Journal of Structural Geology 89 (2016) 230–249

Contents lists available at ScienceDirect

Journal of Structural Geology

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

Original article

Emplacement of sandstone intrusions during contractional tectonics

Giuseppe Palladino [a, *], Antonio Grippa [a], Denis Bureau [b], G. Ian Alsop [a, *], Andrew Hurst [a]

[a] Department of Geology and Petroleum Geology, School of Geosciences, University of Aberdeen, Aberdeen, UK
[b] Basin Studies Group, SEAES, University of Manchester, UK

ARTICLE INFO

Article history:
Received 17 March 2016
Received in revised form
24 June 2016
Accepted 29 June 2016
Available online 1 July 2016

Keywords:
Sand injections
Contractional tectonics
Bed-parallel slip
Great valley sequence
San Joaquin valley

ABSTRACT

Sandstone injections are created by the forceful emplacement of remobilized sand in response to increases in overpressure. However, the contribution provided by horizontal compressive stress to the build-up in overpressure, and the resulting emplacement of sand injection complexes, is still to be substantiated by robust field observations. An opportunity to address this issue occurs in Central California where a large volume of sandstone intrusions record regionally-persistent supra-lithostatic pore-pressure. Detailed fieldwork allows sandstone-filled thrusts to be recognized and, for the first time, permits us to demonstrate that some sandstone intrusions are linked to contractional deformation affecting the western border of the Great Valley Basin. Fluidized sand was extensively injected along thrust surfaces, and also fills local dilatant cavities linked to thrusting. The main aims of this paper are to provide detailed descriptions of the newly recognized syn-tectonic injections, and describe detailed cross-cutting relationships with earlier sandstone injection complexes in the study area. Finally, an evolutionary model consisting of three phases of sand injection is provided. In this model, sand injection is linked to contractional tectonic episodes affecting the western side of the Great Valley Basin during the Early-Middle Cenozoic. This study demonstrates that sand injections, driven by fluid overpressure, may inject along thrusts and folds and thereby overcome stresses associated with regional contractional deformation. It is shown that different generations of sand injection can develop in the same area under the control of different stress regimes, linked to the evolving mountain chain.

Contents

* Corresponding authors.
E-mail addresses: giuseppe.palladino@abdn.ac.uk (G. Palladino), ian.alsop@abdn.ac.uk (G.I. Alsop).

http://dx.doi.org/10.1016/j.jsg.2016.06.010
0191-8141/

1. Introduction

Large volumes of poorly consolidated sand, that are confined by sealing strata such as mudstone, can be mobilized under the effect of increasing fluid overpressure and forcefully injected into fractured host strata (e.g. Vigorito and Hurst, 2010). High pore-fluid pressure required to cause sand injection (Hurst et al., 2011) may be controlled by mechanisms such as depositional compaction, fluid volume change and fluid movement (Osborne and Swarbrick, 1997). Very little is known about sand injection generated by horizontal stress associated with contractional deformation. This gap in knowledge is perhaps due to post-emplacement overprinting processes linked to continuing contraction, and the expectation that contractional deformation will tend to reduce space available to accommodate sandstone intrusions. However, according to current models (e.g. Oliver, 1986; Ge and Garven, 1992; Lawrence and Cornford, 1995), regional tectonic compaction results in a huge amount of groundwater being expelled in major orogenic belts, thereby providing high pore fluid pressures that are potentially able to drive sand injection (Fig. 1). There are however, relatively few examples in the published literature of sandstone intrusions being directly linked to contractional tectonics. Winslow (1983) described clastic dike swarms formed of sandstone and conglomerate that filled extensional fractures developed in the hangingwall of Cenozoic thrusts in southern Chile. Other authors (Taylor, 1982; Di Tullio and Byrne, 1990; Ujiie, 1997) described sandstone intrusions filling contractional structures in southwest Japan, while Phillips and Alsop (2000) suggest that sand may intrude both during and after regional contractional deformation in the Caledonides of Scotland and Ireland.

In the western sector of the Great Valley Basin (Central California) (Fig. 2) large exposures of sandstone intrusions in giant sand injection complexes are recognized at different stratigraphic levels in the Great Valley Sequence. These sand injection complexes suggest that multiple phases of rapid increases in pore-fluid pressure, recorded at basinal scale, occurred during the Early Cenozoic. In particular, two independent giant sand injection complexes, identified as the Panoche Giant Injection Complex (PGIC) and the Tumey Giant Injection Complex (TGIC), formed in the Early Paleocene and Eocene respectively (Vigorito et al., 2008; Hurst et al., 2011) (Fig. 3). As the emplacement of injection complexes occurred in the undeformed sector of the basin, a direct link between sand injection and contractional tectonics is not easy to demonstrate. However, earlier studies in Central California (Smyers and Peterson, 1971) focussed on sand injections in the Early Paleocene complex and first suggested a relationship between contractional tectonic activity and formation of sandstone intrusions. Subsequent work conducted in the study area has mainly focussed on the emplacement mechanisms, and the architectural organization, of sand injections (e.g. Jolly and Lonergan, 2002; Vigorito and Hurst, 2010; Hurst et al., 2011; Scott et al., 2013), whereas further structural investigations have not been undertaken. Recent fieldwork in the Panoche-Tumey hills area in Central California (Fig. 2) allows the recognition of numerous examples of well-preserved thrust and reverse faults filled by injected sand. The occurrence of these syn-tectonic injections reveals for the first time the link between contractional deformation observed in the study sector of Central California, and episodes of basin-scale injection. A detailed description of the newly recognized syn-tectonic injections, analysis of the cross-cutting relationships between sand

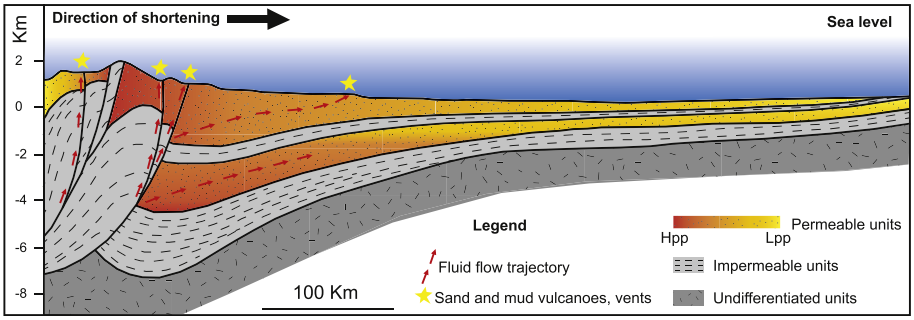

Fig. 1. Simplified model showing the main fluid migration pathways in an orogenic belt (after Oliver, 1986). A huge amount of water is generated and then expelled because of contractional deformation in thrust and fold belts. Hpp: high pore-pressure; Lpp: low pore-pressure.