SURFACE PROCESSES

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Contents

Summary

Many areas are threatened by natural hazards associated with internal processes and surface processes. Every place on earth is affected by various kinds of surface processes: those processes with causes and effects found at or near Earth's surface.

These processes that principally involve the actions of water, ice, wind, and gravity; local climate plays a major role in determining the relative importance of those properties. Earth's surface is, geologically, a very active place. It is here that one sees the interactions of the internal heat of the earth (which builds mountains and shifts the land), the external heat from the sun (which drives the wind and provides the energy to drive the hydrologic cycle), and the inexorable force of gravity (which constantly tries to pull everything down to the same level). This article explores several kinds of surface processes: stream-related processes, including flooding; coastal processes of erosion and mass transport; mass movements, the downhill march of material; and the effects of ice and wind in sculpturing the land. The various hazards associated to the surface processes were discussed briefly.

1. Introduction to Earth's Surface Process

There is a thin layer at the surface of Earth, which constitutes Man's environment in the ecological sense; it provides both the resources and conditions suitable for life. Earth's surface is part of the biosphere humans depend on for its life-giving qualities. The atmosphere and hydrosphere—those thin and volumetrically insignificant shells of Earth—are not only vital to life on the planet's surface but also control its continual reshaping by the forces of weathering and erosion, transport, and deposition.

Like the interior dynamic process in Earth, surface processes have been going on for hundreds of millions of years and have shaped the landscape of our Earth today. At Earth's surface, rocks that were formed at high temperatures and pressures break down into minerals which are stable in the presence of air, water, and, frequently, biological activity. The weathered material may be transported by water, glaciers, or wind and re-deposited as rocks such as sandstones, limestone, or coal beds. Surface processes are all of those processes that sculpt Earth's surface. Most surface processes are driven by water, although wind, ice, and gravity, as well as human activity, are also significant.

2. Dynamics of River Systems

Water is the most important agent sculpturing Earth's surface. The land surface may be thought of as being composed of a complex network of linking drainage basins. Within each basin precipitation, usually falling as rain, hits the soil or vegetation, seeps into the soil, or runs off its surface, and then enters a drainage channel. In this course, water is involved in the process of weathering, erosion, transport, and deposition, and is the cause of change for landforms. Mountains may be raised by the action of plate tectonics and volcanism, but they are shaped primarily by water. Streams carve valleys, level plains, and move tremendous amounts of sediment from place to place.

The transport of water, evaporated from the sea, over the land, its descent as precipitation, drainage from the land and back into the sea is called the "hydrologic cycle." All the water at or near Earth's surface is caught up in the hydrologic cycle (Figure 1).

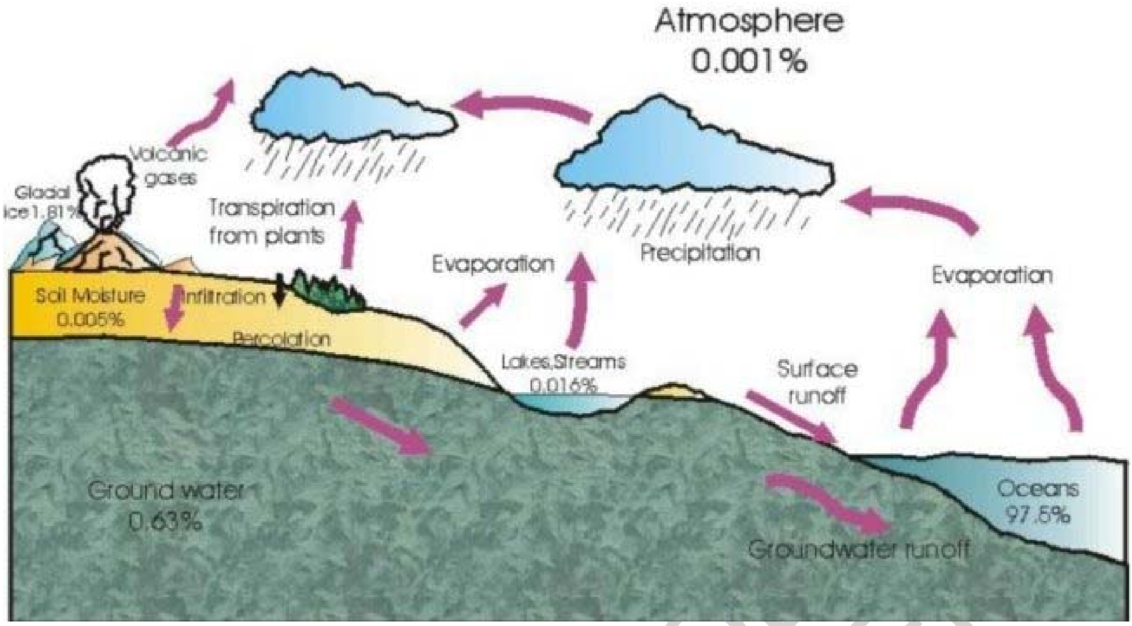

Figure 1. Principal processes of the hydrologic cycle

2.1 A River System and its Major Features

A river system consists of a main channel and all of the tributaries that flow into it. It is bounded by a divide (ridge), beyond which water is drained by another system. A typical river system can be divided into three subsystems: a collecting system, a transporting system, and a dispersing system.

A river's collecting system, or branches, consisting of a network of tributaries in the head-water region, collects and funnels water and sediment to the main stream. It commonly has a treelike drainage pattern, with numerous branches that extend upslope toward the divide.

The transporting system, or "trunks," is the main trunk stream that functions as a channel through which water and sediment move from the collecting area toward the ocean. Although the major process is transportation, this subsystem also collects additional water and sediment. Deposition occurs where the channel meanders back and forth and when the river overflows its banks during a flood stage. Erosion, deposition, and transportation thus occur in a river's transporting subsystem.

The dispersing system, or roots, consists of a network of distributaries at the mouth of a river, where sediment and water are dispersed into an ocean, a lake, or a dry basin. The major processes are the deposition of the coarse sediment load and the dispersal of fine-grained material and river waters into the basin.

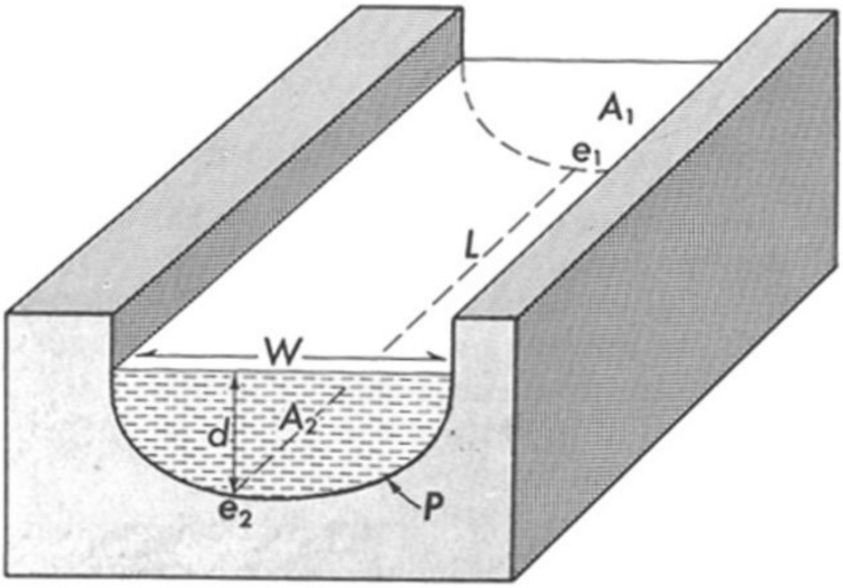

Figure 2. Stream channel dimensions

A stream is any body of flowing water confined within a channel. Studies of flow in stream channels have to take into account the shape of the channel. Commonly used descriptors of channels are indicated in Figure 2 here:

- *W*: the width of water in the channel,
- *P*: the wetted perimeter
- *A*: the area of a transverse section of the stream
- *d*: the water depth
- *S*: the stream gradient (the steepness of the stream channel) or the drop in elevation between two points on the bottom of the channel divided by the projected horizontal distance between them.

Discharge (Q) is the amount of water passing a given point (or more precisely, through a given cross-section) during a specific interval of time. Discharge is the product of channel cross-section area (A) times stream velocity (V):

$$Q = AV \tag{1}$$

The conventional unit used to express discharge is cubic meters per second. Discharge may vary from less than one cubic meter per second on a small creek to millions of cubic meters per second in a major river.

The velocity of flowing water is not uniform through the river channels. It depends on the shape and roughness of the channel, and on the stream pattern. Like all the other things, the higher the gradient, the steeper the channel, and the faster the stream flows. Gradient and velocity commonly vary along the length of a stream, especially if the stream is a large one.

The ability of running water to erode and transport sediment is largely dependent on stream velocity. Figure 3 summarizes the results of experimental studies on water's capacity to erode, transport, and deposit sediment. The velocity at which a particle of a given size is picked up and moved is shown on the upper curve. The threshold velocity is represented by a zone on the graph, not a line, because of variations resulting from stream depth, particle shape and density, and other factors. The lower curve indicates the velocity at which a particle of a given size settles out and is deposited and the velocity here could be called settling velocity—the velocity at which a particle settles out of suspension.

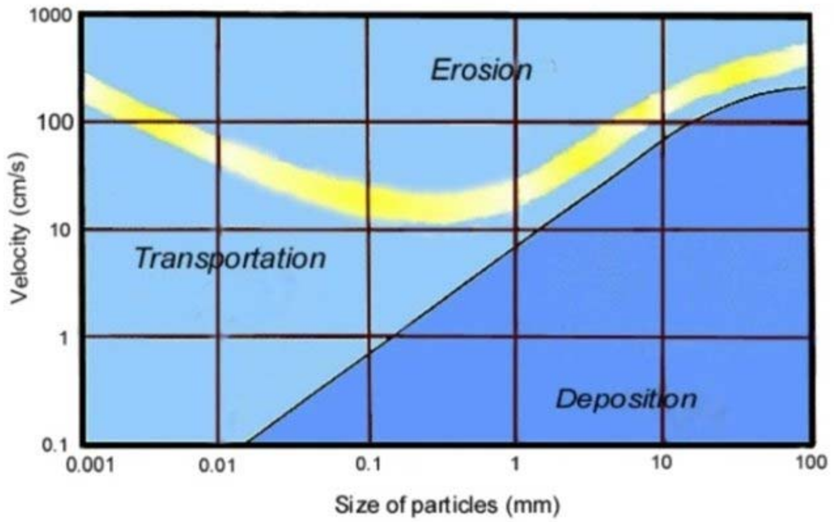

Figure 3. The threshold velocity for sediment transport provides an important insight into processes of stream erosion, transportation, and deposition

Water is a powerful agent for transporting material. Flowing water in natural streams provides a fluid medium by which loose, disaggregated regolith is picked up and transported to the ocean. The total quantity of material that a stream transports is called "load." Within a stream system, sediment is transported in three ways: (a) fine particles are moved in suspended load, which is the most obvious and generally the largest fraction of material moved by a river; (b) coarse particles are moved by traction (rolling, sliding, and saltation) along the streambed; (c) dissolved material is carried in the dissolved load.

2.2 Process of Sediment Transport and Erosion

Streams can move material in several ways. The "suspended load" consists of silt-sized and clay-sized particles that settle slowly and tend to remain suspended. They can settle in a bucket of quiet water in an hour or even longer. Suspended sediment clouds a stream and gives the water a muddy appearance. Heavier debris, like medium and coarse sand grains, may be rolled or pushed along the bottom of the streambed. This is called the "bed load" of the stream. Since water also dissolves some material directly from its channel bottom and from the particles in mechanical transport, these materials can be called the “dissolved load.”

Variations in a stream’s velocity along its length are reflected in the sediments deposited at different points. The more rapidly a stream flows, the larger and denser are the particles moved. Stream channels transport sediments and water from headwaters to mouth, systematically depositing and eroding, abrading and breaking sediment particles during the transport process. The relationship between the velocity of water flow and the size of particles moved accounts for one characteristic of stream-deposited sediments: they are generally well sorted by size or density, with materials deposited at a given point tending to be similar in size or weight. If a stream is still carrying a substantial load as it reaches its mouth, and it then flows into still waters, a large fan-shaped pile of sediment, a delta, may be built up. A similarly shaped feature, an alluvial fan, is formed when a tributary stream flows into a slower flowing larger stream, or a stream flows from mountains into a dry plain or desert.

River systems erode the landscape by three main processes: (a) removal of regolith, (b) down-cutting of the stream channel by abrasion, (c) headward erosion. One of the most important processes of erosion is the removal and transport of rock debris (regolith) produced by weathering. Through weathering and mass-wasting processes, which include landslides and soil creep, and occur when gravity alone moves soil and rock down hill-slopes to stream channels, loose rock debris is washed downslope into the stream system and is transported as sediment load in streams or rivers. In addition, soluble material is carried in solution. The net result is that the blanket of regolith is continually being removed and transported to the sea by stream action.

In the meantime, the channel bottom is chipped and scratched as the particles tumble and bounce along. In mountain streams where the gradient is steep, large heavy boulders bash the bottom, especially in flood time, and abrasion is rapid. We may also notice the effect of the down-cutting of the stream channel. Canyons or gorges that have near-vertical walls are clear examples of the stream‘s power to cut downward, almost as if a giant saw had been cutting through the bedrock.

Erosion is most vigorous in the steep upper reaches of a stream, however, also during the process of stream erosion and valley evolution, streams have a universal tendency to erode headward, or upslope, and to increase the lengths of their valleys until they reach the divide; this is referred to as “headward erosion.”

Stream channels and floodplains are built and maintained by erosion and deposition of sediments. The original small irregularities in the channel cause local fluctuation in flow velocity, which result in a little erosion where the water flows strongly against the side of the channel and some sediment deposited where the flow slows down. Then meander begins to form in the stream. The combined effects of erosion on the outside banks and deposition of sediment on the inside banks of meanders, as well as downstream meander migrations, produce a broad, fairly flat expanse of land covered with sediment—floodplain. This is a form of stability called dynamic equilibrium, where channel bed and banks are not a net source of sediment to the stream system. Channel stability in a given stream reach occurs from a delicate balance among stream flow, channel form, influx of sediment from the watershed, and loss of sediment to downstream reaches. Although stream flows and sediment loads are variable within single years and year-to-year, sediment balance and channel stability occur over the long term.

2.3 Major Hazard: Flooding

Floods are the result of a multitude of naturally occurring and human-induced factors, but they all can be defined as the accumulation of too much water in too little time in a specific area. During the twentieth century, floods were the number-one natural disaster in the United States in terms of number of lives lost and property damage. They can occur at any time of the year, in any part of the country, and at any time of the day or night. Most lives are lost when people are swept away by flood currents, whereas most property damage results from inundation by sediment-laden water. Flood currents also possess tremendous destructive power, as lateral forces can demolish buildings and erosion can undermine bridge foundations and footings leading to the collapse of structures. Types of floods include regional floods, flash floods, ice-jam floods, storm-surge floods, dam- and levee-failure floods, and debris, landslide, and mudflow floods (see *Natural Weather Induced Hazards: Floods, Storms, and Fires*).

Flood disasters have been one of the most serious natural calamities in China, causing 40 percent of the economic loss of the total loss caused by all natural calamities. In 1998, a catastrophic flood occurred in the areas of the Yangtze, Songhua, and Nen river basin, which caused tremendous economic loss. For details of this tremendous disaster, please see the case studies in the following article (see *Case Studies of Natural Disasters*).

3. Mass Movement Process

Mass movement includes all processes by which masses of rock and soil move downhill under the influence of gravity. Mass movement can either be slow, subtle, almost undetectable on a day-to-day basis but cumulatively large over days or years, or sudden, swift, and divesting, as in a rockslide or avalanche. The damage it causes might be much greater than one can imagine from the usually brief coverage in the textbooks or news media, especially in the case of the landslide, one of the most general and important type of mass movements.

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Bibliography

Eardley A. J. (1972). *Science of the Earth*, New York: Harper and Row Publishers. [Intended for general education courses in geology and earth science].

Hamblin W. K. and Christiansen E. H. (1995). *Earth's Dynamic Systems,* seventh edition, New Jersey: Prentice-Hall, Inc. [This book presents how our Earth works as a planet as well as the dynamic process both in the interior and outer part of the Earth].

Botkin D. B. and Keller E. A. (1998). *Environmental Science, Earth as a Living Planet*, second edition, New York: John Wiley and Sons, Inc. [This provides an up-to-date introduction to the most important and useful concepts in the study of the environment].

Montgomery C. W. (1997). *Environmental Geology*, fifth edition, New York: WCB/McGraw-Hill Company. [This book presents geology applied to life, for example, how geologic processes and hazards influence human activities and related environmental problems].

Bryant E. A. (1991). *Natural Hazards*, Cambridge: Cambridge University Press. [This book gives a good description of natural hazards that we face today and related issues].

Stefan J. and Wieczorek G. F. (1994). *Landslide Susceptibility in the Tully Valley Area, Finger Lakes Region*, USGS Open-File-Report, pp. 94–615, New York. [US Geological Survey provides a variety of surface processes information; Figure 6 and Figure 7 are taken from: http://walrus.wr.usgs.gov/].

Biographical Sketches

Li Juan graduated from University of Science and Technology of China, and now is candidate Dr. Student of Institute of Geophysics, China Seismological Bureau. Her research focuses on seismic hazard and risk analysis, and simulation of rock failure. Member of Chinese Geophysical Society.

Prof. Chen Yong graduated from the University of Science and Technology of China in 1965. Member of Chinese Academy of Sciences. Vice president of Chinese Geophysical Society. Vice president of Chinese Seismological Society. He is now engaging in: geophysical characteristics of active continental tectonics, fractal analysis of seismicity, the simulation of natural disasters and rock physical property study.