Syntectonic sedimentation at various scales: Application to Earthquake Geology and Active Tectonics

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In tectonically active regions of the world, sedimentary and tectonic processes go hand in hand, like an unbreakable loving couple. This has become an unquestionable fact in geological sciences since the development of sequence stratigraphy in 1980's, which has clearly brought together in a single frame the interplay of tectonics, sedimentation and eustasy (sea-level changes). Here, tectonics introduces the disequilibrium, modifying base levels of processes, as well as energy and mass balances, while erosion and sedimentation, through morpho-dynamic evolution, try to bring the "unstable" state to conditions tending to equilibrium. Eustatic changes can play in or out of phase (or in between) with tectonics, magnifying or minimizing its effects. However, since the vertical range of sea-level changes is in the order of a hundred meters, its primary and outstanding effects are largely restricted to the continental edges, despite affecting natural systems rather far inland at a lesser extent and intensity.

The recognition and study of this sedimentation-tectonic interplay at very different scales is vital to characterize the degree of activity of a given region or tectonic structure. Next, let us illustrate this from regional to local to outcrop scale. For instance, it is has been well understood for decades that molasse deposits, which can be several kilometer-thick and extend for thousands of square kilometers, and are deposited along thousand-kilometer-long mountain range fronts, are the living proof of growing orogens and are key to date tectonic paroxysm phases. These phases can be tuned by other processes such as glaciations, which also are in turn linked to eustasy. During glacial stages, sedimentary materials are crashed by cryogenesis and piled up in glaciated highlands of tropical regions. At interglacial, these materials are flushed out of the relief and accumulated in the flexural basins at the range front. At a more local scale, the size and shape of sedimentary basins are a response to the genetic fault. An excellent example is the pull-apart basins along jogs or at relays of strike-slip faults. The size of such basins varies from few meters to tens of kilometers and is in relation with the genetic fault. This has led to the development of the concept of "tectonic landscape" (Michetti *et al.*, 2005). In Italy, the Apennines chain exhibits numerous active tectonic depressions, where the size and depth of each basin are directly dependent to length and throw, respectively, of the master bounding normal fault. On the other hand, onset of the bounding fault is defined by the age of the first deposits. In the same way, lateral and vertical variations of the fill reflect changes of rate of tectonic activity of the bounding fault, as well as distance to the active fault. A common picture in these basins is an upward and basinward grain size decrease, implying that fault activity is at a maximum at the fault onset and perishes with time. This trend is reflected in the distribution and evolution of the sedimentary environments within the basin and close surrounds.

At outcrop scale, the most known feature of this process is the syn-sedimentary fault, if viewed by tectonicists, or syn-tectonic sedimentation as named by sedimentologists. These are two parts of a same single process, as abovementioned. From the different relations, it can be stated whether the sedimentation rate is greater, equal to or smaller than that of tectonic activity, depending on if the fault is blanketed or not by sediments, being blind faulting an end member of higher sedimentation rate than fault slip rate.

In the last few decades, earthquake geologists have relied on sedimentation-tectonics interplay to assess the degree and onset of activity, and deactivation, of a given fault. As well, it has helped them define the lateral extent and sense of slip of a fault; being all this information vital for assessing its seismogenic potential. However, this interplay may be reflected beyond the vicinity of and off fault, as has been developed through recent years. Staircased marine and (paired or unpaired) alluvial terraces, erosional surfaces, growth strata, progressive unconformities, drainage anomalies, among many other features, are evidence of regional uplift or activity of a given fault. More recently, these researchers have been looking into more sedimentary evidence of tectonic activity, triggered by earthquakes such as: fluidization (liquefaction features -sand dykes and volcanoes-, degassing –pockmarks-), sediment perturbations (convolute bedding, balls and pillars, etc.) and re-mobilizations (slumping, sliding, mud-volcanism, turbidites, homogenites, tsunamites, etc.).