RIVER MEANDERS

The striking geometric regularity of a winding river is no accident. Meanders appear to be the form in which a river does the least work in turning; hence they are the most probable form a river can take

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Is there such a thing as a straight river? Almost anyone can think of a river that is more or less straight for a certain distance, but it is unlikely that the straight portion is either very straight or very long. In fact, it is almost certain that the distance any river is straight does not exceed 10 times its width at that point.

The sinuosity of river channels is clearly apparent in maps and aerial photographs, where the successive curves of a river often appear to have a certain regularity. In many instances the repeating pattern of curves is so pronounced that it is the most distinctive characteristic of the river. Such curves are called meanders, after a winding stream in Turkey known in ancient Greek times as the Maiandros and today as the Menderes. The nearly geometric regularity of river meanders has attracted the interest of geologists for many years, and at the U.S. Geological Survey we have devoted considerable study to the problem of understanding the general mechanism that underlies the phenomenon. In brief, we have found that meanders are not mere accidents of nature but the form in which a river does the least work in turning, and hence are the most probable form a river can take.

Regular Forms from Random Processes

Nature of course provides many opportunities for a river to change direction. Local irregularities in the bounding medium as well as the chance emplacement of boulders, fallen trees, blocks of sod, plugs of clay and other obstacles can and do divert many rivers from a straight course. Although local irregularities are a sufficient reason for a river's not being straight, however, they are not a necessary reason. For one thing, such irregularities cannot account for the rather consistent geometry of meanders. Moreover, laboratory studies indicate that streams meander even in "ideal," or highly regular, mediums [*see illustration on page 64*].

That the irregularity of the medium has little to do with the formation of meanders is further demonstrated by the fact that meandering streams have been observed in several naturally homogeneous mediums. Two examples are ocean currents (notably the Gulf Stream) and water channels on the surface of a glacier. The meanders in both cases are as regular and irregular as river meanders.

The fact that local irregularities cannot account for the existence of river meanders does not rule out other random processes as a possible explanation. Chance may be involved in subtler and more continuous ways, for example in turbulent flow, in the manner in which the riverbed and banks are formed, or in the interaction of the flow and the bed. As it turns out, chance operating at this level can explain the formation of regular meanders. It is a paradox of nature that such random processes can produce regular forms, and that regular processes often produce random forms.

Meanders commonly form in alluvium (water-deposited material, usually unconsolidated), but even when they occur in other mediums they are invariably formed by a continuous process of erosion, transportation and deposition of the material that composes the medium. In every case material is eroded from the concave portion of a meander, transported downstream and deposited on the convex portion, or bar, of a meander. The material is often deposited on the same side of the stream from which it was eroded. The conditions in which meanders will be formed in rivers can be stated rather simply, albeit only in a general way: Meanders will usually appear wherever the river traverses a gentle slope in a medium consisting of fine-grained material that is easily eroded and transported but has sufficient cohesiveness to provide firm banks.

A given series of meanders tends to have a constant ratio between the wavelength of the curve and the radius of curvature. The appearance of regularity depends in part on how constant this ratio is. In the two drawings on page 62 the value of this ratio for the meander that looks rather like a sine wave (*top*) is five for the wavelength to one for the radius; the more tightly looped meander (*bottom*) has a corresponding value of three to one. A sample of 50 typical meanders on many different rivers and streams has yielded an average value for this ratio of about 4.7 to one. Another property that is used to describe meanders is sinuosity, or tightness of bend, which is expressed as the ratio of the length of the channel in a given curve to the wavelength of the curve. For the large majority of meandering rivers the value of this ratio ranges between 1.3 to one and four to one.

Close inspection of the photographs

ENTRENCHED MEANDERS of the Colorado River in southern Utah were photographed from a height of about 3,000 feet. The meanders were probably formed on the surface of a gently sloping floodplain at about the time the entire Colorado Plateau began to rise at least a million years ago. The meanders later became more developed as river cut deep into layers of sediment. Mean downstream direction is toward right.