

Flow transformations in sediment gravity flows

Richard V. Fisher

Department of Geological Sciences, University of California, Santa Barbara, California, 93106

ABSTRACT

Sediment gravity flows (subaerial or subaqueous) are those in which movement is driven by gravity and the sediment motion moves the interstitial fluid (gas or liquid). Such flows exhibit *flow transformations*, a term introduced here, referring to changes between laminar and turbulent flow, in turn related chiefly to particle concentration, thickness of the flow, and flow velocity (slope).

INTRODUCTION

Experimental studies and field observations of debris flows (Johnson, 1970; Hampton, 1972), experimental studies on turbidity currents (Middleton, 1966, 1967), and field observations of the textures and structures of turbidites (Dzulynski and Walton, 1965) and debris flow deposits (Sharp and Nobles, 1953; Gloppen and Steel, 1981) led to a classification of particulate flows into (1) *fluid gravity flows*, in which the fluid (gas or liquid) is moved by gravity and drives entrained sediment parallel to the bed, and (2) *sediment gravity flows*, in which sediment motion is in response to gravity and moves the interstitial fluid (Middleton and Hampton, 1973, 1976).

Sediment gravity flows (subaerial or subaqueous) exhibit *flow transformations*, defined here as changes in flow behavior between laminar and turbulent states. Laminar-turbulent transformations are influenced chiefly by particle concentration, thickness (size) of the flow, and flow velocity (slope). The classification of sediment gravity flows focuses upon how particles are supported. The concept of flow transformations, however, is concerned with the dynamics of sediment gravity flows and applications to ancient deposits (Fisher, 1983).

FLOW TRANSFORMATIONS

At least four kinds of flow transformations can be identified (Fig. 1): (1) *Body transformations* occur when the flow changes between laminar and turbulent within the body of a flow without significant addition or loss of interstitial fluid. (2) *Gravity transformations* occur when initially turbulent, particle-charged flows become gravitationally segregated and develop a high concentration, essentially laminar-moving underflow with an overriding more dilute turbulent flow. (3) *Surface transformations* occur when ambient air or water become mixed or lost at flow boundaries by drag over the top of a high-concentration flow, at a hydraulic jump, or beneath the nose of a flow, resulting in dilution, consequent turbulence, and separations into laminar and turbulent moving parts. (4) *Fluidization transformations* develop by elutriation of particles by upward-moving fluids from a high-concentration (dense-phase) bed to produce a turbulent dilute-phase bed above the base. This kind of transformation can produce ash-cloud surges from the upper parts of pyroclastic flows (Fisher, 1979).

Field, experimental, and theoretical descriptions of flow transformations are scattered through the literature; the *fact* of flow transformations is not new, nor is it merely conceptual. Use of the new label "flow transformations" focuses emphasis upon dynamics of flow that chiefly determine sedimentary textures, structures, and vertical and lateral facies. It should also be pointed out that a flow can be transformed more than once and in different ways. For instance, in example a in Figure 1, the nose of the flow may be undergoing a surface transformation as is shown in example c (Fig. 1). Furthermore, the turbulent flow developed in example c could undergo a later gravity transformation (example b, Fig. 1), and so on.

Experiments and speculations of Kuenen (1952) and Morgenstern (1967) suggested that slumps or debris flows can change to turbidity currents (body transformations) with no change in water content when velocity is great enough to produce internal turbulence. This can be related to critical Reynolds and Bingham numbers (Hiscott and Middleton, 1979). The possibility of body transformations was suggested by Middleton (1970), and a description of the Parnell Grit, New Zealand (Fisher, 1971) offers evidence that such transformations can be recognized in the field.

Gravity transformations are more commonly described than body transformations. Middleton (1967) experimentally showed the development of a "quick bed," a fluidized sediment flow (Gonzalez-Bonorino and Middleton, 1976) that develops because of gravity segregation at the base of an initially turbulent high-concentration turbidity current. Sequential development and

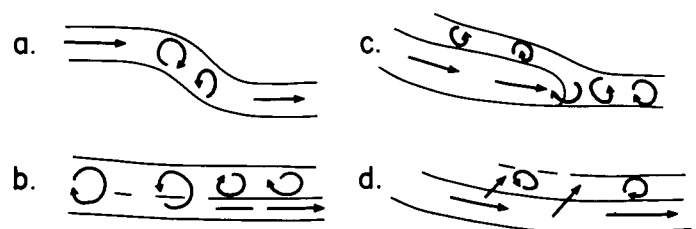


Figure 1. Four kinds of flow transformations as described in text: a = body transformation; b = gravity transformation; c = surface transformations; d = elutriation transformation.

sedimentary structures involving gravity transformations in high-concentration turbidites are described and clarified in an excellent paper by Lowe (1982). Gravity transformations also occur subaerially from initially turbulent pyroclastic flows that develop into low-concentration, turbulent pyroclastic surges flowing above block-and-ash flows (Fisher and Heiken, 1982).

Surface transformations are well described by Hampton (1972). He showed how the stripping of sediment from the nose and surface of a subaqueous debris flow can become a turbulent current that continues beyond the debris flow. Other kinds of transformations included in surface transformations are those that can occur at hydraulic jumps (Van Andel and Komar, 1969; Komar, 1971) or where fluids might enter beneath the nose of a flow (Allen, 1971; Wilson, 1980) to produce mixing and possible laminar to turbulent transformations.

Fluidization transformations from potentially laminar dense-phase to turbulent dilute-phase fluidized systems have long been experimentally confirmed (Leva, 1959) and used by geologists to explain the development of pyroclastic surges from the tops of pyroclastic flows (Sparks, 1976; Fisher, 1979; Sheridan, 1979; Wilson, 1980). Fluidized water-saturated mass flows can occur in subaqueous settings (Middleton and Hampton, 1973, 1976), but the products of subaqueous elutriation transformations have either not been described or not been recognized (Lowe, 1982).

The way that particles are supported within a flow in its final stages of movement largely determines the textures and structures within a bed. The manner of support is a direct function of particle concentration and amount of fine-grained cohesive sediment mixed with pore fluid, which in turn greatly affects whether or not laminar to turbulent or turbulent to laminar transformations take place. The concept of flow transformations is qualitatively useful in visualizing flow dynamics leading to the sequential development of beds within single depositional units.

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Manuscript received November 1, 1982

Revised manuscript received February 4, 1983

Manuscript accepted February 10, 1983