Welded slump-graded sand couplets: evidence for slide generated turbidity currents

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ABSTRACT

Some massive channelized strata preserved in the rock record are characterized by a lower slump member which evolves upward to a turbidite. This merging is indicative of probable generation of sediment gravity flows from submarine sliding. Conditions essential for deposition of such sequences are short transport distance between point of failure and depositional site, and an environment likely to retain both facies. Fan valleys are a likely setting for welded couplets: flowing sand, initiated by the sliding event, comes to rest at nearly the same time and position as the slump mass deposited near the base of the valley wall and in the axis proper.

INTRODUCTION

Most publications that discuss the origin of turbidites state, or at least intimate, that turbidity currents are surges commonly initiated by catastrophic events related to submarine sliding on slopes. This concept is almost universally accepted by specialists of deep-sea sediment transport, although little "hard" observational data are available in direct support of this hypothesis.

In general theory, mass movement of sediment results from failure along one or more surfaces. The displaced mass may be little to greatly deformed, and movement planar or rotational. Failure is triggered by stresses that can result from several factors (high rate of sediment accumulation, slope oversteepening, earthquake, subsurface gas generation, etc.) which give rise to excess pore pressure and a weakening of the sediment. Liquefaction and decrease in overall shear resistance are usually invoked as causes of sediment mobility. In many cases, the allochthonous slab comes to rest as an entity further downslope, displaying various degrees of deformation. Increased mobility within the slab results in increased disorder of original sediment stratification and structure, i.e., from coherent and relatively undeformed to incoherent (showing intraformational folding) slumps [1]. As they move downslope, some slides may evolve to sediment gravity flows such as debris flows and turbidity currents [2]. In such cases, it is believed that grain-to-grain structure is disrupted during acceleration causing changes in pore pressure and allowing mixing with water which, in turn, results in further alteration of original structure. Metastable, high sensitivity, cohesionless sediments are most susceptible to mobility and, in turn, transformation from submarine sliding to turbidity current flow. These contentions are based primarily on theoretical and experimental considerations [1,3].

It has long been recognized that failure and mass movement prevail on slopes and, in particular, on tectonically unstable margins, on those receiving large volumes of sediment such as off deltas and on steep heads and walls of submarine canyons [4,5]. This is confirmed by recent investigations [1,6]. Modern ocean surveys involving high-resolution seismic profiling and coring show a non-random distribution of turbidites with respect to slumps. Seismic reflectors reveal in a general manner the spatial relation between well-stratified (presumably turbidite-rich) series and acoustically chaotic masses, probably slumps [7]. One well-studied event (16 October 1979 failure off Nice, France) indicates that sliding on the upper slope resulted in damage to two submarine cables about 80 and 110 km away, well beyond the base-of-slope. Detailed surveys indicate that the slide, which was deposited on the lower slope, probably generated a turbidity current which caused the cable damage [8].

As in most such cases (1929 Grand Banks event [7,9], and others), seismic profiling lacks sufficient resolution and core density is too low to prove the transformation hypothesis. The present study provides new evidence from the rock record that submarine sliding can give rise to sediment gravity flows, including turbidity currents.
FIELD SITE SELECTION: RATIONALE

The Annot Sandstone Formation (Upper Eocene) in the French Maritime Alps continues to provide a wealth of observation for specialists of deep-sea sediment transport. Outcrops are extensive and well exposed, and the structural-paleogeographic framework of this thick, sand-rich unit is well defined [10]. Both channelized (lower canyon, fan valley) and unconfined outer margin deposits (lower slope, fan, basin plain) are recognized. Geometry and texture, paleocurrent directions and other field data reveal a non-random temporal and areal distribution of submarine valley axes as well as tributary canyons, fan valleys and interchannel deposits [11]. Sediment transport was primarily toward the north, i.e., directed from an area now occupied by the Ligurian Sea, northwestern Mediterranean. Proximal to distal lithofacies changes measured along paleoslopes suggest the transformation downslope of various flow types [12].

Excellent exposures in the Peira-Cava and Turini area north of Nice (Fig. 1) are interpreted as fan deposits comprising largely thick sand channels, overbank and thinner and finer grained interchannel facies (Fig. 2A). A highly sinuous road from the Col de l’Orme to Baisse de la Cabanette (Fig. 1, locality 2) cuts across a large part of the section which exceeds 500 m and displays a remarkable diversity of sediment strata and structures. It is along this section that Bouma [13] defined the various turbidite divisions. This part of the formation comprises essentially upper to mid-fan series [10], i.e., a setting where turbidites were released in a proximal depositional position and, thus, are complete (showing T_a - T_e divisions [11]).

Many of the thick massive and graded layers (Fig. 2C) in the Peira-Cava locality are fan channel and distributary systems, migratory and abandoned [12]. With respect to such channelized environments, Kuenen ([4], p. 31) postulated that “slumps started on the walls and must then have changed to turbidity currents, and that without this change they could not have carried material down the axis out to the deep sea floor.” Subsequent analysis [12] did indicate that gravity-induced processes such as slumps and debris and sand flows on valley walls, combined with axial transport (including turbidity currents), deposited the highly variable lithofacies that form the thick channelized strata of the Annot Sandstone Formation (Fig. 3). It is these massive layers in the Peira-Cava syncline which provide a valuable record of the genetic relation between slides and turbidity currents.

WELDED SLUMP-TURBIDITE COUPLES

The exposures in the Peira-Cava syncline comprise classic sandstone turbidites [13], slump strata (Fig. 2B), and a diversity of depositional types (illustrated in [12]) whose transport origin (debris, slurry and sand flow, and others) is less well defined. Herein, attention is paid to a specific sequence type whose base consists of a slump (Fig. 2C) or slump-debris flow (Fig. 2D) member which merges upward with an overlying sandstone layer. Approximately 50 welded slump-sandstone couplets are mapped in the region, most ranging from 3 to 30 m in thickness (about 9 m in Fig. 2C). The deformation of structures within the basal slump member is highly variable (compare Figs. 2D and 4C, D). The sandstone above the basal slump member is usually well graded (Fig. 4D) although some units show poor or no grading (Fig. 5D). All the turbidite divisions (T_a - T_e) may be present, but most often the sandstone consists of an expanded T_a,b unit (Fig. 2C and 4A). Where present, the T_c to T_e divisions usually account for a smaller proportion of strata thickness. The T_s section includes shale and siltstone rip-up clasts (Fig. 2D) and dish structures. Some slump-turbidite couplets can be traced laterally along outcrop for at least 800 m.

The most remarkable couplet in terms of thickness and areal extension is the one mapped near the base of the formation at the southernmost part of the Peira-Cava syncline (Fig. 4). The exposure lies along road D-2566 several hundred meters above, and about 400 m east of, the Col St. Roch (Fig. 1, locality 1). Here, a highly deformed slump mass overlying a thin (20 cm), undeformed calcareous siltstone (Fig. 4, arrow in B) can be traced for about 300 m. This slump, about 3 to 5 m thick, is formed by highly contorted and disrupted shale and sandstone.

Figure 1. Map showing Annot Sandstone exposures in the Maritime Alps north of Nice, France. Predominant northward sediment transport (arrows) and the two localities discussed in text.