Sedimentary Geology 344 (2016) 277–289

Contents lists available at ScienceDirect

Sedimentary Geology

journal homepage: www.elsevier.com/locate/sedgeo

Deformed cross-stratified deposits in the Early Pleistocene tidally-dominated Catanzaro strait-fill succession, Calabrian Arc (Southern Italy): Triggering mechanisms and environmental significance

Domenico Chiarella [a],*, Massimo Moretti [b], Sergio G. Longhitano [c], Francesco Muto [d]

[a] Department of Earth Sciences, Royal Holloway University of London, Egham, Surrey TW20 0EX, UK
[b] University of Bari, Dipartimento di Scienze della Terra e Geoambientali, 70100 Bari, Italy
[c] University of Basilicata, Dipartimento di Scienze, 85100 Potenza, Italy
[d] University of Calabria, DIBEST, 87036 Arcavacata di Rende, Italy

ARTICLE INFO

Article history:
Received 30 November 2015
Received in revised form 23 April 2016
Accepted 2 May 2016
Available online 11 May 2016

Keywords:
Catanzaro Strait
Tidal cross-strata
Deformed cross-lamination
Liquefaction and fluidization
Autogenic trigger

ABSTRACT

The Early-Pleistocene Catanzaro strait-fill succession consists of large-scale tidal sets, accumulated in a tectonically confined basin during a phase of rapid relative sea-level rise. It crops out mainly in the present-day Catanzaro Trough where numerous field sections supported the characterization of the vertical and lateral facies variations and the documentation of a variety of soft-sediment deformation structures, exposed throughout their vertical and lateral extents. The soft-sediment deformation structures (SSDS) are the result of liquefaction and fluidization processes that deformed cross-laminations and other primary structures into folds, fluid-escape structures, and structureless expanses. Three different groups of SSDS have been documented in the cross-stratified deposits of the Catanzaro strait. The detailed description of these soft-sediment deformation structures in a depositional context established by facies analysis enables interpretation in terms of possible trigger mechanisms. Consistent relationships between the occurrence of distinctive SSDS and specific tidally dominated facies have been established, indicating a probable autogenic origin for the soft-sediment deformations. Liquefaction and fluidization features are interpreted as the result of increases in water pore-pressure, induced by overloading. In particular, two types of overloading agents are hypothesized, which affect the lee and stoss sides of the migrating dunes in distinct events, and inducing the deformation of foreset laminae or sets of cross-strata, respectively.

1. Introduction

Soft-sediment deformation is widespread in cross-stratified deposits since they typically show a loose and metastable texture related with the high porosity of the particles packing (Kolbuszewski, 1953; Owen and Moretti, 2011). In fact, deformed cross-strata (*sensu* Allen, 1982) are widely reported in fluvial (*e.g.* Jones, 1962; Hobday and Von Brunn, 1979; Turner, 1981; Owen, 1995; Samaila et al., 2006) and aeolian deposits (*e.g.* Rice, 1939; Robson, 1956; Steidtmann, 1974; Horowitz 1982; Glennie and Buller, 1983; Bryant and Miall, 2010). Allen and Banks (1972) and Hendry and Stauffer (1975) have grouped all kinds of soft-sediment deformation structures occurring in cross-stratified sedimentary units in three main types. Type I is represented by simple overturned foresets forming recumbent folds (with a sub-horizontal axial plane) that involve only the middle or upper part of the bed ("recumbent-folded deformed cross-bedding" of Allen and Banks, 1972; "parabolic recumbent deformed cross-bedding" of Doe and Dott, 1980). Type II shows various irregular folds that differ in scale, morphology and orientation of the axial planes occurring near the top of cross-bed set ("crumpled or buckled cross-bedding" of Wells et al., 1993). Type III includes more complex deformation showing randomly oriented folded laminae that can be faulted and, locally, primary cross-stratification can be totally obliterated ("disharmonically buckled cross-bedding with faults" of Wells et al., 1993). Types I and II seem to be more frequent in fluvial settings, with rare examples in transitional deposits, while Type III has been described only in aeolian successions and is mainly interpreted as result of seismically-induced liquefaction (Allen and Banks, 1972; Allen, 1982; Bryant and Miall, 2010). Two main genetic mechanisms have been invoked for the Type I and Type II deformation of cross-stratified deposits (see a complete review in Wells et al., 1993): (i) sliding of sediment down the frontal surface of an advancing cross-stratified sand body (Rice, 1939; Rust, 1968; Puga-Bernabèu et al., 2010); and (ii) current drag action on the underlying liquidized cross-stratified sets (Robson, 1956; Allen and Banks, 1972; Owen, 1987, 1996). The trigger mechanism for the complete liquefaction or decrease of shear strength in the cross-stratified units is under debate too being be interpreted as result of:

---

* Corresponding author.
E-mail address: domenico.chiarella@rhul.ac.uk (D. Chiarella).

http://dx.doi.org/10.1016/j.sedgeo.2016.05.003

(a) earthquakes (Selley, 1969; Allen and Banks, 1972; Mazumder et al., 2006); (b) wave action (Dalrymple, 1979); (c) overloading/sand-laden flood (Coleman, 1969; Hendry and Stauffer, 1975; Yagishita and Morris, 1979); (d) flow regime changes as in the dune/plane-bed transition (Røe and Hermansen, 2006); and (e) sudden changes in the groundwater level (Williams, 1970).

High energy tidal deposits contain large portions of cross-stratified sand that are susceptible to liquefaction (high initial porosity/void ratio). Moreover, cross sets for their non-conformable shape, highlight any liquefaction-induced disturbances. Nevertheless, in literature, there are few examples of deformed cross-lamination in tidal deposits (Anderton, 1976; Mazumder, 2005; Longhitano et al., 2014).

In this paper, several well-exposed stratigraphic sections of the Early Pleistocene tidally dominated Catanzaro strait-fill succession (Calabrian Arc, Southern Italy) are described. Here, deformed cross-strata with different morphologies and shapes, in association with other soft-sediment deformation structures, characterize the tidal deposits at various stratigraphic intervals. Facies associations involved in the deformation processes and the SSDs have been described in agreement with the procedures suggested by Owen and Moretti (2011) and Owen et al. (2011). Main aims of this study are to (i) describe the variable morphologies of deformed cross-laminae, (ii) interpret mechanisms of deformation and trigger agents, and (iii) establish the environmental significance of soft-sediment deformation in tidal settings.

2. Geological setting

The Calabrian Arc connects the NNW-trending Southern Apennine Chain with the Maghrebian Chain of Sicily (Bonardi et al., 2001) (Fig. 1). This small orogen mainly consists of Hercynian metamorphic and intrusive rocks, tectonically superposed on ophiolite-bearing units of Tethyan affinity, in turn overlying Mesozoic carbonate platform limestone of Apennine affinity (Tortorici, 1982). The Arc comprises remnants of a former belt of Late Cretaceous(?)–Eocene age superimposed onto the Apennine Chain during the opening of the Tyrrhenian back-arc basin, which occurred during the middle Miocene (Gueguen et al., 1997). The opening of the western Tyrrhenian Sea was associated with the onset of intense thrusting in the Apennine chain, in relation with the progressive migration of the Calabrian Arc over the subducting Ionian lithosphere (Malinverno and Ryan, 1986; Critelli et al., 2013; Maffione et al., 2013). This migration resulted from the development of regional SE- and ESE-trending strike-slip fault zones and differently oriented normal fault sets (Knott and Turco, 1991; Tansi et al., 2007; Zecchin et al., 2015).

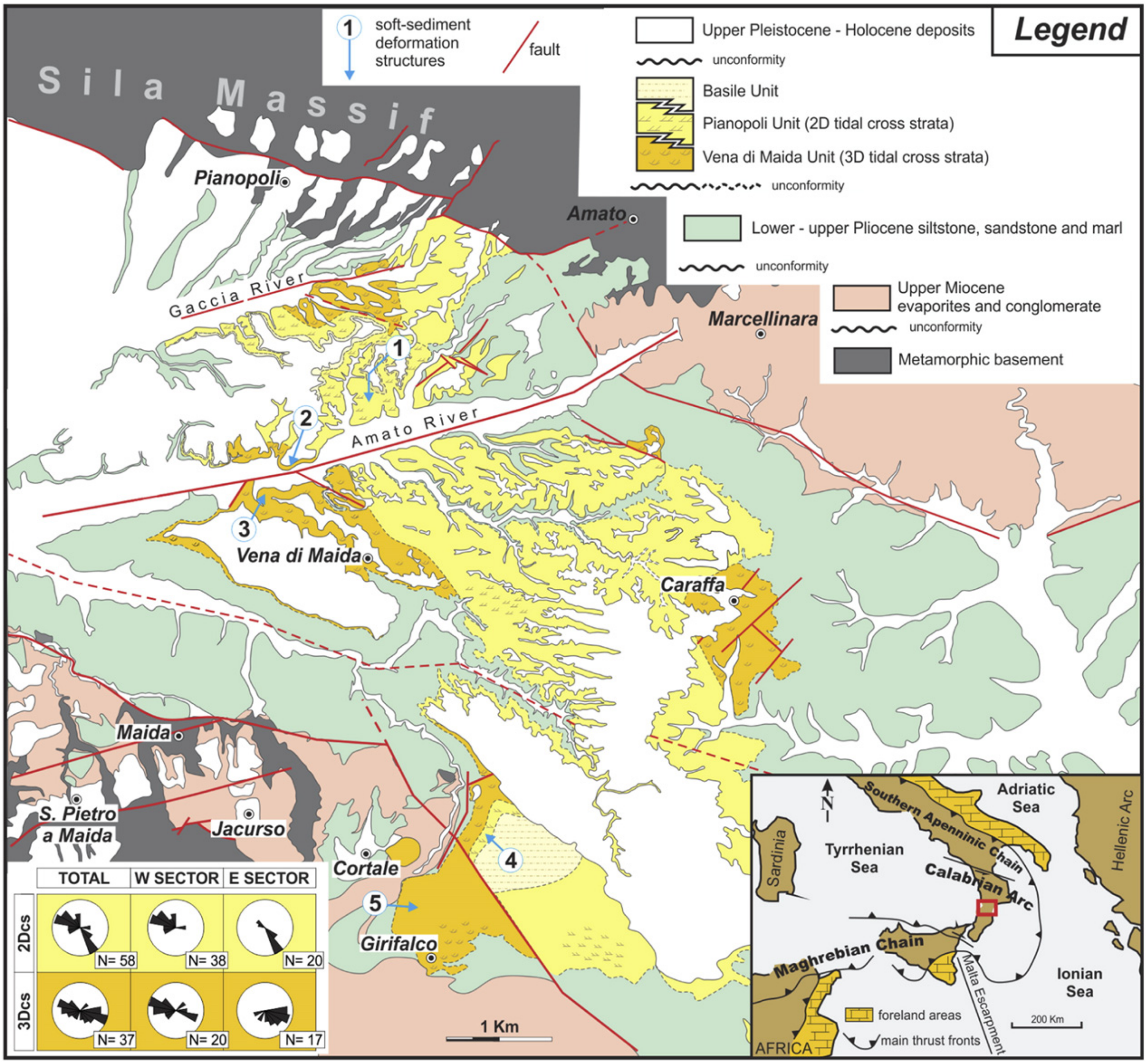

Fig. 1. Geological map of the central Catanzaro Strait, showing the aerial distribution of 3D and 2D tidal cross-strata. The inset shows the location of the study area within the Calabrian Arc (modified after Chiarella, 2011 and Longhitano et al., 2014).