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# SEDIMENT GRAVITY FLOWS: THEIR CLASSIFICATION AND SOME PROBLEMS OF APPLICATION TO NATURAL FLOWS AND DEPOSITS

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## ABSTRACT

A system of classification and nomenclature for sediment gravity flows is proposed based on that developed by Middleton and Hampton (1973, 1976). Flows are classified first by their rheology, with fluidal flows and debris flows distinguished by their fluid and plastic behaviour, respectively. These two basic flow types are further subdivided into five types on the basis of the dominant coarse-particle support mechanism: *turbidity currents* (turbulence), *fluidized flows* (fluidization), *liquefied flows* (escaping pore fluid), *grain flows* (dispersive pressure) and *mudflows* (matrix cohesiveness).

Several considerations influence the application of this terminology to natural flows and deposits. Buoyancy, although an important lift force in natural flows, depends on the presence of other suspended sedimentary particles and is not included as an end-member support mechanism. Multiple support mechanisms characterize most flows, sometimes acting simultaneously on a single grain population or differentially on separate populations, and/or sometimes acting serially over the life of a flow. Many sediment gravity flows evolve from completely laminar to fully turbulent systems. The proposed terminology is not well adapted to the entire range of behaviour and the term *high-density turbidity currents* should be included to described turbulent flows originating as laminar fluidized, liquefied, or grain flows. Many natural flows also include both suspended and traction loads.

The correct interpretation of natural systems must include consideration of all of the above factors and be based on a firm understanding of how each influences the texture and structuring of flows and their deposits.

## INTRODUCTION

Recent studies of submarine sedimentation have shown that a spectrum of processes moves and distributes coarse-grained sediment in the deep sea. The most effective of these processes are driven by gravity acting on the excess weight of entrained solids and have been termed sediment gravity flows, sediment flows, or mass flows. These flows are distinct from those in which moving fluids entrain and transport passive sediment particles. The latter include fluid gravity flows, wave- and tide-driven currents, and contour currents. They also stand in contrast to slumps and slides, where gravity pulls large coherent or semi-coherent blocks downslope with shear concentrated along one or a limited number of glide planes. Although the evolution of subaerial sediment flows from slumps is well documented and is probably common in subaqueous environments as well, transitions between sediment gravity flows and fluid gravity flows appear to be limited. The only documented examples appear to be sediment-laden rivers which, upon entering lakes or oceans, persist beneath the standing water as turbidity currents (Smith and others, 1960).

The evolution of sediment flow classification and nomenclature has been summarized by Dott (1963), Sanders (1965), Middleton (1967), Middleton and Hampton (1973, 1976), and Carter (1975), and will not be reviewed here. Modern terminologies have been offered by Carter (1975); Middleton and Hampton (1973, 1976), the latter modified slightly by Lowe (1976b); and Nardin et al (this volume). Carter's classification is based mainly on the laminar vs. turbulent state of flow and the dominance of viscous vs. inertial grain interactions. It has not been widely adopted because of its complexity, because it lumps together flows of differing rheological properties, because it is difficult to apply to flow deposits where the nature of particle interactions during movement may be indeterminate, and because our understanding of grain interactions within both sediment and fluid gravity flows is rather slight and cannot yet serve as a rational basis for flow definition and discrimination.

The present discussion takes as its basis the classification of Middleton and Hampton (1973, 1976) in which flow types are defined by the nature of the dominant sediment-support mechanisms (Fig. 1). This approach provides for a limited number of end-member models based on flow mechanics. These models should lend themselves to mathematical and empirical testing more easily than less precisely and more complexly defined flow types. Analyses of turbidity currents (Bagnold, 1962; Middleton, 1966, 1967; and many others), grain flows (Bagnold, 1954, 1956; Lowe, 1976a) debris flows (Johnson, 1965, 1970), and liquefied flows (Lowe, 1976b) substantiate the

| FLOW TYPE | SEDIMENT SUPPORT MECHANISM |
|---|---|
| TURBIDITY CURRENT | FLUID TURBULENCE |
| FLUIDIZED FLOW | ESCAPING PORE FLUID |
| GRAIN FLOW | DISPERSIVE PRESSURE |
| DEBRIS FLOW | MATRIX STRENGTH |

(MIDDLETON AND HAMPTON, 1973, 1976)

FIG. 1.—Sediment gravity flow nomenclature of Middleton and Hampton (1973, 1976).

usefulness of end-member support mechanisms in classifying and studying sediment flows.

As the nomenclature of Middleton and Hampton has been applied to real flows and flow deposits, a number of problems have arisen. These reflect imprecision in the application of certain terms, such as debris flow and grain flow; the interaction within individual flows of more than one support mechanism; difficulties in relating conceptual flow models to actual flows and flow evolution; our present inability to characterize quantitatively many flow types; and the paucity of experimental studies. The present-discussion will focus on aspects of the first three of these problems.

## PROPOSED CLASSIFICATION

Middleton and Hampton (1973, 1976) defined four types of sediment gravity flows (Fig. 1):

*turbidity currents* in which the sediment is supported by turbulence within the flow;

"*fluidized sediment flows* in which the sediment is supported by the upward flow of fluid escaping from between the grains as the grains are settled out by gravity";

*grain flows* in which the grains are supported by grain dispersive pressure, and

*debris flows* in which the larger grains are supported by a cohesive matrix.

Lowe (1976b) subsequently pointed out that sediment grains cannot simultaneously be fully supported and settling out and suggested that fluidized flow be redefined and the term "liquefied flow" added (Fig. 2):

*fluidized flows* in which the sediment is fully supported (fluidized) by upward moving fluid; and

*liquefied flows* in which the sediment is not fully supported but is settling through its pore fluid, which is displaced upward.

Perhaps the major problem in standardizing sediment flow terminology has been in conceptually distinguishing debris flows, grain flows, and liquefied flows. The present author would suggest that the problem has arisen mainly because of imprecise application of the term debris flow. Middleton and Hampton (1976, p 209) indicate that the matrix strength of "true debris flows" originates with the cohesive properties of entrained clay: "Support of grains by cohesion of the fluid phase distinguishes true debris flow from grain flow and turbidity current flow" and the "competence of a true debris flow is controlled by the strength and density of the clay-water fluid." The Coulomb-viscous rheological model of debris flows used by Middleton and Hampton (1973, 1976) was developed by Johnson (1965, 1970):

| FLOW TYPE | SEDIMENT SUPPORT MECHANISM |
|---|---|
| TURBIDITY CURRENT | FLUID TURBULENCE |
| FLUIDIZED FLOW | (FULL SUPPORT)<br>ESCAPING PORE FLUID |
| LIQUEFIED FLOW | (PARTIAL SUPPORT)<br>ESCAPING PORE FLUID |
| GRAIN FLOW | DISPERSIVE PRESSURE |
| DEBRIS FLOW | MATRIX STRENGTH |

(LOWE, 1976)

FIG. 2.—Sediment gravity flow nomenclature of Middleton and Hampton (1973, 1976) as modified by Lowe (1976b).

$$T = C + \sigma_\mu \tan \phi + \mu \frac{du}{dy}, \qquad (1)$$

where

$T$ = shear stress
$C$ = cohesion,
$\sigma_\mu$ = internal normal stress,
$\phi$ = angle of internal friction,
$\mu$ = viscosity of flow, and
$\frac{du}{dy}$ = velocity gradient.

Middleton and Hampton (1976, p. 209) observe that "within a steadily moving debris flow, the driving stress is equal to the resistance supplied by cohesion $C$ plus friction $\sigma_\mu \tan \phi$ plus viscosity."

It is clear from the above discussion that two types of flows are being discussed: "true debris flows" in which larger grains are supported by the cohesion of a clay-water matrix slurry and rheological debris flows which are described by equation (1). The former represents the type of debris flow included within the family of sediment gravity flows distinguished and defined on the basis of the sediment-support mechanism. The latter includes all sediment flows which exhibit plastic behaviour.

Allusions and direct references to both types of debris flows are present in the literature. Descriptions of pebbly mudstones and muddy, matrix-supported conglomerate and breccia interbedded within submarine flysch or base-of-slope deposits (Crowell, 1957; Dott, 1963; Peterson, 1965; Stanley, 1969; Abbate, Bortolotti, and Passerini, 1970; Lowe, 1972) leave little doubt that the larger clasts were truly supported, at least during the last stages of movement, by cohesive matrix strength. In other cases, however, the presence of fine-grained matrix material in a flow or flow deposit is taken as sufficient evidence of debris flow transport (Curry, 1966, as cited in Middleton and Hampton, 1973, 1976; Enos, 1977; Johnson, 1970; Montjoy and Playford, 1972). Although it seems probable that many of the described flows and deposits represent plastic or Bingham substances, there is commonly little evidence that the larger grains were actually supported by the cohesive matrix.

The author would suggest that some of the nomenclatorial problems can be relieved by incorporating this dual nomenclature into our terminology. Figure 3 presents the proposed nomenclature in which flow behavior, either plastic or fluid, serves the distinguish between *debris flows* and *fluidal sediment gravity flows,* respectively (see also Nardin et al, this volume). These two general types of flow are divided into specific flow types based on the particle support mechanisms. Instead of applying the term *debris flow* to both Coulomb-viscous flows and those within which larger grains are supported by matrix cohesiveness, the latter are termed *mudflows, cohesive debris flows,* or *cohesive flows.* Although resurrecting the term *mudflow* may meet with some objections, the name has been applied historically to flows "in which mud, although not necessarily quantitatively predominant, endows the mass with specific properties and modes of behavior which distinguish it from flows of debris devoid of mud" (Sharp and Nobles, 1953, p. 550). The distinguishing property of mud, a mixture of clay, silt, and sand, is its cohesiveness. Hence, the definition of mudflow of Sharp and Nobles is coincident with the range of flow types discussed here as cohesive debris flows. It is noteworthy that Sharp and Nobles (1953) considered mudflows to be one variety of debris flow, although they defined debris flows differently than has been done here.

| FLOW BEHAVIOR | FLOW TYPE | | SEDIMENT SUPPORT MECHANISM |
|---|---|---|---|
| FLUID | FLUIDAL FLOW | TURBIDITY CURRENT | FLUID TURBULENCE |
| | | FLUIDIZED FLOW | ESCAPING PORE FLUID (FULL SUPPORT) |
| | | LIQUEFIED FLOW | ESCAPING PORE FLUID (PARTIAL SUPPORT) |
| PLASTIC (BINGHAM) | DEBRIS FLOW | GRAIN FLOW | DISPERSIVE PRESSURE |
| | | MUDFLOW OR COHESIVE DEBRIS FLOW | MATRIX STRENGTH<br>MATRIX DENSITY |

FIG. 3.—Proposed nomenclature for sediment gravity flows.

The proposed terminology merely formalizes the common tendency to apply the term *debris flow* to flows of Bingham substances, whether their strength is frictional or cohesive in origin. To this extent, it better reflects current usage than does the support-mechanism-based definition of debris flow. It is also compatible with current sedimentological usage of the term *mudflow.*

The proposed terminology also offers a clear distinction between cohesive debris flow and grain flow that has been lacking in previous discussions. Most mudflows show plasticity because of the cohesive properties of suspended clay particles, although the yield strength and shear behaviour of clay-water suspensions vary greatly with the composition of the clay, and, once the yield strength is surpassed and deformation begins, clay-water suspensions behave essentially as viscous fluids. If the applied shear stress drops below the yield strength, the flows freeze. Grain flows are characterized by frictional strength because of the role of grain interactions in maintaining the dispersion against gravity. This strength is reflected in the relatively high slopes, generally greater than 20°, required for the maintenance of steady grain flows of uniformly sized particles (Bagnold, 1956; Lowe, 1976a). On moving onto lower slopes, the frictional strength of the colliding grains exceeds the applied tangential component of gravity, and the flows freeze. Thus, mudflows are characterized by cohesive strength and grain flows by frictional strength. In exhibiting a finite yield strength, and as a result the tendency to freeze from the top down during resedimentation, both are here included as debris flows.

In terms of equation (1), most mudflows can be described by the relationship

$$T = C + \mu \frac{du}{dy}$$

whereas the general grain-flow model is

$$T = \sigma_\mu \tan \phi + \mu \frac{du}{dy}.$$

The application of grain flow theory to natural transport problems is probably less well understood than that of any other sediment flow mechanism. As pointed out by Lowe (1976a), the results of experiments by Bagnold (1954) are not directly applicable to natural flows of cohesionless grains. Especially problematic is the role of inertial versus viscous grain interactions. Fully inertial grain flows are commonplace, represented by avalanches on the slipfaces of ripples and dunes. Viscous grain interactions undoubtedly occur, but, as suggested by Lowe (1976a, p. 191) and implied by the experimental results of Bagnold (1954), true viscous grain flows, in which the grains are fully supported by viscous dispersive pressure, require slopes in excess of those required for similar inertial flows. Such flows, if ever developed, could occur only on slopes greater than the angle of repose of the material. Viscous interactions undoubtedly characterize some mudflows, liquefied flows, and the bed load layers of traction or turbidity currents, but, in the absence of additional support mechanisms, viscous dispersive pressure will not maintain flowing particle dispersions over most natural subaqueous slopes. Except on subaqueous slopes in excess of 25° to 30°, therefore, unmodified viscous grain flows probably cannot exist. Suggestions that viscous grain flows can be regarded as fluidal flows because of their fluid-like behavior (Nardin et al, this volume) overlook the fact that, in the absence of external stress or additional support mechanisms, this behavior is manifest only on steep slopes where the downslope gravity component exceeds the internal resistance of the interacting grains: the sediment-water mixtures are behaving effectively as plastic substances.

The dynamics of natural liquefied and fluidized dispersions is not well understood. At relatively low shear rates, concentrated suspensions of rigid solids apparently behave as Newtonian fluids (Roscoe, 1953; Metzner and Whitlock, 1958) but at high shear rates or if confined, can show considerable frictional resistance and dilatancy (Freundlich and Jones, 1936; Seed and Lee, 1966). Hence, although frictional resistance may develop near the bases of thick flows of liquefied sediment, it is unlikely to characterize the flows as a whole (Lowe, 1976b). Liquefied and fluidized flows are most likely to behave as fluidal flows but may, near their bases, show strength and overlap into the area of debris flow if shear rates or flow thickness is great. They also differ from mudflows and most grain flows in resedimenting from the base up.

### *Relationship Among Flow Types*

The sediment-flow types defined in Figure 3 do not represent a parallel series in which the end-members differ from one another only in the dominant process of particle support (Fig. 4). Turbidity currents, for instance, can maintain themselves as steady flows only if turbulent whereas grain flows, fluidized flows, and mudflows can exist and transport sediment as steady, laminar flows. Liquefied flows are, by definition, unsteady because sediment is continuously settling out. They are thus hydraulically similar to the waning, laminar resedimenting tails of turbidity currents in that the prevailing conditions do not permit sediment transport. The main importance of liquefied flows thus lies in the relatively long distances fine-grained sediment may travel before fully resedimenting (Morganstern, 1969; van der Knaap and Eijpe, 1969; Middleton, 1970; Lowe, 1976b) and in their evolution into turbidity currents through the development of turbulence (van der Knaap and Eijpe, 1969; Lowe, 1976b).

When considering turbulent flows, the support-mechanism-based nomenclature is not applicable (Fig. 4). A liquefied flow in which turbulence becomes fully developed is no longer liquefied; it is a *high-density turbidity current.* The same is true for grain flows. Because cohesionless fine-grained sand, silt, and clay is the only natural material likely to be fluidized (Lowe, 1976b), accelerating fluidized flows are likely to evolve into turbidity currents ranging from relatively dilute suspensions to high-density flows. Cohesive debris flows may commonly become turbulent (Enos, 1977), but apparently the effects of sediment cohesion are important in preventing particle size-segregation and in aiding in clast support even

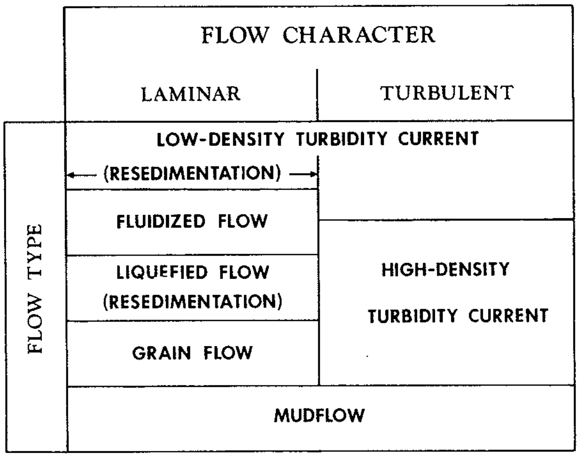

FIG. 4.—Sediment gravity flow nomenclature for both laminar and turbulent flows.

in fully turbulent flows. Thus, the term *turbulent mudflow* seems appropriate.

### DISCUSSION

The classification of sediment flows based on rheology and particle-support mechanisms is useful because the support mechanisms represent discrete end members, and hence, are conceptually distinct, and because both rheology and support mechanism control the mechanics of transport and deposition and, thus, are likely to be reflected in the textures and structures of the final deposits. In fact, a number of problems complicate both the theoretical and practical application of the proposed terminology (see also Nardin et al, this volume).

### *Buoyancy*

Buoyancy is perhaps the single most important coarse-particle support mechanism in mudflows, but is not included as an end-member in terms of flow terminology. Rodine and Johnson (1976) have emphasized the role of buoyancy in supporting large blocks within debris flows. Because the specific gravity of debris-flows is commonly between 1.5 and 2.0 (40% to 60% quartz-density solids), from 30% to 70% of the excess weight of larger quartz-density particles may be supported by the buoyancy of the surrounding solid-liquid mixture. In the case of still-plastic, semi-lithified mudstone chunks, their entire mass may be suspended by buoyant lift.

Rodine and Johnson (1976) discuss several examples of the effectiveness of buoyancy in supporting larger blocks in debris flows. Another example is provided by Lowe (1972). A debris-flow deposit from the Cretaceous Great Valley Sequence of western California is made up largely of pebbly mudstone composed of 15 to 20% rounded, pebble- and cobble-sized exotic clasts suspended within a massive mudstone matrix. Large blocks of bedded mudstone up to 10 m across "float" at the top of the flow. The paucity of mudstone blocks within the flow suggests that they may have been supported largely or entirely by the buoyancy of the pebbly mudstone.

Suspended or floating mudstone clasts are ubiquitous components of proximal turbidites or "fluxoturbidites." Whether these sandstone units were deposited by high-density turbidity currents (Kuenen, 1951; Middleton, 1966, 1967), sandy debris flows (Hampton, 1975), or liquefied flows (Lowe, 1976b), the mud clasts were probably supported largely by the buoyancy of the dense sand-water mixture. Mud clasts with a specific gravity between 1.5 and 2.0 would be entirely, supported, for instance, by suspensions having quartz sand contents between 20% and 40%, well within the probable range of such flows.

Although an additional end-member flow type could be defined based on buoyant support, buoyant lift beyond that provided by water alone occurs only when a significant quantity of other, smaller grains are also entrained. The processes by which these smaller grains are supported is necessarily not a function of buoyant lift and perhaps can be considered to be the dominant support mechanism within the flow: without the smaller grain population, there would be no buoyant support of the larger grains. Consequently, there is no separate end-member flow type characterized only by buoyant support of grains and no need to define one. In grain mixtures, however, buoyancy must be regarded as an important support mechanism for larger particles.

### *Support Versus Lift*

It is essential to recognize the difference between support and lift mechanisms in sediment gravity flows. Actual lifting of the grains against gravity can be accomplished by flow turbulence, dispersive pressure, escaping pore fluids, and buoyancy. All of these mechanisms and flow strength can support the grains, but the latter cannot by itself provide lift. Pore fluids escaping due to liquefaction can only provide partial support for the larger grains. In many sediment flow deposits, such as pebbly mudstones or pebbly sandstones, larger clasts occur evenly dispersed within a structureless fine-grained matrix. The suspension of larger, heavy particles within the matrix suggests that they were, at least during the late stages of flow, supported by matrix strength and that the flows were mudflows. Although the clasts, once suspended, may have been partially supported by matrix strength, they could not have been lifted by matrix strength. Most such flows probably originate through the flowage and mixing of interstratified and gravitationally unstable mud, sand, and gravel. The sinking of gravel and sand into lower density mud, combined with shear during flowage, could produce the observed texture, but, in the absence of lift forces, there would be a tendency for the clasts to work their way to the base of the flow. The common nearly uniform dispersion of clasts is best explained by the existence of dispersive pressure between the colliding gravel-sized particles. Such pressure would maintain a uniform dispersion against the tendency of gravity to cause the particles to settle. Within mud-matrix flows, the bulk of the excess weight of the larger particles is probably supported by the buoyancy of the mud-water matrix and additional support is provided by flow strength, but the actual dispersion is produced and maintained by dispersive pressure. In some flows where dispersive pressure is relatively high, perhaps due to a relatively high concentration of gravel, inverse grading may develop even though the matrix is cohesive mud (Fisher, 1971).

Attempts to name such flows on the basis of particle support mechanism are futile; there is no single or dominant particle support mechanism. The final character of the flow deposit, however, in particular its matrix-supported texture, will reflect the cohesive strength of the mixture during the final stages of movement. The terms *cohesive debris flow* or *mudflow* accurately characterize this type of mass movement even though cohesiveness may not have been either the dominant lift or support mechanism.

Enos (1977) has recently suggested that many debris flows are turbulent. Within turbulent flows, turbulence could provide part or all of the lift force required to support the larger grains. Upon declining to laminar flows, dispersive pressure would replace turbulence as the principal lift mechanism until the flows freeze.

### *Multiple Support Mechanisms*

Middleton and Hampton (1976), Lowe (1976) and others have stressed that debris in real sediment flows is generally kept suspended by more than one support mechanism. At least three different conditions of multiple support may occur. (1) Several processes of lift and/or support may act simultaneously on the same grains. Buoyancy is effective in most sediment flows in addition to the primary support mechanism. In the preceding discussion of pebbly mudstones, it was suggested that the simultaneous interaction of buoyancy, dispersive pressure or turbulence, and cohesive matrix strength maintains many suspensions of gravel-sized clasts. (2) In some sediment gravity flows, different size or composition populations of grains can be simultaneously supported by different mechanisms. In gravel flows termed *density-modified grain flows* by Lowe (1976a), it was suggested that the gravel-sized clasts were supported by the combined processes of sand-mud-water matrix buoyancy and dispersive pressure and that sand-sized grains were supported by a combination of mud-water matrix buoyancy, turbulence, and possibly cohesiveness. In liquefied flows, sand grains may be resedimenting in a liquefied state, mud clasts are fully supported by flow buoyancy, and finer silt and clay are fluidized and elutriated by the escaping pore water. (3) Many flows probably undergo a secular evolution involving changes in the relative effectiveness of a number of support mechanisms. A mass of sediment may fail as a slump, liquefy, accelerate and become a turbulent high-density turbidity current, and finally slow and resediment as a liquefied flow (Lowe, 1976b).

Each of these varieties of multiple support probably leaves a distinctive imprint on the final flow deposit. The accurate interpretation of sediment flow deposits depends, first, on the identification of textures and structures characteristic of each mechanism of particle support and deposition and, secondly, on the discrimination of compound textures and structures produced through the interaction of several support mechanisms acting simultaneously and/or serially.

### *Multiple Transport Mechanisms*

Within many debris flows, it is probable that many of the larger transported clasts are not fully supported. Motion pictures of the 1968 mudflows at Wrightwood, California, taken by D. M. Morton of the U.S. Geological Survey, show that large cobble- and boulder-sized blocks were actually shoved along as bed load, rolling or, less commonly, sliding but remaining in more-or-less continuous contact with the bottom or with other underlying clasts. In some flows, blocks over 0.5 m in diameter were rolled along as bed load within flows less than 0.4 m thick moving at speeds of about 1 m/sec. In other instances, there was a jostling and collision of blocks within a tightly packed mass of material, accompanied by forward grain rotation but relatively slight net shear. The clasts were shoved and dragged forward by the surrounding, more rapidly moving sediment-water mixture, but were not fully supported or suspended within it. This type of movement, with the periodic formation and breakdown of debris dams, may, in fact, represent the main mode of clast transport in many mudflows.

In the debris flow deposit in the Great Valley Sequence discussed previously (Lowe, 1972), blocks of tonalite and gabbro larger than 0.4 m in diameter occur only at the base of the deposit. Although most probably moved several kilometers, they were apparently not suspended within the flow inasmuch as their tendency to settle should have decreased as flow velocity declined and the yield strength of the mud-gravel mixture was approached. Hence, they probably slid or rolled as bed load at the flow base. Associated larger blocks of lithified sandy sedimentary rock up to 50 m high were certainly pushed or rolled along in continuous contact with the bottom.

These observations suggest that rheological debris flows can include both traction and suspended loads as do turbidity currents. This conclusion is not unexpected inasmuch as, beyond their yield strengths, plastic substances exhibit fluid-like behaviour. Hence, larger grains whose weight exceeds the combined effects of yield strength and buoyant lift force of the mud-water matrix will tend to settle. They may be pushed along the bottom as bed load. Smaller pebbles are entrained as suspended load by the combination of cohesive matrix support and lift provided by flow turbulence (Enos, 1977) or, in laminar flows, dispersive pressure. Still smaller sand and silt grains may be fully supported by matrix strength.

It is unlikely that bed load material can exist in most liquefied flows because the continuous rapid resedimentation of liquefied sediment would result in the absence of a well-defined flow base. However, both suspended load, maintained by one or more particle-support mechanisms, and bed load may exist for the other varieties of sediment-flows just as for fluid gravity flows.

Modeling of sediment flow dynamics and evolution and of sediment entainment, transport, and deposition must, therefore, include consideration of multiple modes of sediment transport and the probability of sediment exchange among the loads. Equally important, the textural properties and internal structuring of all types of sediment flow deposits may reflect the existence of more than one mode of sediment transport within a single flow. Instead of evaluating the textures and structures of a deposit in terms only of support mechanisms for the suspended load, they must be evaluated in terms of a traction load as well. The textural identification of these loads may be possible using techniques similar to those used to study fluid gravity flow deposits (Visher, 1969; Middleton, 1976).

## CONCLUSIONS

The present discussion has focused on some of the problems of sediment gravity flow classification and nomenclature. It has not sought to develop any fundamentally new concepts or hypotheses, but to provide a practical taxonomy for sediment flows, compatible with that already in use by sedimentologists, and to explore some of the shortcomings, complexities, and implications of that taxonomy.

A system has been proposed in which flows are named, firstly, on the basis of their rheological behaviour and, secondly, by the dominant coarse-particle support mechanism. Although the taxonomy is conceptually simple, its application to natural flows and deposits must as yet be undertaken with caution. The textures and structures of natural deposits reflect not only the dominant support mechanism, if one exists, but also, (1) the simultaneous or serial interaction of multiple support mechanisms, (2) the character of flow, either laminar or turbulent, before and during deposition; (3) the existence of both suspended and traction loads, and (4) the effects of particle support or lift mechanisms not formally incorporated into the support-mechanism based nomenclature, such as buoyancy. Other processes beyond the scope of the present discussion, most notably water escape, also strongly influence the character of the final deposit.

The greatest problem in the use of sediment flow terminology lies not in its application to relatively well-understood phenomena, such as turbidites or mudflow deposits, but in its application to flow types that are not well understood, as such fluidized flows, liquefied flows, and some debris flows. It is too often convenient to interpret deposits exhibiting textures and structures whose origins are problematic in terms of processes whose dynamics are equally poorly understood. Until objective criteria are developed to identify and evaluate each of the processes active within natural flows and its effect on the composition, texture, and structures of flow deposits, any system of nomenclature based on genetic interpretations must be applied with caution.

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