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River sediment flux and shelf sediment accumulation rates on the Pacific Northwest margin

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Abstract

To test the generality of insight obtained from recent STRATAFORM studies of northern California's Eel margin, river sediment sources and continental shelf sinks were examined on the Pacific Northwest margin from 38° to 44.5°N. River discharge and sediment concentration data acquired by the US Geological Survey were used to update long-term annual suspended-sediment loads for 17 rivers that range in basin area from 635 to ~22,000 km^2. Resulting annual load estimates vary over 3 orders of magnitude ($0.065–18 \times 10^9$ kg/yr), with major suspended-sediment fluxes supplied by, in decreasing order, the Eel, Klamath/Trinity, Mad, Rogue, Umpqua and Russian rivers. Down-core profiles of excess ^{210}Pb and ^{137}Cs were used to estimate sediment accumulation rates (SARs) at prescribed depths (70 and 110 m) and distances (0–40-km north and south along-shelf) from each of the major rivers. SARs were found to vary much less than the river flux estimates, and are mostly in the range of 1.5 to 6 mm/yr. Most significantly, shelf SARs on the other Pacific Northwest margins are only slightly less than those observed on the Eel shelf, implying that much higher proportions of riverine sediment are retained on those shelves. Likely reasons that the Eel dispersal system exhibits greater off-shelf transport are (1) the narrower and steeper shelf geometry, and (2) the existence of a newly documented cross-isobath sediment transport mechanism that involves wave-modulated fluid mud flows. Testing whether the fluid mud flows are a consequence of the Eel River basin's high sediment yield, and are thus unique to the Eel, or are caused by intense wave energy during discharge events, and hence are operative on many other margins, awaits future bottom-boundary layer measurements.

Keywords: Sedimentation; Continental shelves; River discharge; USA; Eastern Pacific

1. Introduction

The sedimentary geology of continental margins is a tale of source-to-sink transport of material (e.g., lithogenic particles, organic carbon). River

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source basin characteristics and processes that operate within basins influence the magnitude of sediment production and its delivery to the coastal ocean. Features such as basin relief, temperature, rainfall magnitude and pattern, as well as vegetation and land use practices all may influence the flux of sediment from a source basin (e.g., Walling, 1983; Milliman and Meade, 1983; Milliman and Syvitski, 1992; Hooke, 2000). Once delivered to the coastal ocean, a separate set of characteristics and processes influence the dispersal and ultimately accumulation of sediment. For example, shelf geometry, wave climate, and tidal energy all may affect patterns of sediment accumulation (i.e., sinks) on continental margins (Nittrouer et al., 1984/1985; Nittrouer and Wright, 1994). Despite the explicit link between source and sink, few studies have examined both terms, especially for small river systems discharging under similar hydroclimatic and oceanographic conditions.

The Pacific Northwest margin (as used herein: 38° and 44.5°N) is a region that is well known for its high sediment production (e.g., Griggs and Hein, 1980; Karlin, 1980) and active continental shelf sediment transport (e.g., Sherwood et al., 1994; Wiberg, 2000). On this margin a large number of relatively small (10^2–10^4 km^2) rivers discharge onto a narrow, energetic shelf. Both the delivery and transport of sediment is strongly episodic, with most events occurring between December and March (Drake and Cacchione, 1985; Ogston et al., 2004). Evidence from a variety of sources, for example high-frequency seismic profiles (Field et al., 1992), ^{210}Pb geochronology (e.g., Demirpolat, 1991), and extrapolation from nearby shelves (e.g., Washington; Nittrouer et al., 1984/1985), suggested that there was ongoing accumulation of fine-grain sediment on the Pacific Northwest shelf. It was with the expectation of an active sediment dispersal system that the STRATAFORM program, a comprehensive, 6-year study of sediment transport and accumulation, was conducted on northern California's Eel River margin (e.g., Nittrouer and Kravitz, 1996).

The collective efforts of STRATAFORM investigators have provided a variety of findings that motivate this study. First, fine-grained sediment was shown to be actively accumulating on the mid to outer shelf and upper slope of the Eel margin on event (Wheatcroft et al., 1997; Wheatcroft and Borgeld, 2000) and century (Sommerfield and Nittrouer, 1999; Alexander and Simoneau, 1999) timescales. Based on ^{210}Pb geochronology, sediment accumulation rates (SAR) on the Eel shelf range from 2 to 14 mm/yr (Sommerfield and Nittrouer, 1999), although sites with rates >8 mm/yr are rare. The area-normalized SAR between the 50- and 130-m isobaths is 4 mm/yr, with a clear decrease with distance offshore. For example, sites along the 110-m isobath have SAR's between 2 and 5 mm/yr, whereas SAR's at 70-m sites are often higher by a factor of two (Sommerfield and Nittrouer, 1999). Overall the Eel shelf SAR's are fairly high, but not unexpected given the proximity of the Eel River, the largest source of terrigenous sediment on the US West Coast (annual load of 1.5–2.5×10^{10} kg/yr, Brown and Ritter, 1971; Janda and Nolan, 1979; Griggs and Hein, 1980; Milliman and Syvitski, 1992; Sommerfield and Nittrouer, 1999).

The second notable feature exhibited by the Eel River dispersal system is significant off shelf transport on both the event and century time scales. Sediment budgets have shown that less than a third of the estimated fine-grained sediment supplied by the Eel River can be accounted for in flood deposits (Wheatcroft et al., 1997; Wheatcroft and Borgeld, 2000) or within the mid-shelf muds (Sommerfield and Nittrouer, 1999) and inner shelf sands (Crockett and Nittrouer, 2004). The likely explanation for widespread off-shelf dispersal of Eel River sediments is the extreme wave climate on the shelf (Wiberg, 2000; Ogston et al., 2004) that results in frequent resuspension, coupled with the relative narrowness of the shelf (i.e., the distance to the 150-m isobath on the Eel is roughly half that observed on other Pacific NW margins). In addition, the proximity of the Eel Canyon may play an important role (Mullenbach and Nittrouer, 2000).

Third, the locus of sediment accumulation on the Eel River shelf was found to be similar on both time scales. That is, sediment depocenters on event and century time scales were found to be north of the Eel River mouth by roughly 20 km and in water depths of 70–110 m (Wheatcroft and