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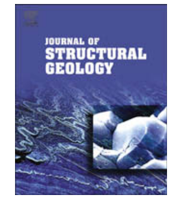

Primary structure influence on compositional banding in psammites: Examples from the Puncoviscana Formation, north-central Argentina

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We investigate the influence of sedimentary structures in development of foliations in banded psammites and pelites in the meta-turbiditic Pampean Belt, Eastern Sierras Pampeanas, northwest Argentina. These anchizone to upper greenschist facies rocks were exhumed from near surface to mid-crustal levels, and preserve sedimentary structures and gradual changes in tectonic fabrics and microstructures. Primary variations in clay content affected the degree of development of a compaction-related pressure-solution cleavage (S_P) resulting in enhancement of the original sedimentary banding. The resulting compositional banding was overprinted by a tectonic cleavage (S_1) related to mid-Cambrian chevron folding. In banded sandstones, pressure-solution and mica growth that define S_P and S_1 foliations are increasingly better developed in phyllosilicate-rich domains with increasing structural depth and metamorphic grade. Clay-rich laminae in the protolith acted as the locus for mica nucleation and growth, favoring dissolution of quartz (up to 42%) causing passive concentration of mica. Pressure-solution thus produced banded sandstones with a spaced, bedding-parallel S_P cleavage in shallower sections and compositionally banded psammites and schists at depth. These observations demonstrate that formation of compositional banding does not require tectonic transposition of an older planar fabric. Similar processes may produce compositional banding in a wide range of meta-sedimentary rocks.

1. Introduction

Cleavage development in shaly and sandy rocks has been the subject of many studies (e.g., Means, 1975; Gray, 1978; Onasch, 1983, 1990; Engelder and Marshak, 1985; Marshak and Engelder, 1985; Gregg, 1985; Schweitzer and Simpson, 1986; Tapp and Wickham, 1987; Waldron and Sandiford, 1988; Price and Cosgrove, 1990; Wu and Groshong, 1991; Yang and Gray, 1994; Hickman and Evans, 1995; Farver and Yund, 1999; Renard et al., 2001; Fueten et al., 2002; Stallard and Shelley, 2005; Stallard et al., 2005). However, despite the numerous examples of preserved sedimentary structures in Precambrian to Paleozoic orogens, e.g., in the Dalradian rocks of Scotland (Banks and Winchester, 2004), the Helgeland Nappe Complex, of the Central Scandinavian Caledonides (Heldal, 2001), the Keseechewun Lake–Many Islands Lake area in Canada (Harper et al., 2002), and the Lachlan Orogen in Australia (Powell, 1984), only a few authors have looked at the influence of primary structures on the development of subsequent cleavage and tectonic fabrics. Maxwell (1962) and Roy (1978) postulated that diagenetic or dewatering foliations that are oblique to bedding may be associated with syn-sedimentary folding, and may even be the initial stage of slaty cleavage. Gray (1978) recognized the effect of sedimentary fabrics such as grain shape, size, orientation, and packing on cleavage type in psammites. In particular, he observed that the original grain/matrix ratio determines the type of "rough cleavage" that develops in deformed psammites. However, the full extent of the influence of primary structures on disjunctive cleavage development is still not very well understood.

Disjunctive cleavage (terminology of Powell, 1979) has been described in sandstones by several authors (see Engelder and Marshak, 1985; Murphy, 1990) also using alternative names, e.g., 'rough cleavage' (Dennis, 1972; Gray, 1978); 'deformation zones' (Boyer, 1984); and 'P-Q fabrics' (Waldron and Sandiford, 1988). Gray (1978) suggested that disjunctive cleavage (his "type C rough cleavage") develops within an initially inhomogeneous rock along primary sedimentary anisotropies such as dewatering channels or bioturbation zones. Nickelsen (1972) invoked initialization of pressure-solution on pre-existing burrows. Disjunctive cleavage has also been shown to form entirely by tectonic pressure-solution (Murphy, 1990) or by mechanical grain rotation and/or mass transfer processes acting on the crenulation of a pre-existing foliation (Borradaile et al., 1982; Worley et al., 1997; Starkey, 2002). However, aspects of spaced cleavage formation such as the

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parameters that determine cleavage spacing and cleavage morphology, or the resultant rheological behavior of a polymineralic rock deforming by pressure-solution, remain enigmatic (Fueten et al., 2002). In this work, we describe how disjunctive cleavage forms at low metamorphic grade from a pre-existing sedimentary banding that is enhanced by the mechanisms of solution transfer deformation and recrystallization. We also demonstrate that development of disjunctive cleavage in sandstones is important to sandstone deformation during chevron folding.

The processes that develop compositionally layered metamorphic rocks under amphibolite and higher metamorphic conditions are also poorly understood, although such rocks make up a significant proportion of exposed continental crust, particularly in Archean cratons (Williams et al., 2000). Almost all published models involve either an ill-defined 'metamorphic segregation' (see review by Goodwin and Tikoff, 2002) or tectonic transposition of original sedimentary planar fabrics to explain the origin of compositional layers in medium- to high-grade rocks (Davidson, 1984; Jordan, 1988; Kusky and De Paor, 1988). In this paper, we demonstrate how a combination of primary bedding and diagenesis-related disjunctive cleavage produce distinctive banded psammites that, with increasing metamorphic grade, transition into compositionally banded schists. We examine Upper Proterozoic to Lower Paleozoic turbiditic rocks in the Cambrian-aged Pampean Orogen of northwestern Argentina, where there is an almost continuous transition with depth from anchizone conditions in the north to amphibolite facies metamorphism and migmatites in the south (Fig. 1). Local effects of Ordovician annealing near plutons and Andean brittle deformation are easily avoided. Thus the section is ideal for a systematic study of the influence of primary variations in mineralogy on the development of a wide range of microstructures at different structural depths in rocks of similar composition during a single tectono-metamorphic event. We argue that these processes involve significant pressure-solution differentiation, and furthermore can be used to explain similar compositionally banded psammites from a wide variety of orogenic settings.

Samples were obtained from several strike-perpendicular transects; in the absence of diagnostic mineral assemblages, deformation temperatures were estimated using natural microstructures in quartz, the experimental creep and recrystallization regimes of Hirth and Tullis (1992), and the natural deformation regimes described by Stipp et al. (2002a,b) and Rosenberg and Stünitz (2003).

2. Geological setting

The Upper Proterozoic to Lower Paleozoic Puncoviscana Formation (Durand and Aceñolaza, 1990; Rapela et al., 1998a) forms a major component of the north central Argentine Pampean Orogen (Fig. 1; Pankhurst et al., 1997; Rapela et al., 1998b; Keppie and Bahlburg, 1999). These turbiditic rocks were initially deposited in a thick accretionary prism on the margin of Gondwana after the break-up of Rodinia and were off-scraped and accreted to the Gondwana margin during the Cambrian-aged Pampean orogenic event (Piñán-Llamas and Simpson, 2006). The Puncoviscana Fm. *sensu stricto* is a relatively unmetamorphosed turbiditic sequence that crops out near the Bolivian border (22–26°S; 65–67°W; Turner, 1960) and has been shown to extend into equivalent and gradually higher-grade rocks to the south (Piñán-Llamas and Simpson, 2006). Neither total thickness, nor basement to the sequence, is known. Analyses of idiomorphic detrital zircons from volcaniclastic beds in the middle of the non-metamorphic section, in the northern part of the orogen, indicate a depositional age range of 530–560 Ma (Lork et al., 1990), although in southern (structurally deeper) sections the depositional age may be older (~600 Ma, Sims et al., 1998; Rapela et al., 1998b; Schwartz and Gromet, 2004). The depositional age of the Puncoviscana Fm. *s.s.* is also constrained by the presence of Tommotian-Vendian (Upper Proterozoic/Lower Cambrian) ichnofauna – *Helminthopsis*, *Planolites*, *Oldhamia*, *Diplichnites*, *Squamodictyon*, and *Tiernavia* – that confirm a deep-sea environment (Aceñolaza, 1978; Aceñolaza and Durand, 1986; Durand and Aceñolaza, 1990; Omarini et al., 1999; Aceñolaza, 2004; Aceñolaza and Aceñolaza, 2007).

Pervasive chevron folding of the entire Puncoviscana Fm. during the Pampean Orogeny was accompanied by formation of a fold-related cleavage (S_1) that is better developed with structural depth (Piñán-Llamas and Simpson, 2006), and which overprints an earlier, diagenesis-related disjunctive cleavage that is the subject of this paper. Published K/Ar whole rock metamorphic ages obtained from Puncoviscana Fm. pelites range from 550 to 535 Ma in locations north of Tucuman (Fig. 1), to 565 ± 7 Ma near Tucuman (Adams et al., 1990). Folding was followed by intrusion of scarce I-type granites, such as the 526 ± 2 Ma (U–Pb age, Hongn et al., 2001) Santa Rosa de Tastil pluton (Fig. 1), and by uplift and erosion prior to deposition of the unconformably overlying Middle Cambrian Meson Group (Turner and Mon, 1979; Rossi de Toselli et al., 1992; Hongn et al., 2001).

Subsequent development of a magmatic arc to the west of the Pampean orogen occurred during the Ordovician (Famatinian orogeny; Pankhurst et al., 1998; Saavedra et al., 1998) and younger, arc-related microplates accreted during the Devonian (Achalan Orogeny; Whitmeyer and Simpson, 2004). However, within the Pampean orogen, the effects of both the Ordovician and Devonian events are localized and mainly involve large-scale, but discrete shear zones (Whitmeyer and Simpson, 2003) and post-tectonic plutons that intruded the folded rocks and produced contact aureoles tens of meters to 2 km wide with local static annealing and overgrowth of unoriented andalusite, garnet, and staurolite porphyroblasts. Thus, large areas of the Pampean orogen were essentially unaffected by these younger events. Separation of the orogen into isolated fault blocks with intervening sediment-filled, pull-apart basins began in the late Carboniferous and continued through the Cretaceous (Simpson et al., 2001), culminating with uplift and tilting during the Tertiary to Recent Andean Orogeny (Jordan and Allmendinger, 1986).

Present-day exposures of the Puncoviscana Formation *s.s.* and related rocks (Fig. 1) exhibit an almost continuous transition from anchimetamorphic shales and greywackes in the northern part of the orogen, to upper greenschist facies pelites and psammites in the central region (Ancasti, Fig. 1), in which bedding and sedimentary structures are still identifiable, to amphibolite facies schists in southern exposures, in which all identifiable sedimentary structures have been obliterated. The metamorphic transition has been attributed to increasing original depth in the orogen coupled with local proximity to thermal domes (Willner and Miller, 1985; Willner, 1990; Piñán-Llamas and Simpson, 2006). Several authors have discussed the metamorphic reactions in the metaturbidites (e.g., Toselli and Weber, 1982; Toselli and Rossi de Toselli, 1984; Do Campo and Omarini, 1990; Do Campo et al., 1994). Willner and Miller (1982) were the first to consider tectonic transposition as responsible for the origin of a ubiquitous and distinctive compositional banding in psammites in Sierra de Ancasti (Fig. 1). However, in the following sections we show that this compositional banding is a consequence of the superposition of a bedding-parallel, pre-tectonic solution cleavage onto primary bedding. We initially document the primary and pre-tectonic structures, which are best exposed in the northern part of the orogen, before describing how these structures have influenced the subsequent tectonic cleavage. In our work we interpret increasing metamorphic grade, as defined by stable mineral assemblages, metamorphic equilibrium textures,