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A potential vorticity hydrodynamic theory for the formation of elongate river channels (Mississippi Bird' s Foot and tie channels)

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Sediment-laden river flows debouch into quiescent see water in the form of a turbulent jet that decelerates and expands rapidly, causing sediment deposition. Turbulent jet spreading may be characterized as a Gaussian velocity profile that flattens and widens downstream as a result of shearing and lateral mixing at the jet margins. Recent experiments have demonstrated that this Gaussian shape controls the time-averaged sedimentation pattern at jet margins, and thus the occurrence of elongate channels. As an example, on the lower Mississippi Delta two fundamentally different channel patterns can be observed: at Wax Lake, channels bifurcate by mouth bar deposition to create a branching distributary network; on the Bird' s Foot, elongate channels persist for long distances without bifurcating. Mississippi Delta restoration schemes propose to construct new delta lobes through diversion of water and sediment, however an understanding of what causes elongate vs. bifurcating channels is still lacking. Elongate channels can also be seen in tie channels connecting floodplain lakes to rivers, and they appear to grow under conditions of rapid levee deposition and progradation relative to mouth bar growth. Beginning from this observation, we propose a hydrodynamic theory for levee deposition at river mouths that seeks to predict the conditions under which such elongate channels form. In our new approach we model this velocity pattern using the vertical component of the flow vorticity, which allows the description of the flow field to be reduced to one dimension without losing generality. We show how both shearing and lateral spreading can be directly related to the jet vorticity. In order to study resulting sediment deposition from the jet we introduce a new kind of potential vorticity that incorporates suspended sediment concentration. By means of the Ertel Potential Vorticity Theorem, the result is a new dynamic equation that can be solved analytically to model the flow pattern at a river mouth. We confirm that a strong and localized potential vorticity input, such that recognized in the Southwest Pass of Mississippi River Bird's Foot, does not remain confined to the coastal zone, but is propagated offshore as a filament or jet. The potential vorticity model is consistent with available theoretical and field observations, and appears to explain key aspects of levee deposition. Our theory predicts that high potential vorticity condition at the river mouth is a necessary condition for the creation of elongate channels.