by a high density of surface states localized near the middle of the GaAs band gap (23). These states are extremely efficient at capturing mobile charge carriers generated in the bulk of the semiconductor and severely limit the luminescent quantum efficiency of the crystal. The presence of surface oxides would be even more deleterious in our microstructures, where surface-to-volume ratios are orders of magnitude larger than in bulk crystals.

Recent experiments, however, have shown that simple chemical treatments are capable of removing the native oxides from GaAs and replacing them with covalently bound phases that considerably reduce the density of nonradiative surface states (24). Because the GaAs clusters are chemically bound to the silica substrate, we believe it should be possible to perform similar modifications on the microcrystallite surface, which would render these extreme quantum systems more attractive candidates for potential opto-electronic applications.

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Experiments on Hydraulic Jumps in Turbidity Currents Near a Canyon-Fan Transition

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The point at which a submarine canyon debouches on its associated abyssal fan is generally characterized by a drop in channel slope. Turbidity currents of the kind responsible for the genesis of the canyon and fan should display an internal hydraulic jump near the slope transition. No direct field observations of any such jump appear, however, to have been made. Experiments on the nature of the jump and the resulting sedimentary deposits indicate that the thickness of the deposits just downstream of the jump tends to increase as the ratio of bed shear velocity immediately behind the jump to particle fall velocity decreases.

TURBIDITY CURRENTS ARE CURRENTS of water laden with suspended sediment that move down slopes of otherwise still bodies of water. Their driving force is obtained from the sediment, which renders the flowing turbid water heavier than the clear water above. Turbidity currents occur in the ocean, lakes, and reservoirs. They constitute an important mechanism for moving sediment brought in by rivers or littoral drift to the ocean floor. In the process of doing so, turbidity currents are widely assumed to be responsible for the excavation of many submarine canyons. Below the mouth of the canyon, such a current deposits an abyssal fan that parallels in many ways its subaerial cousin (1). The sedimentary rocks deposited by turbidity currents (known as turbidites) constitute a major part of the geological record. The mechanics of turbidite formation also influence the development and location of possible petroleum traps in submarine fans (2).

The change in down-channel slope observed at the canyon-fan transition is indicative of a transition from an overall erosive environment upstream (3) to an overall depositional environment downstream (2). This transition appears to be driven at least in part by a change in flow regime of major turbidity currents from high-velocity supercritical flow to low-velocity subcritical flow (4). Studies of subaerial open-channel flows and density flows have indicated that this change in flow regime is accomplished via a hydraulic jump. A bulk Richardson number Ri describing the flow possesses a critical value Ri_c near unity, such that the range $Ri < Ri_c$ corresponds to the high-velocity regime upstream of the jump, and the range $Ri > Ri_c$ corresponds to the low-velocity regime downstream.

The nature of the submerged hydraulic jump and the resultant sedimentary deposits have been the subject of speculation. Menard (5) argued that the development of levees bordering deep-sea channels was caused by the thickening of a turbidity current after a hydraulic jump. Van Andel and Komar (6) posited the occurrence of hydraulic jumps in order to interpret the characteristics of sediment deposits in enclosed basins. Ravenne and Beghin (7) observed that certain characteristics in the sedimentary record of debris flows, for example, strong local deposition, may indicate the location of a jump. Although recent field observations of turbidity currents (8) have contributed greatly to their understanding, the hydraulic jump itself remains unobserved in the field, in part because it is inferred to occur at great depths (>1000 m). Likewise, experimental studies conducted on depositional turbidity currents (9) did not include the change in slope necessary to induce a hydraulic jump. Internal hydraulic jumps associated with salinity or temperature-induced stratification have been studied extensively (10), whereas jumps in sediment-driven flows have received little attention.

Recently Parker, Fukushima, and Pantin (11) have presented a theory of eroding and depositing turbidity currents. The theoretical framework accounts for the attainment of high velocities in submarine canyons and the consequent excavation of the canyons themselves. The model has been used to predict the development of turbidity currents in Scripps Submarine Canyon (12). Attempts to apply the model to the vicinity of the slope change between canyon and fan motivated our experiments described below. For simplicity, we modeled the slope change as a slope discontinuity.

We conducted flume experiments to elucidate: (i) the degree of similarity between internal hydraulic jumps in the vicinity of a slope discontinuity in underflows driven by salt and sediment; (ii) the nature of the deposits of sediment from suspension upstream and downstream of the hydraulic jump; and (iii) the conditions under which the slope discontinuity is clearly reflected in the depositional record.

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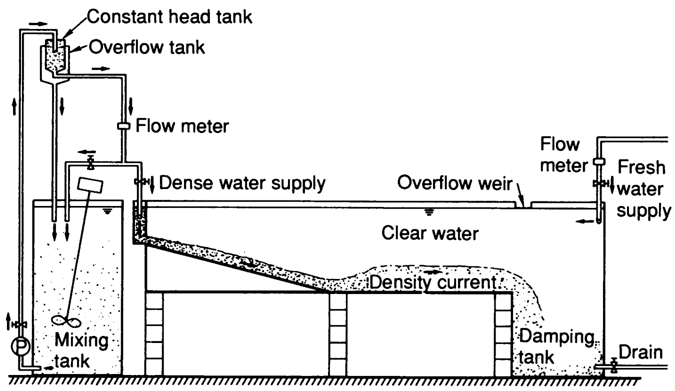
Fig. 1. Experimental apparatus; P, pump.



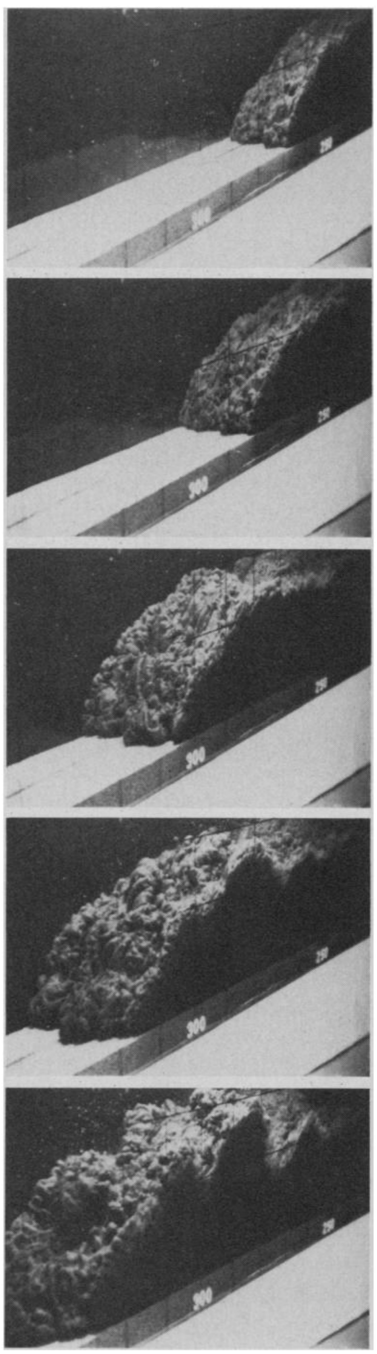


Fig. 2. Head of a continuous turbidity current flowing down the model canyon. The current is driven by 100-μm crushed coal.

The flume was 30 cm wide, 70 cm in depth, and 11.6 m in length (Fig. 1). The slope transition was modeled in a one-dimensional configuration in terms of an inclined bed with a slope S of 8 cm/m (4.6°), which represented the canyon, adjoined to a horizontal bed, which represented the abyssal fan. Before commencing an experiment, we filled the flume with uncontaminated water. The channel bottom at the beginning of each experiment was free of sediment.

The model canyon head consisted of a submerged sluice gate from which a saline or sediment-laden bottom current (Fig. 2) of known concentration could be delivered at a known rate. The density difference between the fluid of the bottom current and the uncontaminated water in the flume acted to drive the current downslope. After traversing the model canyon and fan, the current emptied into an end tank. The level of contaminated fluid in the end tank was kept below the channel bottom. This set-up allowed the downstream end of the channel to act as a submerged outfall, preventing the reflection of the turbidity current from the end tank back upstream. Proper operation of the flume and end tank allowed for the maintenance of sustained bottom currents for as long as one hour. In this way, we were able to measure the flow in detail and to model the formation of rather thick turbidites even though we used only dilute suspensions.

Our study was restricted to well-sorted sediments. This allowed the use of an optical light probe for the measurement of suspended sediment concentrations. This probe, in conjunction with a blue dye, was also used to measure saline concentrations in the salt-driven density underflows. Flow velocities (averaged over turbulence) were measured with a 3-mm micropropeller. The underflow generated in each experiment was maintained for at least 25 minutes. In the case of turbidity currents, the resulting model turbidite was characterized in terms of the downstream variation of the mass of sediment deposited per unit bed area.

We performed more than 60 experiments using salt and five grades (13) of well-sorted silica flour or ground glass (Table 1). Inlet current thickness h_0 was set at 3 cm by means of a sluice gate. Inlet flow rate per unit width q_0 was set at 33 cm^2/s, except in a few runs where it was 40 cm^2/s. Ranges for various parameters evaluated at the inlet were as follows: (i) the inlet fractional excess density θ_0 of the current over the uncontaminated water was 0.002 to 0.015; (ii) the inlet buoyancy discharge per unit width $\phi_0 = g\theta_0 q_0$, where g denotes the acceleration of gravity, was 40 to 450 cm^3/s^3; (iii) the inlet layer-averaged flow velocity $U_0 = q_0/h_0$ was 11 to 13 cm/s; and (iv) the inlet bulk Richardson number $Ri_0 = \phi_0/U_0^3$ was 0.05 to 0.5. The inlet Richardson numbers were sufficiently below unity to ensure that the underflows were supercritical at the inlet.

Table 1. Sediment characteristics.

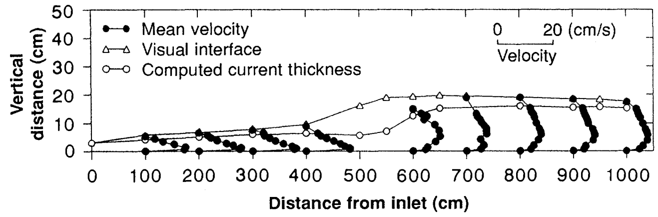
Sediment	Mean size (μm)	Submerged specific gravity	Fall velocity (cm/s)
Silica	5	1.65	0.002
Silica	10	1.65	0.008
Silica	25	1.65	0.060
Glass	30	1.50	0.085
Glass	70	1.50	0.370

Vertical velocity profiles for a typical saline current (Fig. 3) were measured at several sections before and after the jump. These profiles allowed determination of layer thickness h, layer-averaged flow velocity U, and bulk Richardson number $Ri = \phi/U^3$ from the conventions of Parker *et al.* (14); the buoyancy discharge ϕ is constant for saline currents. We were thus able to locate the beginning of the jump at a point near the slope discontinuity.

The measurements show that h is typically doubled and U is nearly halved across the jump. As the jump was traversed, the point in a vertical profile where the maximum flow velocity was attained rose markedly, which indicates that there was rather sudden decrease in bed shear stress on the subcritical (downstream) side of the jump. This decrease has the potential to produce a noticeable discontinuity in the nature of any sediment deposited from such a current.

Turbidity currents driven by 5-μm sediment showed little tendency to deposit sediment either in the model canyon or on the model fan. The structure of the current through the jump was almost identical for the two cases of a saline underflow (Fig. 3) and a turbid underflow with the same inlet conditions, but laden with 5-μm sediment rather than salt (Fig. 4). In both cases, the same sharp decline in bed shear stress could be inferred. The velocity measurements in the proximity of the bed and the law of the

Fig. 3. Observations for a typical saline current.



wall (*15*) for the case of a hydraulically rough flow allow estimation of this parameter. Values of bed shear velocity u_*, that is, the square root of the quotient of the bed shear stress divided by the fluid density, were ~1.6 cm/s before the jump and 0.4 cm/s after the jump.

The flow systematically tended to become more depositional in nature as successively coarser sediments of 10, 25, 30, and 70 μm were tested. The jump was still clearly manifested for 10-μm material, but was rather weak in the case of 25-μm material. For the more dilute runs with 30-μm material, the currents often dissipated because of deposition before reaching the model fan. Even when the flow was dense enough to reach the model fan, no jump was observed. In the case of 70-μm material, all currents were so strongly depositional that only a few of them reached beyond the slope discontinuity.

Turbidite bed thickness decreased roughly exponentially in the downstream direction as the size of the material increased from 25 to 70 μm (Fig. 5). All of the deposited material was traveling in suspension at the inlet. No discontinuity in depositional pattern due to the break in slope could be discerned. Even in the case of currents driven by 50- and 10-μm sediment, for which a jump was clearly manifested, no marked change in the rate of deposition or thickness of the deposits was seen in the vicinity of the jump.

It follows that a sudden drop in bed shear stress associated with a jump does not necessarily leave a discernible signature in the depositional record immediately downstream. The physical reason for this effect can be interpreted in terms of the fall velocity v_s of the material available for deposition from suspension. On the basis of estimates of fall velocities of 0.002 and 0.008 cm/s for 5- and 10-μm material, respectively, and a typical post-jump flow velocity of 5 cm/s, a particle in suspension would fall between 0.4 and 1.6 mm per meter traveled downstream of the jump. Because the model fan is only 6.6 m in length, little of the suspended sediment can settle out in response to even markedly reduced shear stress upstream of the end of the flume. The depositional response to the jump must be manifested farther downstream, perhaps in terms of thickened levees (*5*).

Even though a turbidity current is driven by suspended sediment, it may easily be competent to move rather coarse material as bedload (*16*). This coarser material might respond more quickly to the reduced shear stress across the jump. To test this idea, we exploited the similarity in flow structure displayed by saline and fine-grained turbidity underflows having the same inlet conditions (Fig. 4). In each of several experiments, a saline current colored with a green fluorescent dye was generated. Upon establishment of a developed flow, a small but continuous supply of white plastic particles 3 mm in diameter was incorporated into the flow at the inlet. These particles had a specific gravity of 1.05 and an estimated v_s of 4 cm/s.

The behavior of these particles was clearly visible through the green dye. The particles were transported exclusively as bedload down the model canyon and did not deposit there. The case thus modeled up to the jump was that of supply-limited transport of bedload particles. Upon traversing the jump, most of the plastic beads immediately deposited. A discontinuous jump in turbidite thickness was thus formed in response to markedly reduced bed shear stress on the downstream side of the jump. The deposit (Fig. 6) was similar to that observed in an open-channel flow laden with coarse material downstream of a hydraulic jump (*17*).

The experiments indicate that the thickness of the sediment deposit left immediately downstream of the jump tends to increase as the ratio u_*/v_s of the bed shear velocity immediately behind the jump to the particle fall velocity decreases. This relation is inferred from the observation that this ratio was 200 for the currents driven by 5-μm sediment and 50 for the 10-μm sediment; the jump was clearly manifested with these

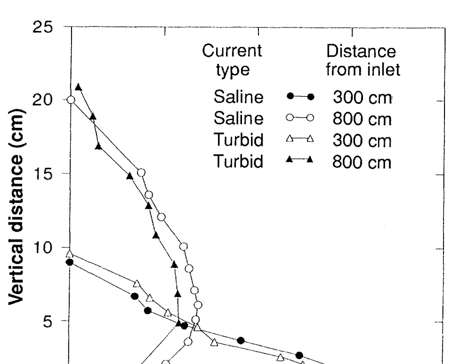


Fig. 4. Velocity profiles before and after the jump produced by a saline and a turbidity current, both having the same inlet conditions. The break in slope is at 500 cm from the inlet.

Fig. 5. Depositional patterns produced by turbidity currents having the same inlet conditions and time duration, but driven by sediment with different size.

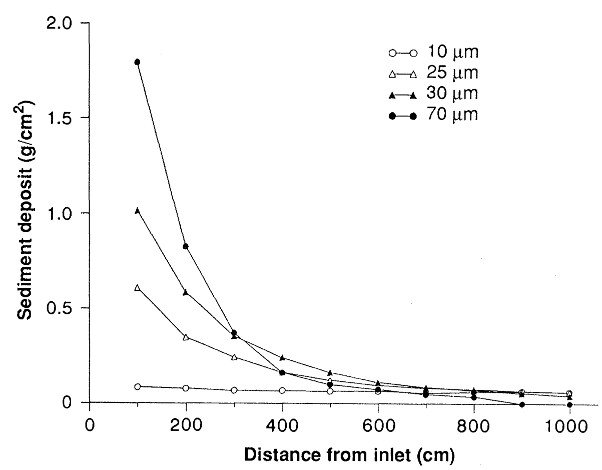
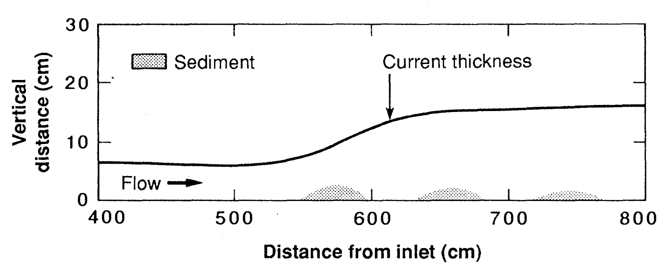


Fig. 6. Schematic of observed deposits of plastic particles based on photographs.



sediment sizes, but no effects were seen on the depositional pattern. For the plastic particles, the ratio was 0.1. These particles moved as bedload on the sloping canyon, but were deposited immediately after the drop in shear stress.

The fan deposits formed in the experiments were two-dimensional because the currents were not able to spread laterally. Many turbidite environments do involve significant lateral flow, but there are a number of cases where turbidity flows are fairly two-dimensional over significant distances. For instance, the major channel of the Rhone river fan (*18*) shows significant spillover from the channel to the sides, but the channel has remained in the same place during thousands of years of deposition, being simply displaced vertically.

On the basis of our observations, a continuous, channelized turbidity current driven by fine material and experiencing a hydraulic jump in the proximity of a canyon-fan transition drops most of its bedload immediately downstream of the jump. The suspended load can be expected to respond more gradually to the change in flow regime, with the resulting deposit spread out over several hundred meters to several kilometers. This result seems to agree with field observations that show a zone of hemipelagic shale separating channel mouth deposits from lobe deposits in submarine fans (*2*) and supports the idea of sediment bypassing put forward by Mutti (*19*). The significance of the shale interval in hydrocarbon exploration is that it could act as a permeability barrier between lower fan lobes and other potential reservoir facies in the upper and middle fan (*2*).

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Understanding the Anomalous Electrophoresis of Bent DNA Molecules: A Reptation Model

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In polyacrylamide gel electrophoresis, the retardation of DNA molecules containing regions of intrinsic curvature can be explained by a novel reptation model that includes the elastic free energy of the DNA chain. Computer simulations based on this model give results that reproduce the dependence of anomalous mobility on gel concentration, which is quantified by new experimental data on the mobilities of circularly permuted isomers of kinetoplast DNA fragments. Fitting of the data required allowing for the elasticity of the gel.

INTRINSIC CURVATURE OF THE DNA double helix, due to structural polymorphism in DNA, as in the case of natural and synthetic DNA sequences containing tracts of oligo(dA)-oligo(dT) (*1–5*), or induced by the binding of specific proteins (*6*), has been demonstrated in a number of systems. These "bent" DNA molecules have dramatically reduced mobilities for a given size in polyacrylamide gel electrophoresis but essentially normal mobilities in agarose gels (*1*). The reduced mobility is correlated with a decrease in the overall dimensions of a DNA molecule, as has been established by independent hydrodynamic measurements made with the use of rotational diffusion techniques (*1, 4, 7*). However, a valid quantitative treatment relating mobility and overall molecular dimensions has remained elusive. We report the results of calculations of the electrophoresis of semiflexible polyelectrolyte chains containing intrinsic bends that provide a model for understanding the anomalous electrophoretic behavior of bent DNA molecules.

Current theories of the electrophoresis of linear DNA are based on the reptation model of deGennes (*8*) and Doi and Edwards (*9*), in which DNA chains migrate in a snakelike fashion among the fibers of an electrophoresis gel. The gel fibers constrain the motion of the chain, confining it largely to translation along the local axis of a "tube" (*9*). The tube is composed of a sequence of segments, which lie between consecutive points of contact between the DNA chain and gel fibers. The conformation of the chain changes as it moves along the tube, entering new tube segments at the leading end of the chain and abandoning tube segments at the trailing end. In an applied electric field this process is biased, with more moves being made in the downfield direction than upfield; hence there is a net displacement of the chain's center of mass. Lerman and Frisch (*10*) and Lumpkin and Zimm (*11*) applied reptation models to the electrophoresis of DNA by equating the component of the electrophoretic force on the DNA acting along the tube axis to the frictional resistance for translation along the tube. The mobility of the chain, μ, is then given by the component of the center-of-mass velocity of the chain in the field direction, $\dot{x}_{cm}$,

$$\mu = \langle \dot{x}_{cm} \rangle / E = \frac{Q}{\zeta} \langle h_x^2 / L^2 \rangle \qquad (1)$$

where the field of strength E is along the x axis, Q is the total electrophoretic charge on the DNA, ζ is the friction constant for motion along the tube, h_x is the component of the tube's end-to-end vector, **h**, in the field direction, L is the contour length of the tube, and the angle brackets denote an average over an ensemble of conformations.

Although Eq. 1 is often cited to explain the anomalous gel electrophoresis behavior of intrinsically bent DNA molecules, logical inconsistencies can arise in applying the underlying model to explain the anomalous mobilities of bent DNAs. If the path taken by the chain is rigidly fixed in space and

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