Appendix 23

Mass Movements in the Formation of Submarine Canyons

There is a variety of downslope flows of debris, such as landslides, slumps, debris flows, hyperconcentrated flows, and turbidity currents (see Appendix 10).[1] A slump is a downward slipping mass of rock or unconsolidated debris, moving as a unit and usually with backward rotation on a more or less horizontal axis parallel to the slope (Figure A23.1).[2,3] Generically, downslope sliding of mixed sediment and water is called a *mass movement* or *sediment gravity flow*. Submarine mass movement during the Flood is a likely explanation for many sedimentary and geomorphic features that remind geologists of ice ages.[4] Of specific interest is submarine mass movement with regard to the origin of submarine canyons.

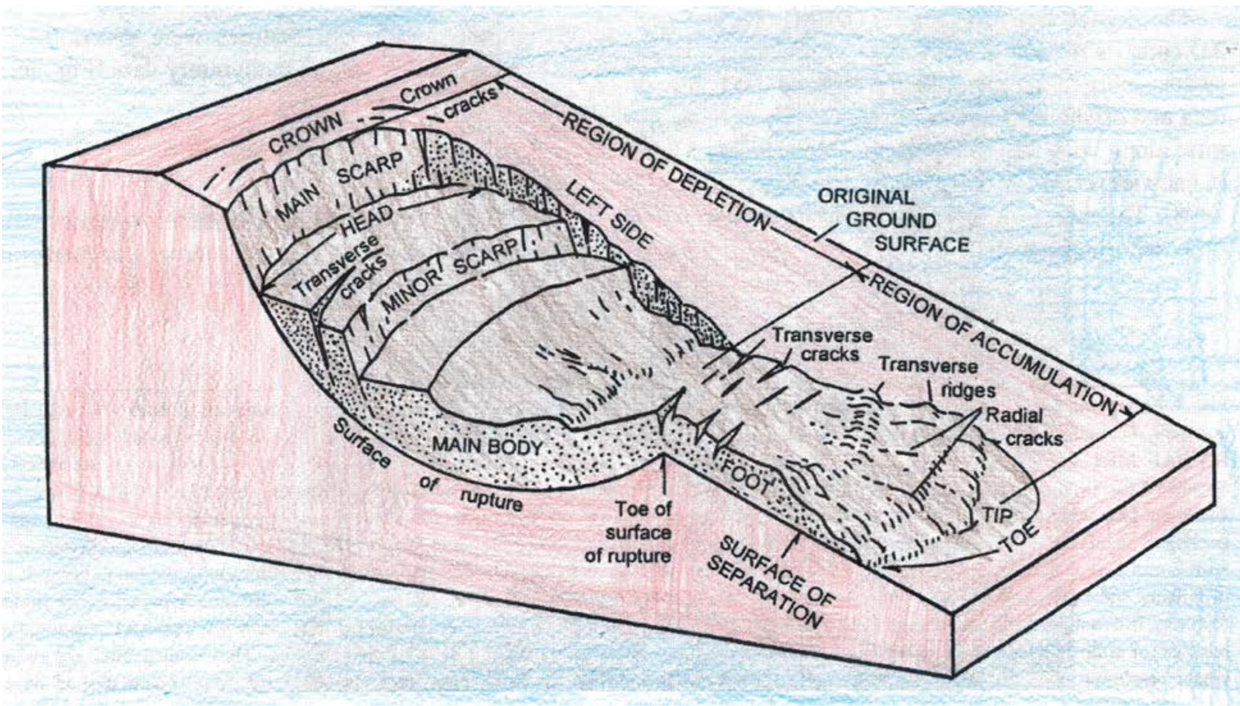

Figure A23.1. Schematic of a rotational slump (after Varnes, 1978).

[1] Oard, M.J., 1997. *Ancient Ice Ages or Gigantic Submarine Landslides?* Creation Research Society Monograph No. 6, Chino Valley, AR., pp. 33–39.

[2] Neuendorf, K.K.E., J.P. Mehl, Jr., and J.A. Jackson, 2005. *Glossary of Geology*, Fifth Edition. American Geological Institute, Alexandria, VA, p. 606.

[3] Varnes, D.J., 1978. Slope movement types and processes; in: Schuster, R.L. and Krizek, R.J. (editors), *Landslides, Analysis and Control*, National Academy of Sciences Special Report 176,, Washington, D.C., pp. 11–33.

[4] Oard, Ref. 1, pp. 1–129.

Turbidity Currents and Debris Flows

There is much debate over the nature of mass movement.[5] A major problem arises from trying to extrapolate flow processes from the resulting *deposit*.[6] It is rare that scientists observe mass movements in action in the ocean. Another problem lies in the confusing and ever-changing classification system.

One helpful way to classify mass movement is to use a spectrum (based on the sediment/water mixture) with two end members: (1) the turbidity current that contains only a little sediment suspended by turbulent flow, and (2) the debris flow that is mostly sediment. Between these extremes, there are many types of sediment gravity flows characterized not only by the relative amounts of sediment and water, but also by the clay content, the bottom slope, and flow velocity.

There is much confusion over the definition of a turbidity current and its products.[7,8,9] True turbidity currents contain less than 9% sediment. This is probably the reason why true turbidity currents are not particularly erosive. Turbidity currents generally *deposit* sediment, although they can erode, if the turbidity current is accelerating. But if a turbidity current accelerates enough, it usually transforms into another type of flow and can no longer be considered a turbidity current.[10] Turbidity currents are usually the last transformation before a mass movement slows down and the sediment is deposited.

The deposition of multiple turbidity currents over many years is believed to have built up submarine fans. However, observations of submarine fans show that they are more complex than previously thought, and that the models for their formation are simplistic and obsolete.[9]

It is fairly well known that debris flows are *not* particularly erosive. Thus, a debris flow origin for the excavation of submarine canyons seems problematic. Debris flows tend to ride atop a cushion of water and commonly fail to erode the underlying bed.[11,12] Therefore, it appears that neither debris flows nor turbidity currents are good candidates for eroding submarine canyons.

Hyperconcentrated flows are similar to debris flows, although the strict definition can be confusing. These flows contain less sediment than most debris flows but more than in turbidity currents.[13]

In regard to the erosion of submarine canyons, scientists have discovered that rivers and their delta deposits rarely produce turbidity currents.[14] Only major events, such as floods, seem able to produce turbidity currents at the head of a submarine canyon. A variety of other mass movements can be generated by the sediment transported into the head of submarine canyons by

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[5] Klaucke, I., D.G. Masson, N.H. Kenyon, and J.V. Gardner, 2004. Sedimentary processes of the lower Monterey Fan channel and channel-mouth lobe. *Marine Geology* 206:181–198.
[6] Mulder, T. and J. Alexander, 2001. The physical character of subaqueous sedimentary density flows and their deposits. *Sedimentology* 48:269–299.
[7] Shanmugam, G., 1996. High-density turbidity currents: are they sandy debris flows? *Journal of Sedimentary Research* 66:2–10.
[8] Shanmugam, G., 1997. The Bouma sequence and the turbidite mind set. *Earth-Science Reviews* 42:201–229.
[9] Shanmugam, G., 2000. 50 years of the turbidite paradigm (1950s—1990s): deep-water processes and facies models—a critical perspective. *Marine and Petroleum Geology* 17:285–342.
[10] Mulder and Alexander, Ref. 6, p. 289.
[11] Shanmugam, Ref. 9, p. 305.
[12] Mulder and Alexander, Ref. 6, p. 280.
[13] Shanmugam, Ref. 9, p. 301.
[14] Mulder, T. and J.P.M. Syvitski, 1995. Turbidity currents generated at river mouths during exceptional discharges to the world oceans. *The Journal of Geology* 103:285-299.

currents flowing parallel to the shoreline. Over time, sufficient sediment builds up to created a slide down the submarine canyon. Earthquakes and landslides can also generate mass movement of loose material down a canyon. So, for most canyons, downslope erosive flow is rather rare. These issues raise the question of whether any present-day process is sufficient to explain the origin of submarine canyons.

The Grand Banks Slide

A little light on the origin of submarine canyons was shed by a magnitude 7.2 earthquake that occurred in 1929 on the Grand Banks off New England and southeast Canada. This earthquake had an epicenter below 6,500 feet (2,000 m) of water, and initiated a submarine landslide. This landslide has been thoroughly investigated over the years and changed the thinking of geologists on catastrophic flows.[15] It spawned the idea of the turbidity current by demonstrating that sediment masses can travel downslope over long distances, even over a low slope, as the sediment becomes suspended by turbulent flow.

Modern analysis by submersible vehicles, seafloor scanning, and ocean bottom cores has shown that the Grand Banks continental slope failed at a several locations. The Grand Banks slide started off as many small slumps that were then transformed into debris flows that accelerated on the steep slope and then changed to turbidity currents as the slope became less steep. *Where the debris flow was accelerating and before it became more watery and transformed into a turbidity current, erosion of the slope did occur*. The turbidity current spread the sediments far out onto the abyssal plain. Deposition was on a nearly flat sea bottom. What was especially surprising is that the initial debris flows accelerated up to 43 mph (69 kph), as demonstrated by the timing of submarine cable breaks. Some investigators, however, believe the debris flows were moving at speeds of 55 to 110 mph (88 to 177 kph) at the beginning.[16] The Grand Banks slide indicated that something was missing in the understanding of sediment mass flows in relation to the erosion of the continental slope and the origin of submarine canyons. This missing mechanism has likely been provided by the Var submarine slide that spawned a new type of mass flow called a “concentrated density flow.” More details of the Var submarine slide are provided in the boxed section at the end of Chapter 74. It is probably during the acceleration of the debris flow and entrainment of water that an erosive concentrated density flow formed.

A major problem in applying modern knowledge to the origin of submarine canyons lies in the unfocused nature of modern mass movements. Submarine canyons would require the focusing of erosion along one particular linear track at sufficient rates to concentrate erosion to form these features. Clearly, the Flood model provides the best explanation for the rapid formation of the numerous continental shelf submarine canyons observed around the world.

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[15] Piper, D.J.W., P. Cochonat, and M.L. Morrison, 1999. The sequence of events around the epicenter of the 1929 Grand Banks earthquake: initiation of debris flows and turbidity currents inferred from sidescan sonar. *Sedimentology* 46:79-97.

[16] Mulder, T., B. Savoye, and J.P.M. Syvitski, 1997. Numerical modelling of a mid-sized gravity flow: the 1979 Nice turbidity current (dynamics, processes, sediment budget and seafloor impact). *Sedimentology* 44:316.