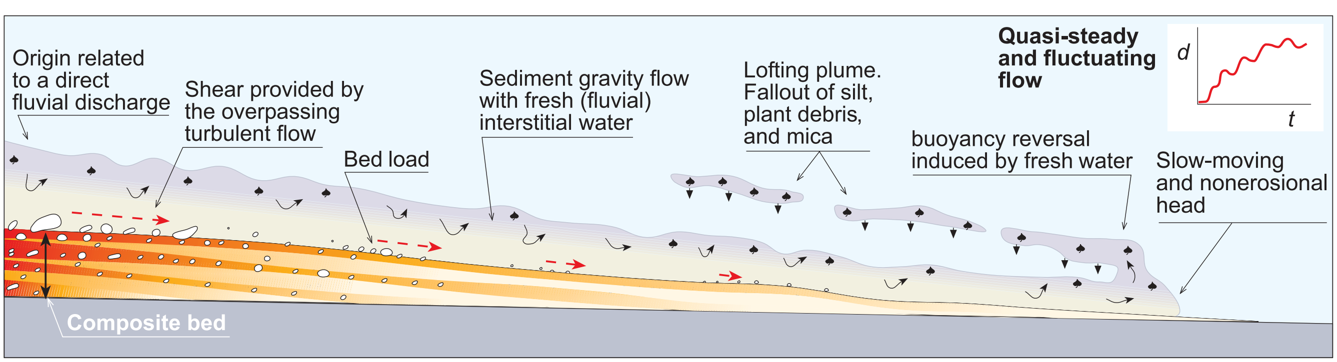



**FIGURE 4.** **Main characteristics of long-lived hyperpycnal flows and their typical deposits. The complexity of these flows results in the accumulation of composite beds (Zavala et al., 2007a).** ***d*** **= discharge;** ***t*** **= time.**

A fundamental difference between bed load related to the movement of fresh water (fluvial) with respect to that associated with sustained hyperpycnal flows is that in the latter, suspended materials transported by the overpassing turbulent flow will be trapped, filling the interstices between the coarser grained materials. For this reason, open packing in bed load associated with sustained hyperpycnal sedimentation is almost impossible. Although similar facies can be temporarily generated during floods in alluvial channels, the later washout (reworking) by fresh waters commonly results in better sorting and open packing in gravels. Consequently, the recognition of open packing in fossil gravels (commonly filled by chemical precipitates) can be used as a field criterion to distinguish bed-load deposits related to subaerial fluvial streams from those associated with hyperpycnal flows. Other typical characteristics of sustained hyperpycnal flows in marine settings are related to the buoyancy flow reversal induced by the lift-up effect provided by the interstitial fluid once the sediment concentration falls below a certain threshold in a process known as ''lofting'' (Sparks et al., 1993; Hesse et al., 2004).

The characteristics previously discussed result in the accumulation of three main facies categories related to the three main processes that characterize all sustained hyperpycnal discharges in marine settings: bed load, turbulent suspension, and lofting. These facies categories are here termed as B (bed-load-related sedimentary facies), S (suspended-load-related sedimentary facies), and L (lofting-related sedimentary facies) (Figure 5).

### *Facies Related to Bed-load Processes (Facies B)*

Type B facies includes different coarse-grained deposits related to shear/drag forces exerted by the overpassing long-lived turbulent (hyperpycnal) flow over coarse-grained materials lying on the flow bottom. Three main categories of bed-load facies are recognized, here termed B1, B2, and B3 (Figure 6).

#### *Facies B1*

Facies B1 is composed of massive and crudely stratified conglomerates with abundant coarse- to fine-grained sandstone matrix. The largest clasts are embedded in the matrix (facies B1; Figure 7A, C, D) or imbricated following diffuse subhorizontal alignments. The overall texture is matrix supported, although some varieties of clast-supported conglomerates are recognized (facies B1c) (Figure 7A). Unlike the deposits related to laminar dense flows (hyperconcentrated flows), large clasts move freely at the base of the overpassing turbulent flow and commonly appear imbricated. Large clasts are probably transported by sliding and rolling, whereas the finest materials composing the matrix would correspond to suspended load transported by turbulence, which became trapped at the low-velocity and relatively high-concentration basal zone (Manville and White, 2003). Field relationships suggest that a vertical evolution between facies B1c and B1 (Figure 7A) could be related to a progressive decrease of drag forces exerted by the overpassing turbulent flow. In systems that lack coarse-grained clastics, B1 facies could be entirely composed of matrix- or clast-supported clay clasts (facies B1s) (Figures 6, 8A).

#### *Facies B2*

Facies B2 is composed of fine-grained conglomerates and pebbly sandstones with low-angle asymptotic cross-stratification (Figures 6, 7B). Large clasts in this facies appear floating in a medium- to coarse-grained sandstone matrix. Individual sets of cross-bedding commonly show thicknesses between 0.3 (1 ft) and 1 m (3.2 ft) and asymptotic relationships with top and base (Figure 8C). The foreset inclination in general does not exceed 20°. Depending on the rate of sediment fallout from the overpassing turbulent flow, bedset-bounding surfaces can be erosional (like an anisotropic hummocky cross-stratification) or transitional (Figure 6), conforming with climbing dunes (in the sense of Mutti et al., 1996). Field observations suggest a close association of this facies with channel-fill deposits. In gravel-free systems, facies B2 is almost entirely composed of medium- to coarse-grained sandstones (Figure 8C, D), commonly displaying abundant clay clasts in the lower foreset. This sandstone variety is termed facies B2s. If clay clasts are numerous and of small size, this structure can easily be confused with a tidal bundle (Figure 8C). The key for a correct interpretation resides in differentiating the small clay clasts from a true mud couplet. Like facies B2, facies B2s relates to the migration of straight or sinuous bed forms at the base of a long-lived turbulent flow carrying high suspended load.

#### *Facies B3*

Facies B3 is characterized by coarse-grained to pebbly sandstones with diffuse horizontal to subhorizontal stratification and levels of small aligned pebbles (Figures 6; 7C, D). Pebbles in general do not exceed 10 mm in diameter and seem dispersed in a coarse-grained sandstone matrix. The sandy variety

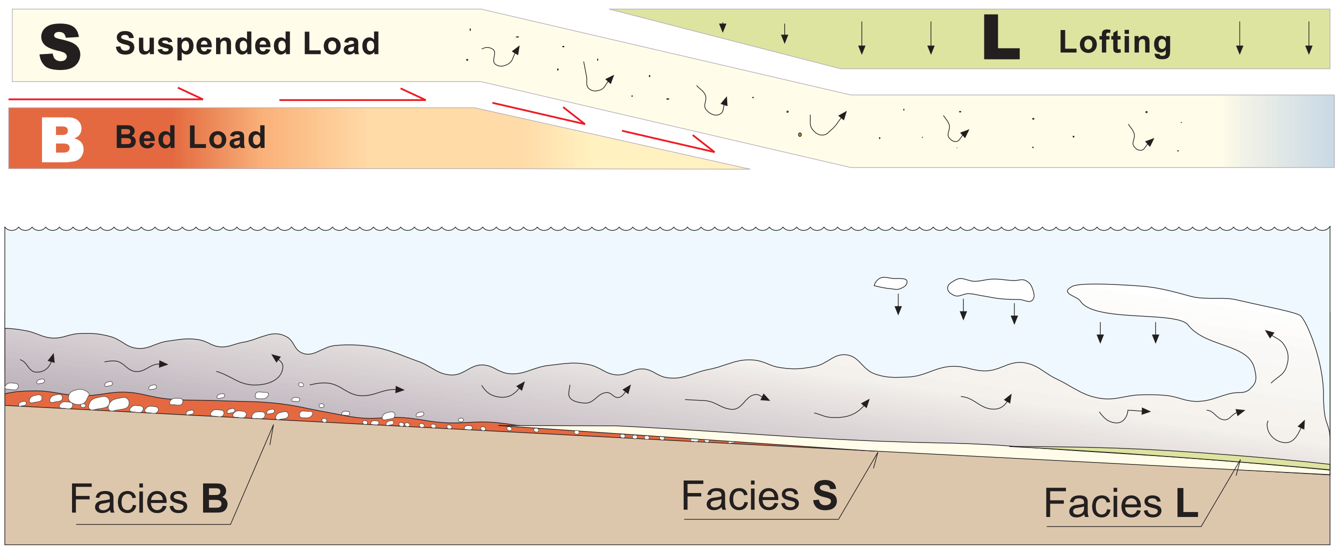



**FIGURE 5.** **Basic conceptual diagram for the origin of the genetic facies deposited from sustained hyperpycnal flows in a marine environment. Facies B include all those facies related to bed-load processes developed at the base of an overpassing long-lived turbulent flow. Facies S correspond to the gravitative collapse of sand-size materials transported in suspension by the turbulent flow (suspended-load facies). Facies L are related to the fallout of fine-grained materials lifted up in the interstitial fresh water contained in the flow once it has lost part of the sand-size suspended load. After Zavala et al. (2006b); Zavala, 2008; and Zavala et al., 2011.**

of this facies (facies B3s) is characterized by aligned clay clasts and plant fragments (Figure 8B). Facies B3 comprises tabular to lenticular bodies commonly filling erosive depressions. It is interpreted that these facies accumulated by the combined effect of bed load and the gravitational segregation of sandstone materials transported in the overpassing hyperpycnal turbulent flow. In shallow-water settings, B3 facies may display low-angle diverging and truncated laminae that closely resemble gravelly hummocky cross-stratification (facies B3h in Figure 6). Mutti et al. (1994) suggested that subaerially derived gravity flows may develop an internal oscillatory component during their downslope motion through the setting in motion of standing bodies of water in the shallower parts of the receiving basin.

### *Facies Related to the Collapse of Suspended Load (Facies S)*

Facies S are mostly fine grained and composed of sediments transported as suspended load, forming thick and commonly complex intervals that can be massive or display traction plus fallout sedimentary structures.

#### *Facies S1*

Facies S1 is one of the most common within the facies tract of hyperpycnal systems. This facies is composed of tabular fine- to medium-grained massive sandstone beds (Figure 6). These sandstones commonly integrate monotonous and very thick successions, internally showing subtle and gradual grain-size variations (Figure 9A). Small floating clay chips are common and could seem dispersed within the sandstone body or grouped toward the top at the boundary with facies related to more diluted flows (facies S2). Carbonaceous remains and wood fragments are also common within massive sands, commonly displaying leaf fragments with exceptional preservation. Leaves in massive sands can be very abundant and have been proposed as the main source of hydrocarbons in the Kutei Basin, Indonesia (Saller et al., 2006). The S1 facies mostly lack any bioturbation. Nevertheless, some massive very thick intervals show isolated *Ophiomorpha* and *Thalassinoides*, which can be related to crustaceans (doomed pioneers), bulked and transported by the turbulent flow from shallower areas (Grimm and Föllmi, 1994).

The origin of this facies would be related to the progressive aggradation from the bottom by long-lived flows having high suspended load (Sanders, 1965; Kneller and Branney, 1995; Camacho et al., 2002). This progressive aggradation has been proposed as a mechanism that inhibits the formation of primary sedimentary structures. Massive deposits could therefore be caused by the absence of a sharp boundary between the moving flow and the deposit, probably related to a zone of aggrading transition

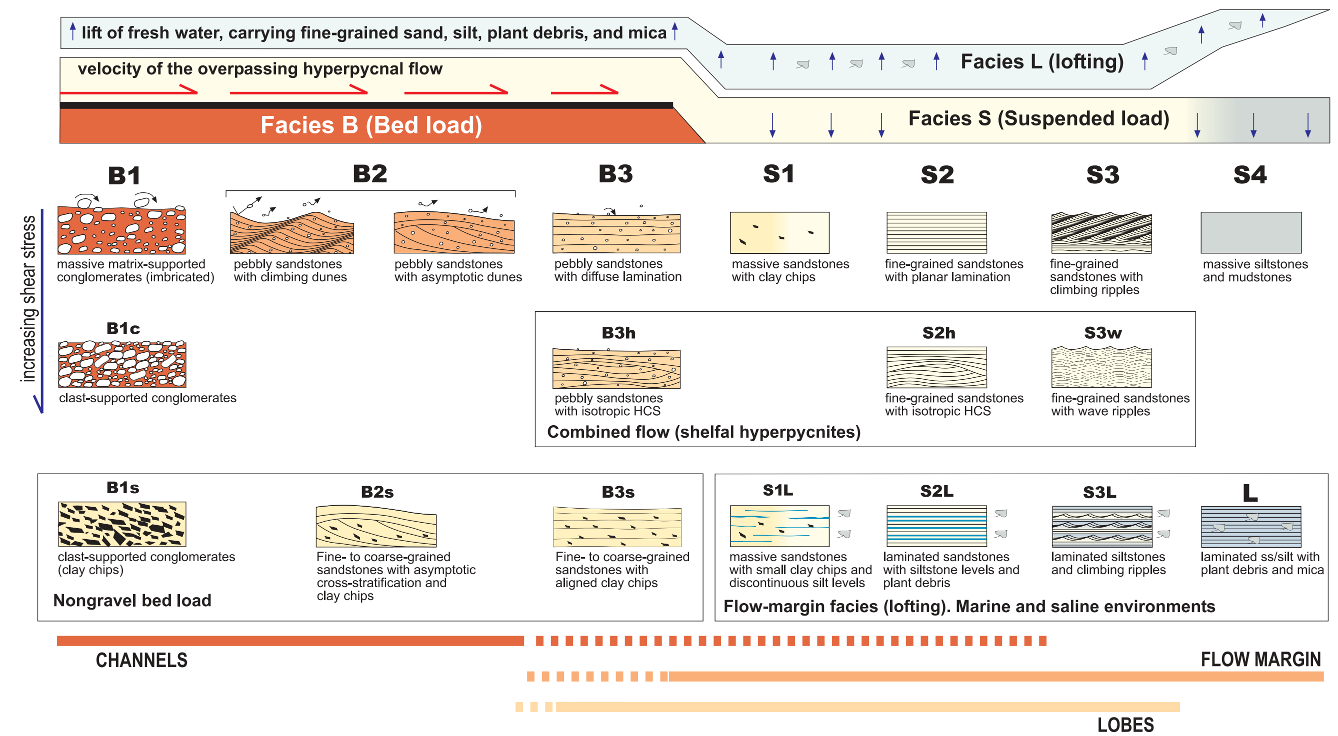



**FIGURE 6.** **Conceptual schema for the genetic classification of clastic facies associated with hyperpycnal systems. Type B facies relate to bed-load processes at the base of an overpassing long-lived turbulent flow. Type S facies originate from the gravitative collapse of sand-size suspended materials carried in the turbulent flow. Facies L are composed of very fine-grained sandstones interbedded with laminated silts with abundant plant debris and mica, accumulated by fallout from lofting plumes. Facies L are exclusive of marine/saline environments. HCS = hummocky cross-stratification; ss/silt = sandstone/silt. After Zavala et al., 2006b; Zavala, 2008; and Zavala et al., 2011.**

characterized by high sediment concentration and water escape. Experimental studies (Arnott and Hand, 1989; Sumner et al., 2008) indicate that this facies originates from a turbulent flow with fallout rates greater than 0.44 mm/s. For smaller fallout rates at similar flow velocities, the result will be laminated sands similar to facies S2 (Figure 9B). In structurally controlled depocenters, the individual thickness of single massive sandstone bodies can be very impressive (Amy et al., 2007), in some cases exceeding 45 m (148 ft) (Arcuri and Zavala, 2007, 2008).

### *Facies S2*

Facies S2 is composed of tabular fine-grained sandstone bodies having subhorizontal parallel lamination (facies S2) or internally low-angle diverging (hummocky-like) lamination (facies S2h) disposed over a sharp or transitional boundary. Individual laminae are millimeter thick and in some cases are bounded by thin levels with micas and carbonaceous material.

Facies S2 is commonly associated with parting and other current lineation structures such as those associated with heavy minerals. The origin of this facies has been related to dilute unidirectional flows at the upper flow regime (Simons et al., 1965). However, Sanders (1965) noted that parallel lamination commonly grades laterally into climbing ripples, suggesting a common origin of traction plus fallout processes. This last conclusion is also consistent with the experimental results of Arnott and Hand (1989) and Sumner et al. (2008), and it is also supported by the common association of facies S2 with massive intervals (facies S1) (Figure 9B) commonly constituting very thick rhythmical successions. The low-angle variety (facies S2h) is more common in shallow hyperpycnal systems and is similar to the isotropic hummocky cross-stratification related to combined flow (Harms et al., 1975, 1982; Southard, 1991; Mutti et al., 1994).

### *Facies S3*

Facies S3 is composed of tabular to irregular fine-grained sandstone bodies with climbing ripples (Figures 6, 9C). This facies has been related to traction plus fallout processes from waning turbulent flows with high suspended load (Jopling and Walker, 1968; Mulder and Alexander, 2001; Sumner et al.,

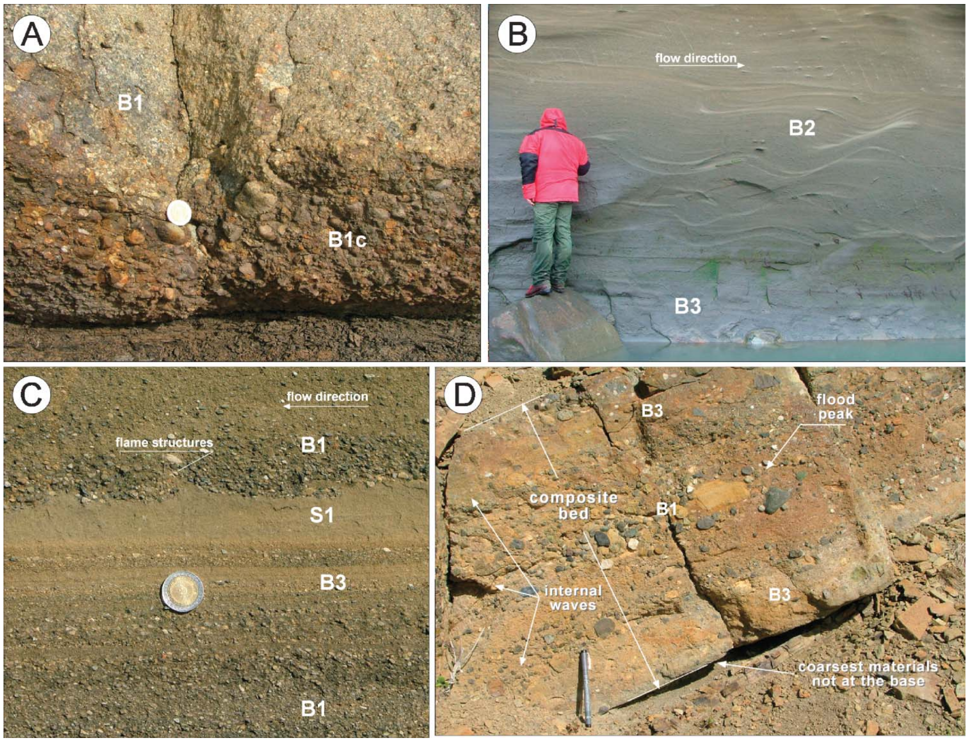



**FIGURE 7.** Main characteristics of coarse-grained deposits related to bed-load processes associated with sustained hyperpycnal flows. (A) Clast-supported conglomerates (facies B1c) followed by matrix-supported conglomerates (facies B1), suggesting a decrease in the shear stress. Outer-shelf deposits (early Jurassic), Neuquén Basin, Argentina. (B) Large-scale cross-bedding associated with climbing dunes (facies B2). Deep-marine deposits, Miocene of the Austral Basin, Argentina. (C) Gradual passage between facies B1, B3, and S1, suggesting variations in flow conditions associated with long-lived hyperpycnal flows. Flames at the top of facies S1 indicate almost continuous deposition of facies B1. Deep-marine deposits, Miocene of the Austral Basin, Argentina. (D) Detail showing the internal complexity of a coarse-grained hyperpycnite (composite bed). Gradual changes in texture and sedimentary structures suggest long-lived and fluctuating flows. Shelfal deposits (middle Jurassic), Neuquén Basin, Argentina.

2008). Facies S3 commonly grades horizontally and vertically with facies S2 (Sanders, 1965; Zavala et al., 2006a), thus evidencing a common origin for both facies, controlled by fluctuations in the velocity of the overpassing turbulent flow. Gradual fluctuations in the flow velocity (in this case indicated by the gradual passage between facies S2 and S3) and in the rate of sediment fallout (passage between facies S1 and S2) are diagnostic elements of long-lived turbulent flow with fluctuating energy. The location of these elements in a subaqueous setting suggests the existence of a hyperpycnal system (Zavala et al., 2006a). In shallow-water environments affected by combined flows, ripples can show aggrading wave structures (facies S3w) (Figure 6), suggesting sediment fallout associated with unidirectional to oscillatory flows.

### Facies S4

Facies S4 is characterized by massive to laminated siltstones and mudstones. It is composed of the finest materials transported by the hyperpycnal flow, which accumulated by normal settling when the flow completely stopped. Consequently, facies S4 is useful to identify boundaries between different hyperpycnal events. The differentiation of facies S4 from prodelta/shelfal mudstones may be difficult and sometimes requires micropaleontological studies because facies S4 commonly contains continental/shallow-water species. In the absence of microfossils, facies S4 is characteristic of nonmarine hyperpycnal deposits because, in marine settings, fine-grained materials are lofted up by the lighter interstitial fluid and accumulate as facies L.

## Facies Related to Flow Lofting (Facies L)

### Facies L

Facies L is characterized by thin couplets of siltstones and sandstones having great lateral extension and commonly showing abundant intercalations of plant debris (Figures 6, 9D) and micas. These couplets

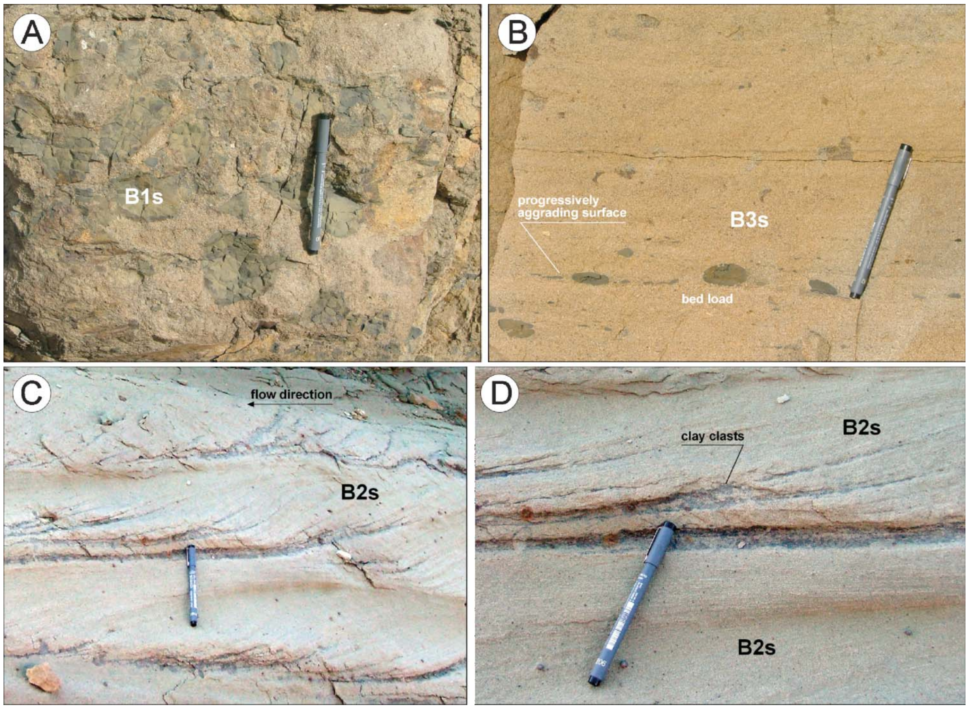



**FIGURE 8.** Bed-load facies in sand-bearing hyperpycnal systems. (A) Massive conglomerates composed of clay clasts (facies B1s). Early Jurassic outer-shelf deposits, Neuquén Basin, Argentina. (B) Coarse-grained sandstones with aligned clay clasts (facies B3s). Early Jurassic outer-shelf deposits, Neuquén Basin, Argentina. (C) Cross-bedded facies related to migrating sand dunes at the base of an overpassing long-lived hyperpycnal flow (facies B2s). Cross-bedding is low angle and asymptotic and can be easily confused with tidal bundles. The main difference resides in the fact that in these dunes, dark horizons are small clay clasts and not mud couplets such as in tidal deposits. (D) Close-up of picture C, showing a detail of clay clasts levels. Lower Jurassic shallow lacustrine strata, Neuquén Basin, Argentina.

display abundant small-scale load-cast structures, commonly associated with syneresis cracks and siderite nodules. Trace fossils are scarce and mostly limited to some forms of *Palaeophycus*. These laminated levels can form isolated bedsets up to 2 m (6.6 ft) thick or be located alternating at the top of facies B or S, but they are more commonly associated with massive sandstones (facies S1) (Figure 9D). The individual levels commonly display a variable thickness from a few millimeters up to 1 cm (0.39 in.) and are separated

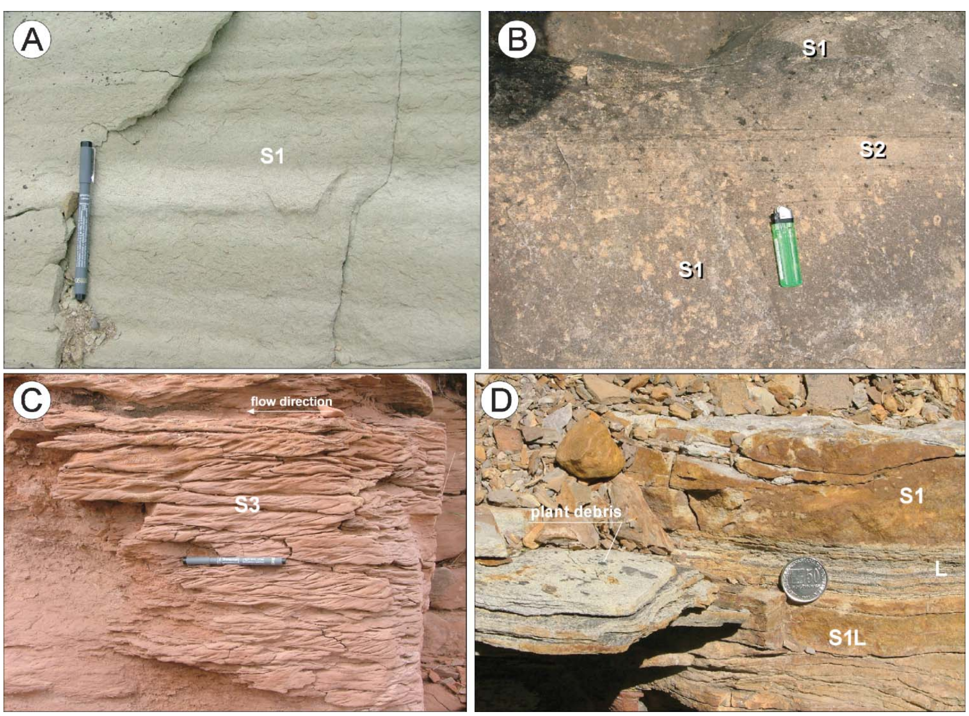



**FIGURE 9.** Main facies types associated with fallout from sustained turbulent suspensions. (A) Massive sandstones (facies S1). The diffuse banding marks the different positions of the rising depositional surface. Middle Jurassic, Neuquén Basin, Argentina. (B) Laminated sandstones (facies S2). The gradual passage between massive and laminated sandstones probably relates to variations in the fallout rate. Shelfal deposits, Late Cretaceous of Burgos Basin, Mexico. (C) Climbing ripples (facies S3). Shallow lacustrine deposits. Early Cretaceous of the Neuquén Basin, Argentina. (D) Lofting rhythmites (facies L) interbedded within massive sandstones. Shelfal deposits. Late Oligocene of the eastern Venezuela Basin, Venezuela.

by thin layers with abundant plant debris (Figure 9D). Plant debris provides definitive evidence of a direct connection between the fluvial system and the marine-related basin (Petter and Steel, 2005; Lamb et al., 2008). The absence of tractive structures in these sandstones suggests an accumulation by normal settling from a suspension cloud elevated over the depositional surface. Based on the contributions of Sparks et al. (1993), Mutti et al. (2003), and Hesse et al. (2004), these materials are interpreted to be related to the accumulation of the finest materials transported by the hyperpycnal flow, which settled from a lofting plume (Zavala et al., 2008b). Facies L constitutes a diagnostic and characteristic element of hyperpycnal sedimentation in a marine environment because it suggests the existence of a less dense interstitial fluid (fresh water) with respect to that of the environment (marine water), derived from direct fluvial discharge (Zavala et al., 2006c). Vertical and lateral relationships between L and S (S1, S2, and S3) facies are not sharp and result in transitional categories (Figure 6) termed S1L (massive sandstones with discontinuous siltstone levels) (Figure 9D), S2L (laminated sandstones with abundant plant debris and micas), and S3L (siltstone levels interbedded with sandstones having small climbing ripples).

## THE LOFTING POINT

The lofting point (LP) is the position in which the hyperpycnal flow reverses its negative buoyancy as a consequence of the progressive loss of suspended load by deposition out of the flow. The velocity threshold for the LP could be quite variable because the hyperpycnal flow is a heterogeneous mixture composed of buoyant and load components (Figure 10).

The buoyant component is provided by the density difference between fresh water and other light materials (e.g., plant debris) with respect to the more dense ambient (marine) water. The load component, however, is related to the heaviest materials transported in suspension by the hyperpycnal flow (fine-grained sand, silt, and mud). If the load component is greater than the buoyant component, the flow will follow along the basin floor. Nevertheless, the load component at the flow head will decay because the amount of sand material in turbulent suspension will decrease by deposition as the flow progressively wanes. The velocity threshold for the flow lift-up (LP) will therefore depend on the amount of clay in suspension because clay content will remain constant until the flow stops completely. Consequently, in flows having a low clay content, buoyancy reversal will occur early at faster velocities, preventing in some cases the development of plane beds and climbing ripples at the top of massive intervals (Mutti et al., 2003). The buoyancy reversal of hyperpycnal flows (lofting) is very sensitive to velocity changes. Velocity changes in a hyperpycnal flow occur not only in the flow direction, but also laterally as the flow spreads across the sea floor (Zavala et al., 2006a), favoring deposition of lofting facies (or lofting rhythmites; Zavala et al., 2006c) at flow margins (Figure 11).

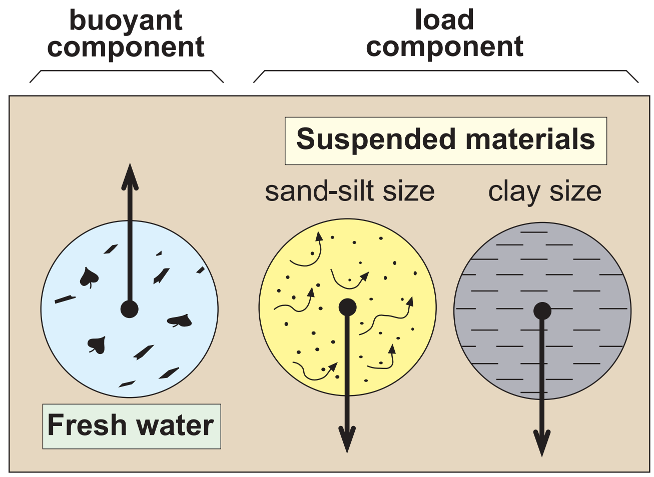



**FIGURE 10. Buoyant and load components as the basic constituents of a turbulent hyperpycnal flow. The buoyant component results from the density difference between fresh water and ambient marine waters. If the load component is greater than the buoyant component, the flow will move along the basin floor. Nevertheless, the load component will decay in time because the amount of sand in turbulent suspension will decrease as the flow wanes, favoring buoyancy reversal (lofting).**

The position of the LP is not fixed. The LP will move basinward or landward depending on the magnitude and concentration of the sustained hyperpycnal discharge. Almost all sustained hyperpycnal flows are triggered from an initial hypopycnal (''normal'') delta stage (1 in Figure 12). As the fluvial discharge increases, the bulk concentration of the incoming flow will rise exponentially (Mulder et al., 2003). When the density of the fluvial discharge equals that of seawater, a transitional homopycnal flow will develop (2 in Figure 12). In stages 3 and 4 (Figure 12), a fluvial discharge with a progressively increasing density exceeds that of seawater. The flow therefore has plunged below marine waters and has started its travel basinward as a sustained hyperpycnal flow. The sinking of fluvial waters in the sustained hyperpycnal flow has two important consequences.

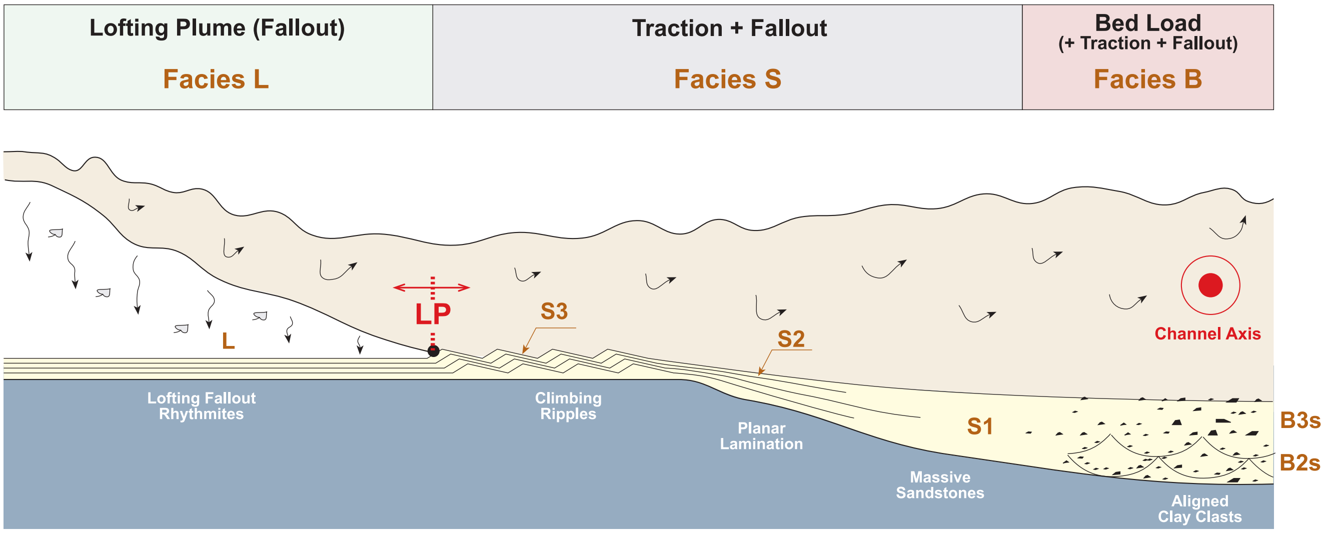



**FIGURE 11.** **Diagram showing the lateral relationships between channel and levee deposits. Note that as a consequence of drastic velocity variations recognized between the channel axis and adjacent levees, facies changes tend to show the entire facies association within a short distance. This facies association is the same as that expected to occur for hundreds of kilometers in the longitudinal direction. Note that lofting rhythmites are typical of flow-margin areas. LP = lofting point.**

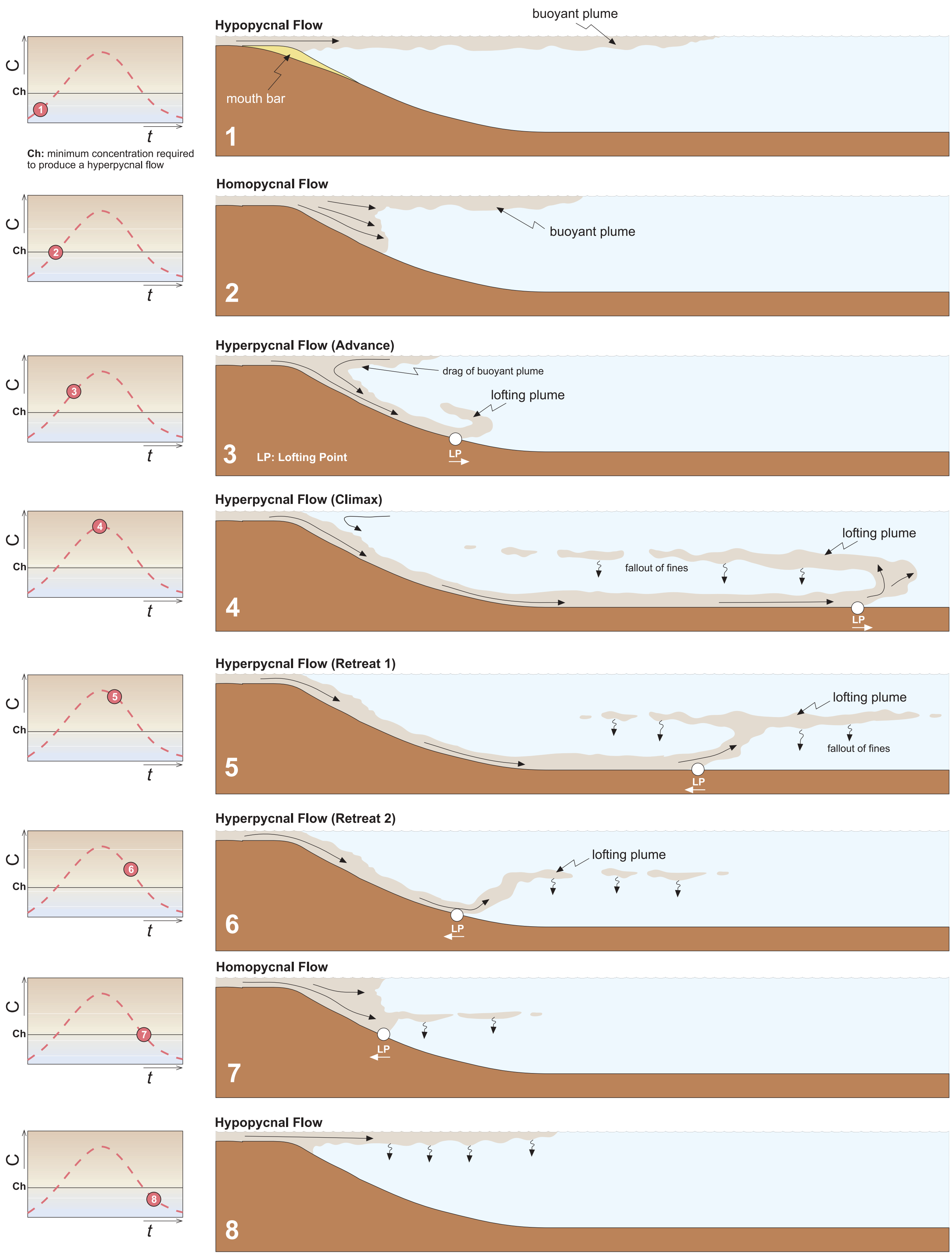
The first consequence is related to the downwelling effect with the ensuing suppression of the surficial buoyant plume previously developed contemporaneously with the hypopycnal delta. As a result, fine-grained light materials contained in the flow, including plant debris suspended in the previous buoyant plume, will be suctioned and dragged basinward with the sustained hyperpycnal flow. Once the surficial plume disappears, the dragging effect provided by the sinking hyperpycnal flow continues, thus generating a marked contrast between the dirty (by sediment load) fluvial discharge and the clear waters of the basin (Mulder et al., 2003).

The second consequence is related to the less dense interstitial fluid contained in the hyperpycnal flow, which will cause a reversal of the flow density at the LP. In the flow head, the LP is characterized by a lift-up effect associated with a sudden flow deceleration. Consequently, the advancing density flow tends to move beneath the lofting plume that contains the finest and lightest materials transported by the hyperpycnal flow (including plant debris and micas). The lofting plume will have a great lateral dispersion with respect to the more confined hyperpycnal flow. Sediments will be deposited from fallout, forming characteristic sand/silt couplets (facies L) or lofting rhythmites (Zavala et al., 2006c, 2008b). The reversing buoyancy effect (lofting) at the hyperpycnal flow margin will result in less lateral continuity of sandstone bodies compared with those related to resedimentation processes, with important consequences for the case of sandstone reservoirs.

Once the density of the incoming flow begins to decay, the LP will move progressively landward (5–6 in Figure 12). This retraction can be simple and continuous or it can be a series of forward-backward pulses related to a more dynamic long-lived hyperpycnal flow with fluctuating energy. Finally, when the flow density returns to the normal low-density values, the fluvial-deltaic system will evolve into homopycnal (7 in Figure 12) and then hypopycnal (8 in Figure 12) conditions (littoral delta).

## COMPOSITE BEDS AND HYPERPYCNAL DEPOSITS

The complex nature of the fluvial drainage network associated with medium to large rivers results in long-lived discharges (floods) having very complex hydrographs. This complexity is commonly reflected in the associated hyperpycnal deposits and results in the accumulation of internally highly complex sedimentary bodies. Hyperpycnal flows related to long-lasting floods have short- and long-term variations not only in the flow speed, but also in the concentration of the overpassing flow. These variations can be clearly read from the fossil record in single beds that internally show gradual and sharp facies transitions without having a definite and predictable internal arrangement (Figures 13, 14). The resulting


C
Ch
t
Ch: minimum concentration required to produce a hyperpycnal flow
Hypopycnal Flow
buoyant plume
mouth bar
1
Homopycnal Flow
buoyant plume
2
Hyperpycnal Flow (Advance)
drag of buoyant plume
lofting plume
3
LP: Lofting Point
LP
Hyperpycnal Flow (Climax)
lofting plume
fallout of fines
4
Hyperpycnal Flow (Retreat 1)
lofting plume
fallout of fines
5
Hyperpycnal Flow (Retreat 2)
lofting plume
6
Homopycnal Flow
7
Hypopycnal Flow
8

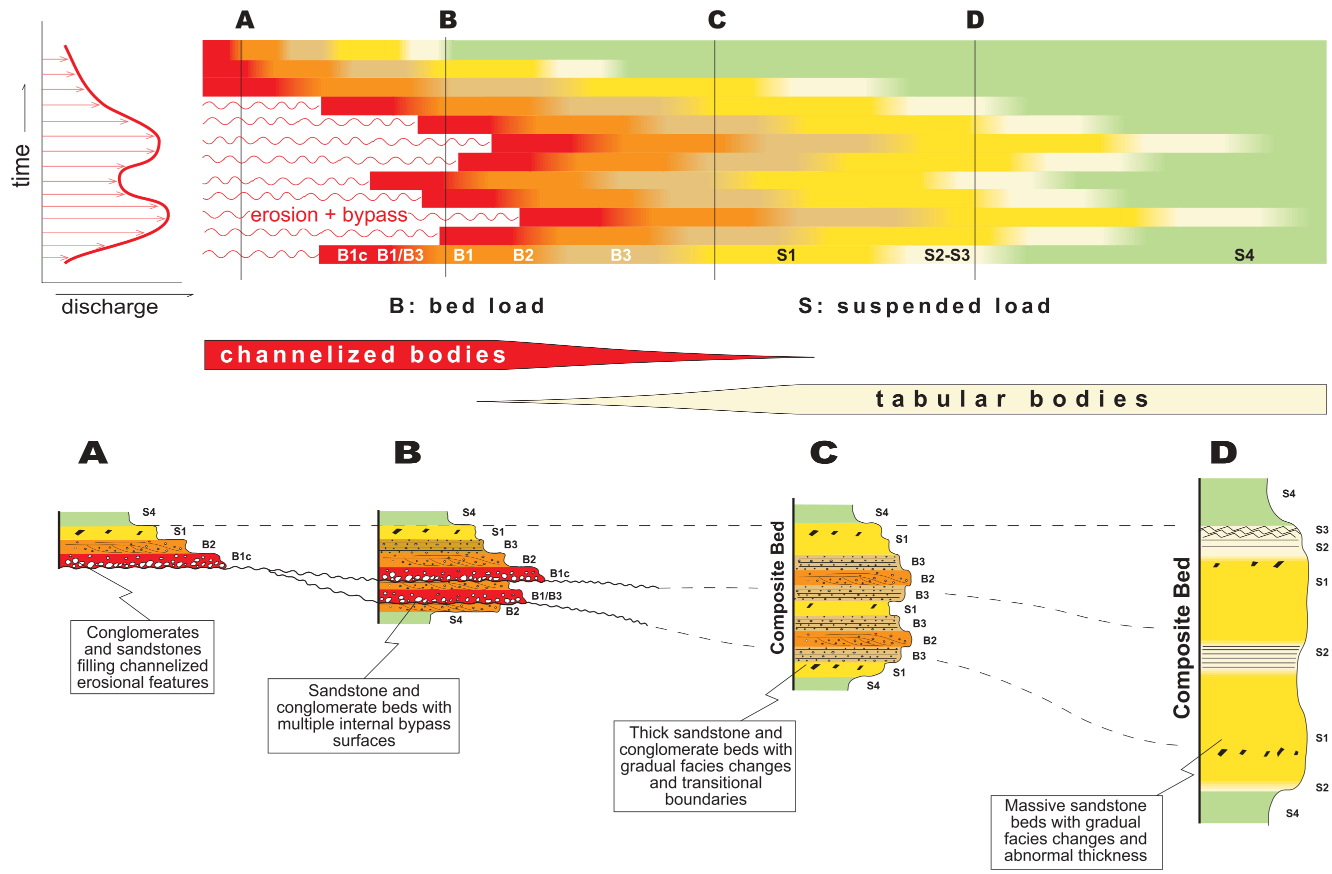



**FIGURE 13. The origin of a composite bed is related to variations in flow velocity and sediment concentration during a single long-lived hyperpycnal discharge. Note that the erosional surfaces do not always bound different events and grade basinward into nonerosional/transitional levels.**

sedimentary body is a composite bed (Zavala et al., 2007a). A composite bed is an internally complex depositional body accumulated during a single long-lived hyperpycnal discharge. Commonly, this body internally shows a facies arrangement that strongly departs from that expected for surgelike or episodic flows. Composite beds are typical and diagnostic features of long-lived hyperpycnal sedimentation because they indicate a deposit continuously fed by a long-lasting, fluctuating, and dilute sediment-gravity flow.

Composite beds typically display a vertical succession of different lithofacies showing cyclical recurrences and transitional to sharp passages between them. These cyclical and gradual changes between different facies are the result of near-continuous deposition from a quasi-steady turbulent flow. Composite beds can be very thick (up to 45 m [148 ft]) depending on the duration of the related hyperpycnal flow and the available accommodation space (Arcuri and Zavala, 2007, 2008). Other common attributes of composite beds include internal and laterally discontinuous erosional surfaces, scarce burrows, and a basal coarsening-upward interval. In marine environments, composite beds evolve laterally into packages of lofting rhythmites. Composite beds related to cyclical velocity variations are commonly characterized by recurrent facies changes that suggest different and recurrent equilibrium flow conditions (Zavala et al.,

**FIGURE 12. This figure depicts the whole conceptual evolution of a single sustained hyperpycnal discharge. In (1), the low density of the incoming flow results in a hypopycnal flow with an associated buoyant plume. In (2), the density of the incoming flow has reached that of seawater and consequently a homopycnal flow develops. In (3) and (4), the bulk density of the incoming flow has exceeded that of seawater. Consequently, fluvial waters sink, dragging by suction the buoyant plume previously developed, then the overlying waters. In (5) to (8), the density of the incoming flow progressively decreases. Consequently, the LP progressively moves landward and the deltaic system returns to the hypopycnal initial conditions. C = relative concentration of fluvial discharge; *t* = time.**

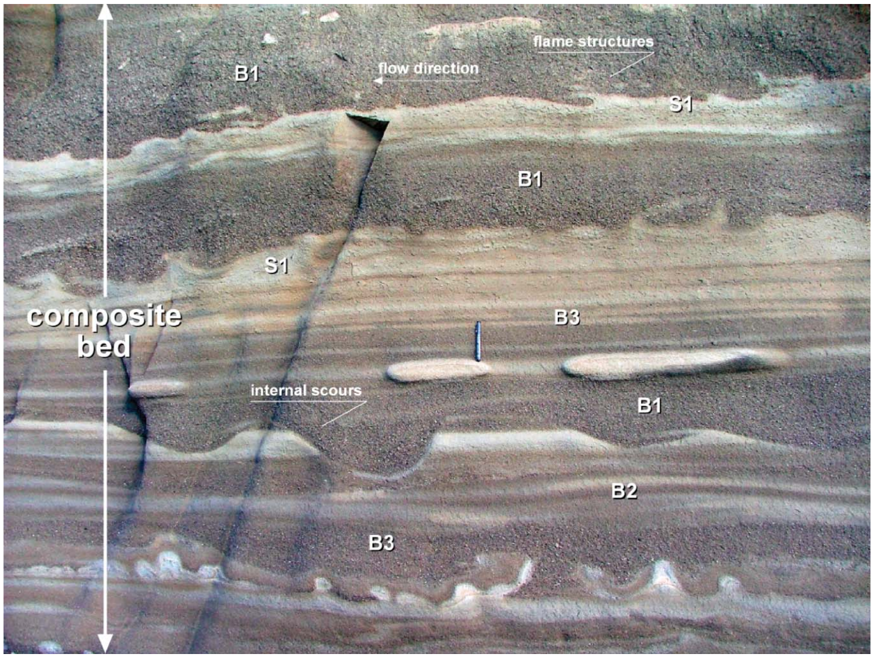



**FIGURE 14.** Some internal characteristics of composite beds. This composite bed lacks any bioturbation and is characterized by an impressive facies recurrence with abundant load casts. Flame structures indicate a flow direction from right to left. Deep-marine deposits, Miocene of the Austral Basin, Argentina.

2006a; Lamb et al., 2008; Lamb and Mohrig, 2009). As an example, the gradual vertical passage between climbing ripples and plane beds could be related to a velocity increase in the overpassing hyperpycnal flow (Zavala et al., 2006a). More commonly, composite beds related to sustained hyperpycnal flows show a very complicated internal arrangement, reflecting cyclic depositional changes between suspended-load- and bed-load-dominated facies associated with different velocity and fallout rates. The vertical anisotropy in facies and the relatively rapid accumulation result in the common occurrence of load cast and flame structures (Figure 14).

## SUMMARY AND CONCLUSIONS

The hyperpycnal system is a relatively new category of depositional system that corresponds to the subaqueous extension of the fluvial system. A single hyperpycnal system can extend for hundreds of kilometers away from the river mouth and will develop a predictable path of genetically related facies during its travel basinward. Three main categories of genetic facies are recognized in hyperpycnal systems corresponding to B (bed-load-related), S (suspended-load-related), and L (lofting-related) facies.

The B facies are related to bed-load processes (mostly sliding and rolling) developed at the base of a long-lived turbulent (hyperpycnal) flow and tend to dominate in proximal to medial parts of the hyperpycnal system. Three main types of B facies correspond to B1 (clast to matrix-supported massive conglomerates), B2 (pebbly sandstones with large-scale cross-bedding related to migrating climbing dunes), and B3 (pebbly sandstones with diffuse horizontal lamination).

The S facies comprise finer grained deposits related to the gravitative collapse of materials transported in suspension within the turbulent (hyperpycnal) flow. Four categories of S facies are recognized: S1 (massive sandstones), S2 (parallel to low-angle laminated sandstones), S3 (fine-grained sandstones with climbing ripples), and S4 (massive mudstones). The S4 facies are more common in lacustrine environments because in marine environments, muddy sediment is lifted up (lofted) with the less dense interstitial water as the flow wanes.

The L facies is composed of a rhythmic intercalation of thin beds of massive sands, silts, micas, and plant debris having great lateral continuity. The L facies develops exclusively in marine and saline environments and is related to the fallout of fine-grained sands, silts, micas, and plant debris from lofting plumes. Lofting plumes originate from the buoyant inversion induced by the lift-up of the less dense fresh water contained in the hyperpycnal flow as it progressively loses part of the suspended load by deposition.

All these facies categories are genetically related and occupy a definite position within the hyperpycnal system. The B facies is diagnostic of proximal areas and progressively disappears as the flow enters the area of lobe deposition. The S facies is the consequence of the loss of flow capacity and is typical of the medium to distal parts of the system. The L facies results from the flow inversion, which is diagnostic of flow-margin areas (both down the depositional axis and laterally along the axis).

This proposed facies tract is a first attempt to try to achieve a better understanding of hyperpycnal systems. Nevertheless, our understanding of these deposits is still very limited, and considerable effort will be required during future years to try to improve upon facies models, develop new sedimentologic tools, and assess the real importance of hyperpycnal deposits in the accumulation of ancient strata, including those associated with hydrocarbon reservoirs.

## ACKNOWLEDGMENTS

We thank all those people who generously contributed during the years to field discussions related to hyperpycnal sedimentation, particularly E. Mutti, E. Remacha, G. Davoli, D. DiBiase, H. Maretto, J.J. Ponce, H. Gamero, C. Contreras, M. Sanguinetti, J. Marcano, and J Carvajal. Field discussions with S. Pattison, C. Olariu, J. Bhattacharya, T. Mulder, S. Dasgupta, B. Romans, M. Perlmutter, and R. Higgs deeply contributed to improving this chapter. Roger Slatt carefully reviewed the manuscript, providing helpful comments and corrections. This research was partially funded by the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) of Argentina.

## REFERENCES CITED

Amy, L. A., B. Kneller, and W. D. McCaffrey, 2007, Facies architecture of the Grès de Peïra Cava, SE France: Landward stacking patterns in ponded turbiditic basins: Journal of the Geological Society (London), v. 164, p. 143–162, doi:10.1144/0016-76492005-019.

Antobreh, A. A., and S. Krastel, 2006, Morphology, seismic characteristics and development of Cap Timiris Canyon, offshore Mauritania: A newly discovered canyon preserved off a major arid climatic region: Marine and Petroleum Geology, v. 23, p. 37–59, doi:10.1016/j.marpetgeo.2005.06.003.

Arcuri, M., and C. Zavala, 2007, Very thick massive sandstone bodies: Origin and internal architecture: AAPG Annual Conference, session 3853, effects of active structural growth and confined basins on sandbody architecture I: AAPG Search and Discovery Article 90063, March 30 to April 4, 2007, Long Beach, California, 1 p., http://www.searchanddiscovery.net/abstracts/html/2007/annual/abstracts/lbArcuri.htm?q=%2Btext%3Aarcuri (accessed August 3, 2010).

Arcuri, M., and C. Zavala, 2008, Hyperpycnal shelfal lobes—Some examples of the Lotena and Lajas formations, Neuquen Basin, Argentina, *in* J. J. Ponce and E. B. Olivero, conveners, Sediment transfer from shelf to deepwater—Revisiting the delivery mechanisms: Conference Proceedings, AAPG Search and Discovery Article 50066, AAPG Hedberg Conference, March 3–7, 2008, Ushuaia-Patagonia, Argentina, 4 p., http://www.searchanddiscovery.net/documents/2008/08018arcuri/index.htm?q=%2Btext%3Aarcuri (accessed August 3, 2010)

Arnott, R. W. C., and B. M. Hand, 1989, Bedforms, primary structures and grain fabric in the presence of suspended sediment rain: Journal of Sedimentary Petrology, v. 69, p. 1062–1069.

Bates, C., 1953, Rational theory of delta formation: AAPG Bulletin, v. 37, p. 2119–2162.

Bouma, A. H., 1962, Sedimentology of some flysch deposits: A graphic approach to facies interpretation: Amsterdam, Netherlands, Elsevier, 168 p.

Bourget, J., S. Zaragosi, T. Mulder, J. L. Schneider, T. Garlan, A. Van Toer, V. Mas, and N. Ellouz-Zimmermann, 2010, Hyperpycnal-fed turbidite lobe architecture and recent sedimentary processes: A case study from the Al Batha turbidite system, Oman margin: Sedimentary Geology, v. 229, p. 144–159, doi:10.1016/j.sedgeo.2009.03.009.

Bruhn, C. H. L., and R. G. Walker, 1997, Internal architecture and sedimentary evolution of coarse-grained, turbidite channel-levee complexes, early Eocene Regencia Canyon, Espírito Santo Basin, Brazil: Sedimentology, v. 44, p. 17–46, doi:10.1111/j.1365-3091.1997.tb00422.x.

Camacho, H., C. J. Busby, and B. Kneller, 2002, A new depositional model for the classical turbidite locality at San Clemente State Beach, California: AAPG Bulletin, v. 86, p. 1543–1560.

Cheng-Shing, C., and Y. Ho-Shing, 2008, Evidence of hyperpycnal flows at the head of the meandering Kaoping Canyon off SW Taiwan: Geo-Marine Letters, v. 28, p. 161–169, doi:10.1007/s00367-007-0098-7.

Collins, M. B., 1986, Processes and controls involved in the transfer of fluviatile sediments to the deep ocean: Journal of the Geological Society (London), v. 143, p. 915–920, doi:10.1144/gsjgs.143.6.0915.

Deptuck, M. E., G. S. Steffens, M. Barton, and C. Pirmez, 2003, Architecture and evolution of upper fan channel-belts on the Niger Delta slope and in the Arabian Sea: Marine and Petroleum Geology, v. 20, p. 649–676, doi:10.1016/j.marpetgeo.2003.01.004.

De Rooij, F., and S. B. Dalziel, 2001, Time and space resolved measurements of deposition under turbidity currents, *in* B. McCaffrey, B. Kneller, and J. Peakall, eds., Particulate gravity currents: International Association of Sedimentologists Special Publication 31, p. 207–215.

Gamero, H., C. Zavala, and C. Contreras, 2005, A reinterpretation of the Misoa facies types: Implications of a new depositional model, Maracaibo Basin, Venezuela (abs.): AAPG Search and Discovery Article 90046, 2005 AAPG International Conference and Exhibition, Evolving Stratigraphic Techniques and Interpretation III, Paris, 1 p., http://www.searchanddiscovery.net/documents/abstracts/2005intl_paris/gamero.htm (accessed August 3, 2010).

Gamero, H., J. Reader, C. Izatt, C. Zavala, and C. Contreras, 2007, Herrera sandstones in the southern basin area, Trinidad: Evidence of hyperpycnites deposited away from ancient Oficina delta systems in eastern Venezuela: AAPG Search and Discovery Article 90063, Annual AAPG Convention, April 2–5, 2007, Long Beach, California, 1 p., http://www.searchanddiscovery.net/abstracts/html/2007/annual/abstracts/lbGamero.htm?q=%2Btext%3Agamero (accessed August 3, 2010).

Gamero, H., N. Lewis, R. Welsh, C. Zavala, and C. Contreras, 2008, Evidences of a shelfal hyperpycnal deposition in the Pliocene sandstones in the Oilbird field, SE coast, Trinidad: Impact on reservoir distribution and field redevelopment, *in* J. J. Ponce and E. B. Olivero, conveners, Sediment transfer from shelf to deepwater—Revisiting the delivery mechanisms: Conference Proceedings, AAPG Search and Discovery Article 90079, AAPG Hedberg Conference, March 3–7, 2008, Ushuaia-Patagonia, Argentina, 4 p., http://www.searchanddiscovery.net/abstracts/html/2008/hedberg_argentina/extended/gamero/gamero.htm?q=%2Btext%3Azavala (accessed August 3, 2010).

Gervais, A., T. Mulder, B. Savoye, and E. Gonthier, 2006, Sediment distribution and evolution of sedimentary processes in a small sandy turbidite system (Golo system, Mediterranean Sea): Implications for various geometries based on core framework: Geo-Marine Letters, v. 26, p. 373–395, doi:10.1007/s00367-006-0045-z.

Grimm, K. A., and K. B. Föllmi, 1994, Doomed pioneers: Allochthonous crustacean tracemakers in anaerobic basinal strata, Oligo-Miocene San Gregorio Formation, Baja California Sur, Mexico: Palaios, v. 9, p. 313–334, doi:10.2307/3515054.

Guzmán, O., and C. Campos, 2008, The Pampatar Formation (Margarita Island, Venezuela): A result of gravity flows in deep marine water, *in* J. J. Ponce and E. B. Olivero, conveners, Sediment transfer from shelf to deepwater—Revisiting the delivery mechanisms: Conference Proceedings, AAPG Search and Discovery Article 50070, AAPG Hedberg Conference, March 3–7, 2008, Ushuaia-Patagonia, Argentina, 7 p., http://www.searchanddiscovery.com/abstracts/html/2008/hedberg_argentina/extended/guzman/guzman.htm (accessed August 3, 2010).

Harms, J. C., J. B. Southard, D. R. Spearing, and R. G. Walker, 1975, Depositional environments as interpreted from primary sedimentary structures and stratification sequences: SEPM Short Course Notes no. 2, 161 p.

Harms, J. C., J. B. Southard, and R. G. Walker, 1982, Structures and sequences in clastic rocks: SEPM Short Course Notes no. 9, 249 p.

Hesse, R., and S. Khodabakhsh, 1998, Depositional facies of late Pleistocene Heinrich events in the Labrador Sea: Geology, v. 26, p. 103–106, doi:10.1130/0091-7613(1998)026<0103:DFOLPH>2.3.CO;2.

Hesse, R., and S. Khodabakhsh, 2006, Significance of fine-grained sediment lofting from melt-water generated turbidity currents for the timing of glaciomarine sediment transport into the deep sea: Sedimentary Geology, v. 186, p. 1–11, doi:10.1016/j.sedgeo.2005.10.006.

Hesse, R., H. Rashid, and S. Khodabakhsh, 2004, Fine-grained sediment lofting from meltwater-generated turbidity currents during Heinrich events. Geology, v. 32, p. 449–452, doi:10.1130/G20136.1.

Johnson, K. S., C. K. Paull, J. P. Barry, and F. P. Chavez, 2001, A decadal record of underflows from a coastal river into the deep sea: Geology, v. 29, p. 1019–1022, doi:10.1130/0091-7613(2001)029<1019:ADROUF>2.0.CO;2.

Jopling, A. V., and R. G. Walker, 1968, Morphology and origin of ripple-drift cross lamination, with examples of Pleistocene of Massachusetts: Journal of Sedimentary Petrology, v. 38, p. 971–984.

Joseph, P., and S. A. Lomas, 2004, Deep-water sedimentation in the Alpine Foreland Basin of SE France: New perspectives on the Grés d'Annot and related systems—An introduction, *in* P. Joseph and S. A. Lomas, eds., Deep-water sedimentation in the Alpine Basin of SE France: New perspectives on the Grés d'Annot and related systems: Geological Society (London) Special Publication 221, p. 1–16.

Kassem, A., and J. Imran, 2001, Simulation of turbid underflows generated by the plunging of a river: Geology, v. 29, p. 655–658, doi:10.1130/0091-7613(2001)029<0655:SOTUGB>2.0.CO;2.

Klaucke, I., B. Savoye, and P. Cochonat, 2000, Patterns and processes of sediment dispersal on the continental slope of Nice, SE France: Marine Geology, v. 162, p. 405–422, doi:10.1016/S0025-3227(99)00063-8.

Knapp, R. T., 1943, Density currents: Their mixing characteristics and their effect on the turbulence structure of the associated flow: Proceedings of the Second Hydraulics Conference: University of Iowa Studies in Engineering, Bulletin, v. 27, p. 289–306.

Kneller, B., and M. Branney, 1995, Sustained high-density turbidity currents and the deposition of thick massive sands: Sedimentology, v. 42, p. 607–616, doi:10.1111/j.1365-3091.1995.tb00395.x.

Lamb, M. P., and D. Mohrig, 2009, Do hyperpycnal-flow deposits record river-flood dynamics?: Geology, v. 37, p. 1067–1070, doi:10.1130/G30286A.1.

Lamb, M. P., P. M. Myrow, C. Lukens, K. Houck, and J. Strauss, 2008, Deposits from wave-influenced turbidity currents: Pennsylvanian Minturn Formation, Colorado, U.S.A.: Journal of Sedimentary Research, v. 78, p. 480–498, doi:10.2110/jsr.2008.052.

Lowe, D. R., 1979, Sediment gravity flows: Their classification and some problems of application to natural flows and deposits: SEPM Special Publication 27, p. 75–82.

Lowe, D. R., 1982, Sediment gravity flows: II. Depositional models with special reference to the deposits of high-density turbidity currents: Journal of Sedimentary Petrology, v. 52, p. 279–297.

Mansurbeg, H., M. A. K. El-ghali, S. Morad, and P. Plink-Björklund, 2006, The impact of meteoric water on the diagenetic alterations in deep-water, marine siliciclastic turbidites: Journal of Geochemical Exploration, v. 89, p. 254–258, doi:10.1016/j.gexplo.2006.02.001.

Manville, V., and J. D. L. White, 2003, Incipient granular mass flows at the base of sediment-laden floods, and the roles of flow competence and flow capacity in the deposition of stratified bouldery sands: Sedimentary Geology, v. 155, p. 157–173, doi:10.1016/S0037-0738(02)00294-4.

Migeon, S., B. Savoye, N. Babonneau, and F. Spy Andersson, 2004, Processes of sediment-wave construction along the present Zaire deep-sea meandering channel: Role of meanders and flow stripping: Journal of Sedimentary Research, v. 74, p. 580–598, doi:10.1306/091603740580.

Migeon, S., T. Mulder, B. Savoye, and F. Sage, 2006, The Var turbidite system (Ligurian Sea, northwestern Mediterranean) morphology, sediment supply, construction of turbidite levee and sediment waves: Implications for hydrocarbon reservoirs: Geo-Marine Letters, v. 26, p. 361–371, doi:10.1007/s00367-006-0047-x.

Mulder, T., and J. Alexander, 2001, The physical character of subaqueous sedimentary density flows and their deposits: Sedimentology, v. 48, p. 269–299, doi:10.1046/j.1365-3091.2001.00360.x.

Mulder, T., and J. P. M. Syvitski, 1995, Turbidity current generated at river mouths during exceptional discharges to the world oceans: Journal of Geology, v. 103, p. 285–299, doi:10.1086/629747.

Mulder, T., S. Migeon, B. Savoye, and J. C. Faugéres, 2001a, Inversely graded turbidite sequences in the deep Mediterranean: A record of deposits from flood-generated turbidity currents?: Geo-Marine Letters, v. 21, p. 86–93, doi:10.1007/s003670100071.

Mulder, T., S. Migeon, B. Savoye, and J. M. Jouanneau, 2001b, Twentieth century floods recorded in the deep Mediterranean sediments: Geology, v. 29, p. 1011–1014, doi:10.1130/0091-7613(2001)029<1011:TCFRIT>2.0.CO;2.

Mulder, T., J. P. M. Syvitski, S. Migeon, J. C. Faugéres, and B. Savoye, 2003, Marine hyperpycnal flows: Initiation, behavior and related deposits: A review: Marine and Petroleum Geology, v. 20, p. 861–882, doi:10.1016/j.marpetgeo.2003.01.003.

Mutti, E., 1992, Turbidite sandstones: AGIP-Istituto di Geologia Università di Parma, San Donato Milanese, 275 p.

Mutti, E., and F. Ricci Lucchi, 1972, Le torbiditi dell'Appennino Settentrionale: Introduzione all'analisi di facies: Memorie della Società Geologica Italiana, v. 11, p. 161–199.

Mutti, E., G. Davoli, and R. Tinterri, 1994, Flood-related gravity-flow deposits in fluvial and fluvio-deltaic depositional systems and their sequence-stratigraphic implications, *in* H. W. Posamentier and E. Mutti, eds., Second high-resolution sequence stratigraphy conference, Tremp, Abstract Book: Italy, Istituto di Geologia, Universita di Parma, p. 137–143.

Mutti, E., G. Davoli, R. Tinterri, and C. Zavala, 1996, The importance of ancient fluvio-deltaic systems dominated by catastrophic flooding in tectonically active basins: Memorie di Scienze Geologiche, Universita di Padova, v. 48, p. 233–291.

Mutti, E., N. Mavilla, S. Angella, and L. L. Fava, 1999, An introduction to the analysis of ancient turbidite basins from an outcrop perspective: AAPG Continuing Education Course Notes no. 39, p. 1–98.

Mutti, E., R. Tinterri, G. Benevelli, D. Di Biase, and G. Cavanna, 2003, Deltaic, mixed and turbidite sedimentation of ancient foreland basins: Marine and Petroleum Geology, v. 20, p. 733–755, doi:10.1016/j.marpetgeo.2003.09.001.

Mutti, E., D. Bernoulli, F. Ricci Lucchi, and R. Tinterri, 2009, Turbidites and turbidity currents from Alpine "flysch" to the exploration of continental margins: Sedimentology, v. 56, p. 267–318, doi:10.1111/j.1365-3091.2008.01019.x.

Myrow, P. M., M. P. Lamb, C. Lukens, and K. Houck, 2006, Paleohydraulic interpretations of wave-modified hyperpycnal flow deposits: American Geophysical Union, Fall Meeting 2006, Abstract PP23B-1763, v. 87, no. 52, 1 p.

Myrow, P. M., M. P. Lamb, C. Lukens, K. Houck, and J. Strauss, 2008, Proximal to distal facies relationships in deposits of wave-influenced hyperpycnal flows, *in* J. J. Ponce and E. B. Olivero, conveners, Sediment transfer from shelf to deepwater—Revisiting the delivery mechanisms: Conference Proceedings, AAPG Hedberg Conference, March 3–7, 2008, Ushuaia-Patagonia, Argentina, 5 p.

Nakajima, T., 2006, Hyperpycnites deposited 700 km away from river mouths in the Central Japan Sea: Journal of Sedimentary Research, v. 76, p. 59–72.

Normark, W. R., and D. J. Piper, 1991, Initiation processes and flow evolution of turbidity currents: Implications for the depositional record: SEPM Special Publication 46, p. 207–230.

Olariu, C., and J. P. Bhattacharya, 2006, Terminal distributary channels and delta front architecture of river-dominated delta systems: Journal of Sedimentary Research, v. 76, p. 212–233, doi:10.2110/jsr.2006.026.

Pattison, S., 2005, Isolated highstand shelf sandstone body of turbiditic origin, lower Kenilworth Member, Cretaceous Western Interior, Book Cliffs, Utah: Sedimentary Geology, v. 177, p. 131–144, doi:10.1016/j.sedgeo.2005.02.005.

Pattison, S., 2008, Role of wave-modified underflows in the across-shelf transport of fine-grained sediments: Examples from the Book Cliffs, Utah, *in* J. J. Ponce and E. B. Olivero, conveners, Sediment transfer from shelf to deepwater—Revisiting the delivery mechanisms: Conference Proceedings, AAPG Search and Discovery

Article 90079, AAPG Hedberg Conference , March 3–7, 2008, Ushuaia-Patagonia, Argentina, 4 p., http://www.searchanddiscovery.com/abstracts/html/2008/hedberg_argentina/extended/pattison/pattison.htm (accessed August 3, 2010).

Peakall, J., M. Felix, B. McCaffrey, and B. Kneller, 2001, Particulate gravity currents: Perspectives, *in* B. McCaffrey, B. Kneller, and J. Peakall, eds., Particulate gravity currents: International Association of Sedimentologists, Special Publication 31, p. 1–8.

Petter, A. L., and R. J. Steel, 2005, Deepwater-slope channels and hyperpycnal flows from the Eocene of the central Spitsbergen Basin: Predicting basin-floor sands from a shelf edge/upper slope perspective: AAPG Search and Discovery Article 90039, AAPG Annual Meeting, June 19–22, 2005, Calgary, Alberta, 1 p., http://www.searchanddiscovery.net/abstracts/html/2005/annual/abstracts/petter.htm?q=%2Btext%3Apetter (accessed August 3, 2010).

Petter, A. L., and R. J. Steel, 2006, Hyperpycnal flow variability and slope organization on an Eocene shelf margin, Central Basin, Spitsbergen: AAPG Bulletin, v. 90, p. 1451–1472, doi:10.1306/04240605144.

Plink-Björklund, P., and R. J. Steel, 2004, Initiation of turbidite currents: Outcrop evidence for Eocene hyperpycnal flow turbidites: Sedimentary Geology, v. 165, p. 29–52, doi:10.1016/j.sedgeo.2003.10.013.

Ponce, J. J., E. B. Olivero, and D. R. Martinioni, 2008a, Syndepositional lateral migration of hyperpycnal lobes in submarine ramp systems—Early Miocene, Austral Basin, Argentina, *in* J. J. Ponce and E. B. Olivero, conveners, Sediment transfer from shelf to deepwater—Revisiting the delivery mechanisms: Conference Proceedings, AAPG Search and Discovery Article 50074, AAPG Hedberg Conference, March 3–7, 2008, Ushuaia-Patagonia, Argentina, 4 p., http://www.searchanddiscovery.net/documents/2008/08027ponce/index.htm?q=%2Btext%3A50074 (accessed August 3, 2010).

Ponce, J. J., E. B. Olivero, and D. R. Martinioni, 2008b, Deepmarine hyperpycnal channel-levee complexes in the Miocene of Tierra del Fuego, Artentina: Architectural elements and facies associations, *in* J. J. Ponce and E. B. Olivero, conveners, Sediment transfer from shelf to deepwater—Revisiting the delivery mechanisms: Conference Proceedings, AAPG Search and Discovery Article 50073, AAPG Hedberg Conference, March 3–7, 2008, Ushuaia-Patagonia, Argentina, 6 p., http://www.searchanddiscovery.net/documents/2008/08026ponce/index.htm?q=%2Btext%3A50073 (accessed August 3, 2010).

Posamentier, H., and V. Kolla, 2003, Processes and reservoir architecture of deep-water sinuous channels from the shelf edge to the basin floor, based on analyses of 3d seismic and sidescan imagery (abs.), *in* D. Hodgson, C. Edwards, and R. Smith, eds., Submarine slope systems: Processes, products and prediction. April 28–29, 2003, University of Liverpool, Conference Abstracts Volume, p. 67.

Prior, D. B., B. D. Bornhold, W. J. Wiseman, and D. R. Lowe, 1987, Turbidity current activity in a British Columbia fjord: Science, v. 237, p. 1330–1333, doi:10.1126/science.237.4820.1330.

Saccavino, L., L. Buatois, and C. Zavala, 2008, Integrating sedimentologic and ichnologic data in characterization of hyperpycnal flow deposits of Cretaceous fluvio-dominated deltas (Magallanes Basin, southern Argentina), *in* J. J. Ponce and E. B. Olivero, conveners, Sediment transfer from shelf to deepwater—Revisiting the delivery mechanisms: Conference Proceedings, AAPG Search and Discovery Article 90079, AAPG Hedberg Conference, March 3–7, 2008, Ushuaia-Patagonia, Argentina, 4 p., http://www.searchanddiscovery.net/abstracts/html/2008/hedberg_argentina/extended/saccavino/saccavino.htm?q=%2Btext%3Asaccavino (accessed August 3, 2010).

Saitoh, Y., 2004, Hyperpycnal-flow deposits from the Miocene continental delta complex in the Ryukyu island arc, southwest Japan (abs.): 5th International Conference on Asian Marine Geology, Abstract Volume, p. 176.

Saller, A., R. Lin, and J. Dunham, 2006, Leaves in turbidite sands: The main source of oil and gas in the deep-water Kutei Basin, Indonesia: AAPG Bulletin, v. 90, p. 1585–1608, doi:10.1306/04110605127.

Sanders, J. E., 1965, Primary sedimentary structures formed by turbidity currents and related sedimentation mechanisms, *in* G. V. Middleton, ed., Primary sedimentary structures and their hydrodynamic interpretation: SEPM Special Publication 12, p. 192–219.

Schumm, S. A., 1977, The fluvial system: New York, John Wiley and Sons, 338 p.

Schumm, S. A., 1981, Evolution and response of the fluvial system: Sedimentologic implications: SEPM Special Publication 31, p. 19–29.

Simons, D. B., E. V. Richardson, and C. F. Nordin, 1965, Sedimentary structures generated by flow on alluvial channels, *in* G. V. Middleton, ed., Primary sedimentary structures and their hydrodynamic interpretation: SEPM Special Publication 12, p. 34–52.

Southard, J. B., 1991, Experimental determination of bedform stability: Annual Review of Earth and Planetary Sciences, v. 19, p. 423–455, doi:10.1146/annurev.ea.19.050191.002231.

Soyinka, O., and R. M. Slatt, 2008, Identification and micro-stratigraphy of hyperpycnites and turbidites in Cretaceous Lewis Shale, Wyoming: Sedimentology, v. 55, p. 1117–1133, doi:10.1111/j.1365-3091.2007.00938.x.

Sparks, R. S. J., R. T. Bonnecaze, H. E. Huppert, J. R. Lister, M. A. Hallworth, J. Phillips, and H. Mader, 1993, Sediment-laden gravity currents with reversing buoyancy: Earth and Planetary Science Letters, v. 114, p. 243–257, doi:10.1016/0012-821X(93)90028-8.

Stow, D. A. V., and M. Mayall, 2000, Deep-water sedimentary systems: New models for the 21st century: Marine and Petroleum Geology, v. 17, p. 125–135, doi:10.1016/S0264-8172(99)00064-1.

Sumner, E. J., L. A. Amy, and P. J. Talling, 2008, Deposit structure and processes of sand deposition from decelerating sediment suspensions: Journal of Sedimentary Research, v. 78, p. 529–547, doi:10.2110/jsr.2008.062.

Walker, R., 1984, Facies models: Geoscience Canada, Reprint Series 1, 317 p.

Warrick, J. A., J. Xu, M. A. Noble, and H. J. Lee, 2008, Rapid formation of hyperpycnal sediment gravity currents offshore of a semi-arid California river: Continental Shelf Research, v. 28, p. 991–1009, doi:10.1016/j.csr.2007.11.002.

Zavala, C., 2000a, Nuevos avances en la sedimentología y estratigrafía secuencial de la Formación Mulichinco (Valanginiano) en la Cuenca Neuquina: Boletín de Informaciones Petroleras, v. 63, p. 40–54.

Zavala, C., 2000b, Stratigraphy and sedimentary history of the Plio-Pleistocene Sant'Arcangelo Basin, southern Apennines, Italy: Rivista Italiana di Paleontologia e Stratigrafia, v. 106, p. 399–416.

Zavala, C., 2005, Tracking sea bed topography in the Jurassic. The Lotena Group in the Sierra de la Vaca Muerta (Neuquén Basin, Argentina): Geologica Acta, v. 3, p. 133–145.

Zavala, C., 2008, Toward a genetic facies tract for the analysis of hyperpycnal deposits, *in* J. J. Ponce and E. B. Olivero, conveners, Sediment transfer from shelf to deepwater—Revisiting the delivery mechanisms: Conference Proceedings, AAPG Search and Discovery Article 50075, AAPG Hedberg Conference, March 3–7, 2008, Ushuaia-Patagonia, Argentina, 2 p., http://www.searchanddiscovery.net/documents/2008/jw0805zavala/index.html?q=%2Btext%3A50075 (accessed August 4, 2010).

Zavala, C., and R. Gonzalez, 2001, Estratigrafía del Grupo Cuyo (Jurásico inferior-medio) en la Sierra de la Vaca Muerta, Cuenca Neuquina: Boletín de Informaciones Petroleras, v. 65, p. 52–64.

Zavala, C., G. Azúa, H. Freije, and J. Ponce, 2000, Los sistemas fluvio-deltaicos del Grupo Curamalal (Paleozoico Inferior). Cuenca Paleozoica de Ventania, Provincia de Buenos Aires, Argentina: Revista de la Asociación Geológica Argentina, v. 55, p. 165–178.

Zavala, C., J. Ponce, D. Drittanti, M. Arcuri, H. Freije, and M. Asensio, 2006a, Ancient lacustrine hyperpycnites: A depositional model from a case study in the Rayoso Formation (Cretaceous) of west-central Argentina: Journal of Sedimentary Research, v. 76, p. 41–59, doi:10.2110/jsr.2006.12.

Zavala, C., M. Arcuri, and H. Gamero, 2006b, Towards a genetic model for the analysis of hyperpycnal systems (abs.): Geological Society of America Abstracts with Programs, v. 38, no. 7, p. 541.

Zavala, C., H. Gamero, and M. Arcuri, 2006c, Lofting rhythmites: A diagnostic feature for the recognition of hyperpycnal deposits (abs.): Geological Society of America Abstracts with Programs, v. 38, no. 7, p. 541.

Zavala, C., M. Arcuri, H. Gamero Díaz, and C. Contreras, 2007a, The composite bed: A new distinctive feature of hyperpycnal deposition (abs.): AAPG Annual Convention & Exhibition, v. 16, p. 157.

Zavala, C., J. Marcano, J. Carvajal, 2007b, Proximity and Laterality indexes: A new tool for the analysis of ancient hyperpycnal deposits in the subsurface, *in* Proceedings of the 4th Geological Society of Trinidad and Tobago Geological Conference, 3 p.

Zavala, C., J. Carvajal, J. Mercano, and M. Delgado, 2008a, Sedimentological indices: A new tool for regional studies of hyperpycnal systems, *in* J. J. Ponce and E. B. Olivero, conveners, Sediment transfer from shelf to deepwater—Revisiting the delivery mechanisms: Conference Proceedings, AAPG Search and Discovery Article 50076, AAPG Hedberg Conference, March 3–7, 2008, Ushuaia-Patagonia, Argentina, 4 p., http://www.searchanddiscovery.net/documents/2008/jw0806zavala/index.html?q=%2Btext%3A50076 (accessed August 3, 2010).

Zavala, C., L. Blanco Valiente, and Y. Vallez, 2008b, The origin of lofting rhythmites: Lessons from thin sections, *in* J. J. Ponce and E. B. Olivero, conveners, Sediment transfer from shelf to deepwater—Revisiting the delivery mechanisms: Conference Proceedings, AAPG Search and Discovery Article 50077, AAPG Hedberg Conference, March 3–7, 2008, Ushuaia-Patagonia, Argentina, 4 p., http://www.searchanddiscovery.net/documents/2008/jw0807zavala/index.html?q=%2Btext%3A50077 (accessed August 3, 2010).

Zavala, C., J. Marcano, J. Carvajal, and M. Delgado, 2011, Genetic indices in hyperpycnal systems: A case study in the late Oligocene–early Miocene Merecure Formation, Maturin Subbasin, Venezuela, *in* R. M. Slatt and C. Zavala, eds., Sediment transfer from shelf to deep water—Revisiting the delivery system: AAPG Studies in Geology 61, p. 53–73.