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Chromium and nickel as indicators of source-to-sink sediment transfer in a Holocene alluvial and coastal system (Po Plain, Italy)

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A reliable quantitative estimate of changes in source-to-sink sediment transfer requires that high-resolution stratigraphic studies be coupled with accurate reconstructions of spatial and temporal variability of the sediment-routing system through time. Source-to-sink patterns from the contributing upland river catchments to the deltaic and coastal system are reconstructed from the Holocene succession of the Po Plain on the basis of selected geochemical indicators. Sediment supplied to the delta area by the major trunk river (the Po) exhibits naturally high Cr and Ni values, which invariably exceed the maximum permissible concentrations for unpolluted sites. This 'anomaly' reflects remarkable sediment contribution from ultramafic (ophiolitic) parent rocks cropping out in the Po drainage basin (Western Alps and NW Apennines). In contrast, alluvial and coastal plain deposits supplied by ophiolite-free, Apenninic catchments invariably display lower Cr and Ni contents. For constant sediment provenance domain, Cr and Ni distribution is observed to be controlled primarily by hydraulic sorting. Clay-silt deposits (floodplain, swamp and lagoon/bay facies associations) invariably show higher metal concentrations than their sandy counterparts (fluvial-channel, distributary-channel and beach-ridge facies associations). From a stratigraphic perspective, in sedimentary basins characterized by strong differences in sediment composition geochemical fingerprinting of individual facies associations framed by surfaces of chronostratigraphic significance is proposed as an invaluable approach towards an accurate quantitative assessment of sediment storage in alluvial and coastal depositional systems as opposed to volumetric reconstructions based on lithologic or geometric criteria alone.

1. Introduction

One of the major innovations in stratigraphy during the last 30 years, a period of time roughly coinciding with the growth and development of sequence stratigraphy, has been the subdivision of sedimentary basin fills into genetically related packages developed under common forcing conditions (Vail et al., 1977; Posamentier and Vail, 1988; Van Wagoner et al., 1988; Catuneanu et al., 2009). Identification and lateral tracking of the sequence-bounding unconformities (and related correlative conformable surfaces) across the basin fills and their internal subdivision into depositional sequences and their constituent systems tracts has stimulated over the past decades the development of a comprehensive strategy for basin-scale depositional systems observation in terms of source-to-sink dynamics (Allen, 2008; Brommer et al., 2009; Martinsen et al., 2010; Paola and Leeder, 2011; Sømme et al., 2011). By focusing on the stratigraphic relationships developed during relatively short intervals of time, such as the Holocene, one of the most intriguing applications of the sequence-stratigraphic concepts is the possibility to add new insight on the traditional (geomorphologic) approach to sediment budget evaluation (see Brown et al., 2009, for a review of old and new approaches to sediment budgeting). This new approach may lead to predict realistic scenarios of future environmental evolution under changing sea-level and sediment supply conditions (Blum and Roberts, 2009).

Despite inherent problems in inferring sediment provenance from the final product, quantitative provenance analysis (Basu, 2003; Weltje and von Eynatten, 2004), i.e. the attempt at reconstructing mass transfer from source areas to the sedimentary basin, has met an increasing interest over the last decade. Traditional sediment-budget modeling has been rarely constrained by accurate stratigraphic data. Sediment budget calculations have been commonly performed through assumptions that may be correct for small catchments on a local scale (Evans and Warburton, 2005), but that are not necessarily successful when applied to large-scale depositional systems, where dispersal pathways show a high degree of complexity (Rosati, 2005; Hoffmann et al., 2007). A common practice is to use volumes of sediment incorporated into the depositional systems as constraints to the eroded headland volume (Hoffmann and Lampe, 2007). To this purpose, digital terrain models and GIS modeling have been used to calculate volumes of the eroded rocks (Van Balen et al., 2000; Sømme et al., 2009). Seismic data can also be used for the estimate of sediment storage (Saito et al., 2001; Schrott et al., 2003; Liu et al., 2007), but this technique may just provide a rough estimate of sediment transfer if not

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calibrated with detailed core data (Cattaneo et al., 2003). New methods and techniques have evolved in recent years, from experimental and numerical modeling to analysis of ancient systems (Martinsen et al., 2010). High-resolution stratigraphic and chronologic constraints, however, have frequently been neglected, and the issue of how to track the physical boundaries between separate provenance domains in the rock record has generally been overlooked, with very few exceptions (Brommer, 2009; Brommer et al., 2009; Covault et al., 2011).

The purpose of this paper, which focuses mostly on the 'sink' and its final products, is to show how combined sequence-stratigraphic and geochemical analyses may represent the basis for a reliable estimate of source-to-sink sediment transport and storage within Holocene alluvial and deltaic depositional systems. Based upon previously published data, specific objectives are: (i) to highlight the spatial and temporal distribution of chromium and nickel concentrations as a powerful tool to reconstruct changes in sediment source and dispersal patterns through time, (ii) to propose a pragmatic approach to the estimate of sediment budgets on the basis of geochemical fingerprinting at the scale of individual facies associations, and (iii) to emphasize the role of demonstrated rather than inferred key stratigraphic surfaces in sediment volume calculations.

The Holocene succession of Po River Basin, for which both high-resolution stratigraphic studies (Amorosi et al., 1999, 2003, 2005; Stefani and Vincenzi, 2005; Amorosi et al., 2008) and provenance analysis (Marchesini et al., 2000; Amorosi et al., 2007) are available, represents an excellent testing ground for this methodology. The area selected for this study coincides with the site investigated by Amorosi and Sammartino (2007), i.e. the area covered by Sheet 223 (Ravenna) and Sheet 205 (Comacchio) of the Geological Map of Italy at 1:50,000 scale. Due to its peculiar, two-fold geological history (see below), during the last few centuries this area has been supplied by two distinct sediment sources (Fig. 1). Its northern portion, north of Reno River, corresponds to part of an abandoned delta lobe supplied by an old branch of Po River, whereas the southern part is an alluvial depositional system fed by rivers of Apenninic provenance.

A geochemical approach to sediment-budget modeling over the western Adriatic area, based upon modern sediments, has been recently undertaken on a variety of scales by Frignani et al. (2005), Brommer (2009) and Weltje and Brommer (2011). On the other hand, only isolated examples occur of integrated sedimentological and geochemical studies aimed specifically at understanding the role of transport mechanisms in the physical dispersal of heavy metals (Miller, 1997; Box and Wallis, 2002; Garcia et al., 2004a,b; Myers and Thorbjornsen, 2004; Amorosi and Sammartino, 2007).

2. Cr and Ni as indicators of sediment pathways in the Po River basin

Chromium and nickel have been used to evaluate the influence of separate sediment sources in a number of papers (Hiscott, 1984; Feng and Kerrich, 1990; Garver et al., 1996; Bauluz et al., 2000; von Eynatten, 2003; Lužar-Oberiter et al., 2009). The same metals make powerful source discriminants even in the Po Plain–Adriatic Sea depositional system, as documented from a variety of deposits spanning from the Middle Pleistocene to present. Anomalously high Cr and Ni values have been detected for the first time from bed-load sediments of modern Po River (Dinelli and Lucchini, 1999; Dinelli et al., 1999; Vignati et al., 2003). Similar high Cr and Ni concentrations, even exceeding the Italian threshold limits designated for contaminated areas (150 mg/kg and 120 mg/kg, respectively), were reported few years later from recent (post-Roman) overbank and deltaic deposits supplied by Po River (Bianchini et al., 2002; Amorosi and Sammartino, 2007; Sammartino et al., 2007). Refined geochemical characterization of the entire Middle-Late Pleistocene and Holocene succession of the Po

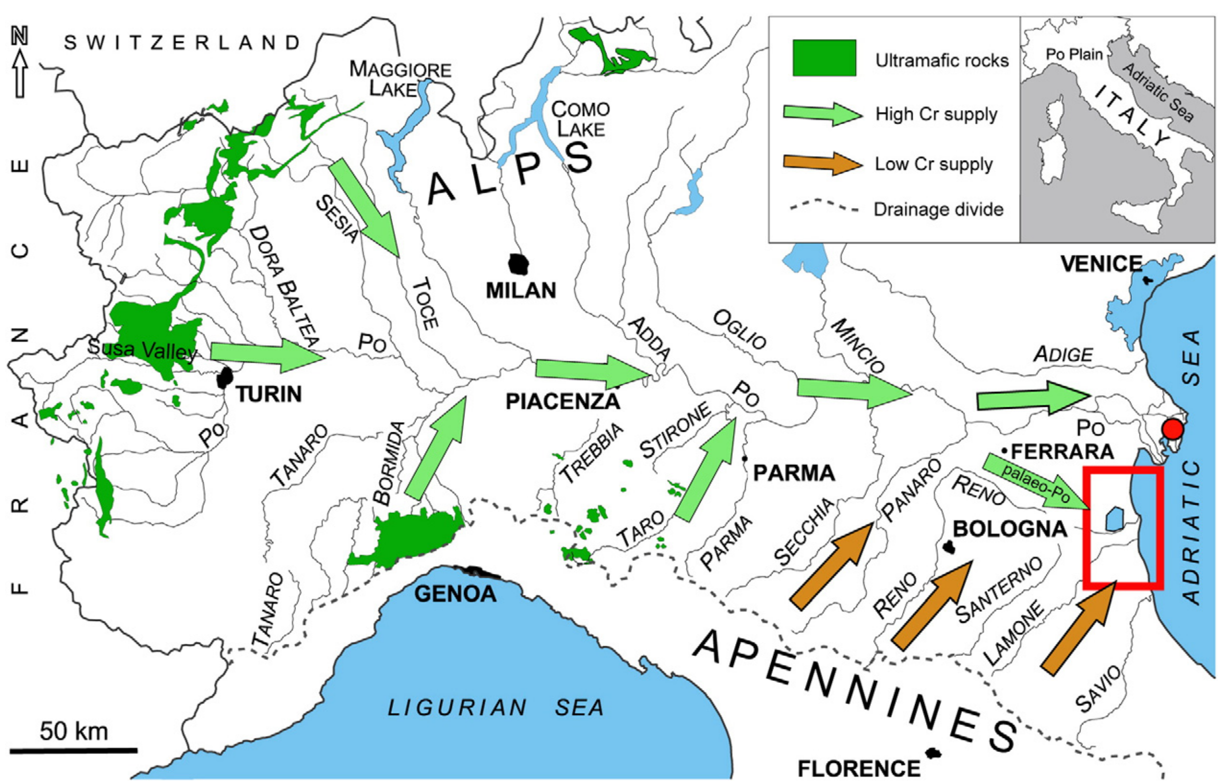

Fig. 1. The ultramafic complexes of northern Italy (western Alps and NW Apennines) contribute Cr-rich (and Ni-rich) sediments to the Po Plain and to the adjacent Adriatic coastal system, via Po River and its tributaries. In contrast, the Apenninic catchments between Parma and Savio rivers are virtually ophiolite-free and supply Cr-poor (and Ni-poor) sediment downstream, to the alluvial plain and to the Adriatic coastal area south of Po River. The rectangle indicates the study area of Fig. 2; the red dot in the modern Po Delta, the location of the core of Fig. 6.