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Storms in the deep: tempestite- and beach-like deposits in pelagic sequences (Middle-Upper Jurassic, Subbetic, South of Spain)

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Fine-peloidal- to coarse oolitic-bioclastic grainstones with hummocky cross stratification (HCS) occur interbedded in Middle-Upper Jurassic pelagic lime-mudstone successions (Betic ranges, Southern Spain). These strata were deposited in pelagic troughs and swells, away from continental areas, in the Southern Iberian Continental Margin of the Western Tethys. Previously interpreted as tempestites, mainly due to the attribution of the HCS to surface storm waves, they are now reinterpreted as the product of turbulence in deeper conditions.

Among many, some selected examples are here presented. All of them share:
1) Grainstone beds are interbedded with pelagic mudstones and marls
2) Grainstone components were reworked by oscillatory flows superimposed to unidirectional tractive flows (unidirectional ripple lamination and HCS).
3) Components were either derived from shallow-water environments (e.g., ooids), or produced in pelagic conditions (e.g., radiolarians, Saccocoma, peloids, etc).
4) Although surface-storm tempestite flows can be required to bring downslope components from shallow-water settings, the grainstone beds reflect sediment reworking at a depth dominated by fine pelagic sedimentation.
5) Internal waves propagating along a pycnocline and breaking against a sloping surface are the best candidate to induce the sedimentary structures and sediment organization that characterize these grainstone beds.

The examples here presented (Middle-Upper Jurassic of the Subbetic) include:
a) Peloid grainstones interbedded with radiolarite marls deposited on the flanks of volcanic guyots. The interbedded lime muds and marls contain 'filaments', sponge spicules and radiolarians.
b) Peloid-bioclastic (radiolarians, Saccocoma, etc.) grainstone beds with HCS, interbedded with pelagic lime muds.
c) Coarse oolitic grainstone unit, encased in pelagic marls, with wedge-shaped crossbed-sets with gently seaward-dipping parallel lamination, and sets of low-angle up-slope dipping parallel lamination. These oolitic grainstones hold characteristics similar to the ridge-berm-swash zone of modern beaches and are here interpreted to represent an "internal beach".
d) Crossbedded peloidal-skeletal (Saccocoma) grainstones with HCS and wave ripples on top, interbedded with pelagic mudstones and wackestones with abundant bioturbation and ammonites (Ammonitico Rosso facies).

All these grainstones are reinterpreted as the product of breaking internal waves. This breaking produces episodic high-turbulence events and remobilizes sediments at the depth where the pycnocline intersects the sea floor. The swash run-up produces erosion and the backwash return flow can bypass the breaker and travel downdip where the oscillatory-flow component of the IWs become dominant and form the characteristic HCS bedforms. Coarser sediments "trapped" at the breaker zone form sediment accumulations similar to the sediments caught by the "littoral fence" in the surface beach. This scenario evidences the HCS not to be necessarily linked to the surface storms but to the bathymetry of the pycnocline, solving the problem of having HCS in pelagic zones where the storm and hurricanes wave action can be considered "out-of-context".

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