TECTORIC CONTROL ON FLUVIAL VALLEY-FILL: FIELD INFERENCES AND NUMERICAL MODELING

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Cycle: XXVI

Abstract
This PhD project aims to unravel the role of tectonic control on fluvial sedimentation within upstream reaches of incised valleys, specifically looking at aggradational and degradational phases and variations in sedimentological and architectural features of fluvial deposits. The selected study case is an outstanding example of fluvial-valley fill deposited beyond any sea-level influences. It concerns Plio-Pleistocene deposits of the Ambra River valley (Tuscany, Italy), where the sedimentation was controlled by a tectonically-induced modification of vallie profile, influencing the river transport capability. The present study was carried out through field techniques and geophysical analysis, aimed at defining river response to tectonic deformation. A numerical reconstruction has been performed to validate and verify our geological interpretation and to quantify the tectonic role on valley-fill aggradation. This reconstruction provided the reference parameters for generic models, aimed to monitor the effects of variation in fluvial mass balance, tectonic uplift and uplift dynamics.

Introduction

In the last decades, the interest for incised-valleys increased in the frame of petroleum industrial research and sequence stratigraphy, as a result of the preservation of their infill in fossil record.

Although most of the valley-fills record the influence of downstream relative sea-level changes (Dalrymple et al., 1994; Allen & Posamentier, 1993), only few authors highlight the importance of tectonic and climatic upstream control on valley-fill aggradation (Shanley and McCabe, 1991; Holbrook, 2001; Blum and Tornqvist, 2000) which occurred through fluvial deposits accumulation, and beyond any influence of relative sea-level. Syn-sedimentary tectonic deformation in upstream reaches of valleys can upset the fluvial patterns, with consequent development of heterogeneous valley-fill architectures. The effects of syn-sedimentary tectonics are known in modern settings (Schumm, 1986) or laboratory experiments (Ouchi, 1985), whereas study cases from fossil record are almost missing.

In order to investigate the role of tectonic on fluvial aggradation in valley settings, the Ambra River valley succession (Northern Apennines, Italy) was investigated.

The modern Ambra River is located along the Southern margin of the Chianti Ridge (Central Tuscany) and drains toward NE, whereas, during the Early Pleistocene, the paleo-Ambra drained toward SW accumulating a 60-70 m thick fluvial valley-fill succession (Aldinucci et al., 2007; Bianchi et al., 2013). The valley fill forms a NS-oriented sedimentary body and consists of two intervals separated by an erosive surface. The lower interval has been the focus of a previous study (Aldinucci et al., 2007), which emphasized the role of tectonic and climate during the accumulation of the alluvial deposits. Whereas the upper interval deposits (main focus of this PhD project) show a strong along-valley facies heterogeneity (Bianchi et al., 2013) mainly developed across a syn-sedimentary fault zone. These deposits have been studied through outcrop (geological survey, facies analysis and paleohydraulic studies) and underground methods (Electrical Resistivity Tomography and passive seismic data). Numerical modeling has been performed in order to assess the geological interpretation and to provide reference parameters for running simplified generic models. These last ones helped to understand and predict the cumulative effects of the interplay between fluvial and tectonic variables.

Methods
The goal of this research is to understand the variations in sedimentological and architectural features of fluvial deposits across an area affected by a syn-sedimentary tectonic disturbance, which is represented by a normal fault crossing the studied valley. During the last three-years a high-resolution map (1:10,000 scale) of the valley-fill deposits (~20 km²) was completed, allowing to identify spatial distribution of different depositional environments (Bianchi et al., 2013). This sedimentological approach has been carried out through a bed-by-bed logging, outcrop linedrawing and paleocurrents measurements. Moreover, structural data concerning the syn-sedimentary fault have been also collected in collaboration with the Earth Science Department of University of Bari (Dr. A. Brogi). The buried part of the valley fill succession has been investigated through Electrical Resistivity Tomography (ERT) and passive seismic data (HSVR). The integration of subsurface and outcrop methods led to a scenario of syn-tectonic sedimentation. Paleomagnetic analyses and paleo-hydraulic calculation have been carried out in the frame of scientific collaborations with University of München (Dr. E. Dallanave) and University of Ferrara (Prof. P. Billi) respectively.

Once the tectono-stratigraphic frame was depicted, it was analyzed in the frame of a collaboration with CSIRO of Sydney (Dr. T. Salles & Dr. G. Duclaux) using LECODE (Landscape Evolution Climate Ocean and Dynamic Earth), a new geomorphic and stratigraphic forward modelling code capable of simulating surface evolution and elastic sedimentary processes in 3D through geological times. A numerical reconstruction of the inferred depositional dynamics was carried out, along with development of generic models, applicable to a wider spectrum of cases (Whipple, 2004). The Ambra Valley numerical reconstruction was performed giving basal layers to the model as topography (DEM), substratum geology and a sediment-supply source, and then playing with changes in valley profile (i.e. tectonics) and water discharge (i.e. climate). Generic models allowed investigating the interplay between variations in mass balance and tectonics in several combinations.

**Results and discussions**

**The Plio-Pleistocene Ambra Valley: depositional evolution**

The coupling of outcrop methods and subsurface ones allowed depicting spatial distribution and stratigraphic relationships between the two main intervals forming the valley-fill succession. In the northern sector of the study area the intervals are conformable stacked, as confirmed by ERT, HSVR and boreholes data, whereas in the southern sector they are offset and locally separated by an erosive surface, as attested by field mapping and HSVR. This scenario reveals a bi-phasic evolution of the valley, where deposition of the upper interval documents a lateral shift of the valley axis and the development of marked along-valley facies heterogeneity. The hinge of valley shift is located where the valley is crossed by the syn-sedimentary fault. This fault allows dividing the upper interval in two portions. In the northern portion (i.e. upstream of the fault zone), the upper interval is about 30 m thick and consists of organic-rich mud containing isolated channelized sand bodies. In the southern portion (i.e. downstream of the fault zone), the upper interval is almost 25 m thick and consists of cross-stratified fluvial gravels passing downstream into sandy deposits. Lateral tributaries fed gravelly alluvial fans along the valley flanks in both portions.

Structural analyses highlight that the syn-sedimentary fault is EW oriented (i.e. normally to the valley axis) and shows a dominant normal component, subsiding the upstream part of the valley. The fault zone is still characterized by natural CO₂ emissions. Evidence of tectonics affecting the lower valley-fill interval agrees with a fault activity during accumulation of the upper valley fill interval.

Paleo-magnetism analysis along with regional constraints, allow to ascribe the valley fill succession to the Late Pliocene – Middle Pleistocene time, with a magnetic inversion within the lower interval, which could be ascribed to the Matuyama-Brunes (0.78 Ma) or Matuyama-Olduvai (1.9 Ma) boundary.

Paleo-hydraulic investigations allowed estimating a paleo-discharge (average of bankfull discharge), which is 280 m³/s.

The change in fluvial dynamics across the fault zone is ascribed to a syn-depositional activity of the normal fault during accumulation of the upper interval deposits. The fault activity is thought to be the main cause of the shift of the valley axis, which produced the offset of lower and upper valley-fill.
deposits in the central part of the study area. In particular, the change in fluvial transport capability recorded by the upper valley-fill interval across the fault zone represents the response of the river systems to tectonic movements. Specifically, tectonic upwarping caused a decrease in transport capability in the upstream reaches of the paleovalley, manifested by the aggradation of poorly-drained floodplain deposits. In contrast, a significant increase in bedload grain-size and fine-sediment bypass is recorded by the gravelly rivers downstream of the fault zone, where aggradation was promoted by the increase in sediment supply from erosion of the uplifted area.

**Numerical modeling**

Using hydraulic, geologic and sedimentological field data to constrain the numerical experiment, we successfully reproduce with LECODE the sedimentological pattern for the upper and lower units. Firstly, the experiment monitored the progressive steps of valley-fill aggradation, achieving the steady-state with sediment bypass; secondly, the simulation checked the facies heterogeneities in the framework of a syn-depositional tectonics, controlling avulsion, fluvial architectural changes and grain-size variations; thirdly, the model quantified the fault activity required to obtain both sedimentary thickness and trend observed in the outcrops, calculating the instantaneous sedimentation rate for each time step. This approach revealed that fault-induced aggradation did not occur synchronously in the upstream and downstream reach of the valley probably as consequence of the different time of reaction of the fluvial system to tectonic damming (Ouchi, 1985). Furthermore, since fluvial response to uplift disturbance is less known in comparison with subsidence control on fluvial deposition, predictive simulations were elaborated and calibrated with field data, combining fluvial mass balance with tectonic parameters. In response to different uplift rate, the fluvial system behaves with (i) aggradation of different fluvial pattern deposits, (ii) developing of intensely amalgamated successions, (iii) changes of grain-size and (iv) triggering of localized degradation.

**Conclusions**

- Ambra valley-fill aggradation was forced by a syn-depositional tectonics manifested by an upstream-dipping, normal fault striking transverse to the valley axis.
- Two different successions aggraded as consequence of fault activity: fine material aggraded upstream of the fault, coarse material downstream of the fault.
- This facies heterogeneity was driven by: i) changes in fluvial transport capability, ii) comprising of valley slope; iii) alteration of the water and bedload discharge and bedload grain-size.
- The use of LECODE validated our geological interpretation of a natural case and allowed to have a geomorphic and stratigraphic monitoring during the overall evolution of the valley.
- From the numerical reconstruction, the two aggradations of succession located upstream and downstream of the fault were time shifted.
- Simplified generic models contribute to unravel the interplay between changes of fluvial mass balance and tectonic activity.

**References**


SUMMARY OF PHD-PROJECT ACTIVITIES:

Courses:

2011
W. NEMEC: “ Sedimentology and Facies Analysis”, Department of Earth Science, University of Bergen.
W. NEMEC: “ Geostatistics”, Department of Earth Science, University of Bergen.
A. TAYLOR: Short Course: “Trace Fossils”, Department of Earth Science, University of Bergen.
S. BOESSO: “Introduzione alla Biblioteca” Dipartimento di Goescienze, Università degli Studi di Padova.
ELENA CALANDRUCCIO: “Inglese parlato”, Dipartimento di Geoscienze, Università degli Studi di Padova.
LIDIA GULIK: “Inglese scientifico” Dipartimento di Geoscienze, Università degli Studi di Padova.

2012
W. HELLAND-HANSEN: “Sequence Stratigraphy” Workshop, Dipartimento di Geoscienze, Università degli Studi di Padova.
ELENA CALANDRUCCIO: “Inglese parlato”, Dipartimento di Geoscienze, Università degli Studi di Padova.
LIDIA GULIK: “Inglese scientifico” Dipartimento di Geoscienze, Università degli Studi di Padova.

2013

Field work:

2011
2110 – 2610 February 2011: explorative field work on Siena-Valdarno area.
3rd June – 2nd July 2011: sedimentological field work and geophysical investigations on the Ambra Valley area

2012
19th – 23rd March 2012: sedimentological field work on the Ambra Valley area.
4th April 2012: geophysical investigations on Ambra Valley area.
5th – 14th December 2012: passive seismic investigations (HVSR) on Ambra Valley area.

2013
1st – 5th February 2013: sedimentological field work and passive seismic investigations (HVSR) on Ambra Valley area.

Publications:

DOI:10.1080/17445647.2013.829412

BIANCHI V., GHINASSI M., ALDINUCCI M., BOAGA J., BROGI A., DELANA R. Effects of tectonics on fluvial aggradation: the Plio-Pleistocene Ambra Valley-fill succession (Tuscany, Italy). (In prep. To be submitted to Sedimentology)

BIANCHI V., SALLES T., DUCLAUX G., GHINASSI M., BILLI P., DALLANAVE E. Evolution of a syn-depositional cross-valley faulting: numerical reconstruction of the Plio-Pleistocene Ambra paleovalley (Northern Apennines, Italy). (In prep. To be submitted to ESPL)
Communications:

2011

2012

2013

Visiting Period:

March-April 2011: fellowship at the Department of Earth Science, University of Bergen (Norway).
March-July 2013: Internship CESRE – CSIRO, North Ryde (Sydney, NSW, Australia)

Teaching Activity:

Field assistant: 15-17 January 2013, course of “Sedimentology” (Dr. M. Ghinassi), Laurea Magistrale in Geologia e Geologia Tecnica (2012/2013).

Extra:

2011
Participation at fieldwork phase of the project “Gilbert-type deltas in the Gulf of Corinth” (Project Leader Prof. W. Nemec, University of Bergen). May, 13-20, 2011.

2012
Participation at sedimentological field-work on Adwa area and stratigraphical expedition for studying Adigrat Sandstone (Ethiopia) (Project Leader: Dr. M. Ghinassi). February, 2-22, 2012
Partecipation to geophysical investigations in Grosseto area for ERT acquisitions (Leader: Anna Breda), April, 5-10, 2012.
Editor of the Rendiconti Online della Società Geologica Italiana 20th vol., July 2012.
Awarded of the travel grant for IAS meeting (Schaldming, 2012).

2013