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Pseudofaults resulting from compartmentalized Liesegang bands: update

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ABSTRACT

Liesegang bands with apparent offset along fractures are common in some calcisiltite beds. Thin sections show, however, that primary laminations are not offset along the fractures. Following the development of fracture sets in the calcisiltite, the fractures were cemented by calcite. This formed polyhedral compartments of low-permeability calcisiltite bounded by impermeable walls of calcite. Liesegang bands formed when oxygen in ground water diffused into polyhedra containing soluble ferrous iron in pore water. Each joint-bounded polyhedral compartment behaved as an independent diffusion cell. Liesegang bands with nearly the same pattern and thickness tended to develop in adjacent compartments, but not at the same stratigraphic level; this resulted in the formation of pseudofaults.

Keywords Calcisiltites, iron oxide, Liesegang bands, pietra paesina, pseudofaults.

INTRODUCTION AND PURPOSE

Liesegang bands of iron oxide are a common secondary chemical structure found in many permeable igneous, metamorphic and sedimentary rocks that have undergone weathering. Some fine-grained, generally thin-bedded, limestones contain Liesegang-banded patterns that appear to have been offset along millimetre-scale faults (Figs 1 and 2). One style of this feature, apparently first noted by Kirchner in 1664 (in Civitelli *et al*., 1970), is known in Italy as '*pietra paesina*' because the pattern resembles the profile of closely spaced ruined houses or a 'turreted village' (Civitelli *et al*., 1970). The latter authors illustrate *pietra paesina* from slightly clayey carbonate siltstones of the Alberese facies (Danian–Montian) of Tuscany, Liguria and Lazio that are rarely more than a few centimetres square on joint faces. Similar features occur in carbonate beds of the Solignano flysch in Emiglia-Romagna, Italy. Civitelli *et al*. (1970) showed that the apparent offset of Liesegang bands along faults was erroneous, because laminations in the rocks are continuous and are not offset.

The purpose of this note is to describe two additional and larger scale examples of carbonate siltstones (calcisiltites) with Liesegang band patterns that can be mistakenly interpreted as faults and to expand on the origin proposed by Civitelli *et al*. (1970).

METHODS

Samples were examined in outcrop, sawn slabs and thin sections. Minerals were identified optically and using X-ray diffraction. Modal compositions were determined by estimation. Carbonate content of samples was determined as HCl-insoluble residues. Total iron content of microdrilled light and dark Liesegang bands was determined by inductively coupled plasma mass spectrometry on samples dissolved in nitric acid. NIST-traceable standards were used for calibration of the instrument.

GENERAL OBSERVATIONS

The first example consists of thin-bedded (4–8 cm thick) calcisiltite beds from the lower part of the Dimple Formation (Pennsylvanian) at two localities in Brewster County, TX, USA. One locality

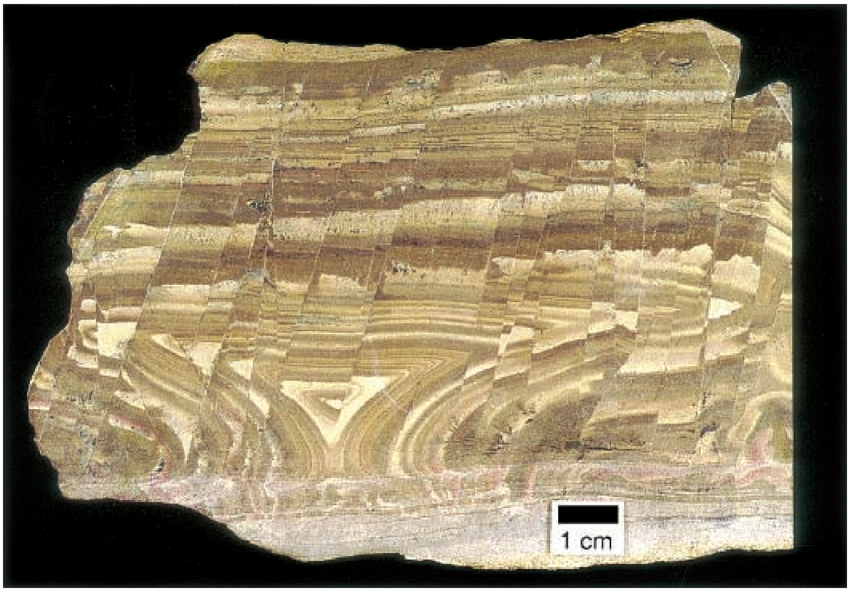

Fig. 1. Pattern of Liesegang bands in a calcisiltite of the Dimple Formation (Pennsylvanian, TX, USA) that gives the impression of complex small-scale faults. Colour contrast has been computer enhanced.

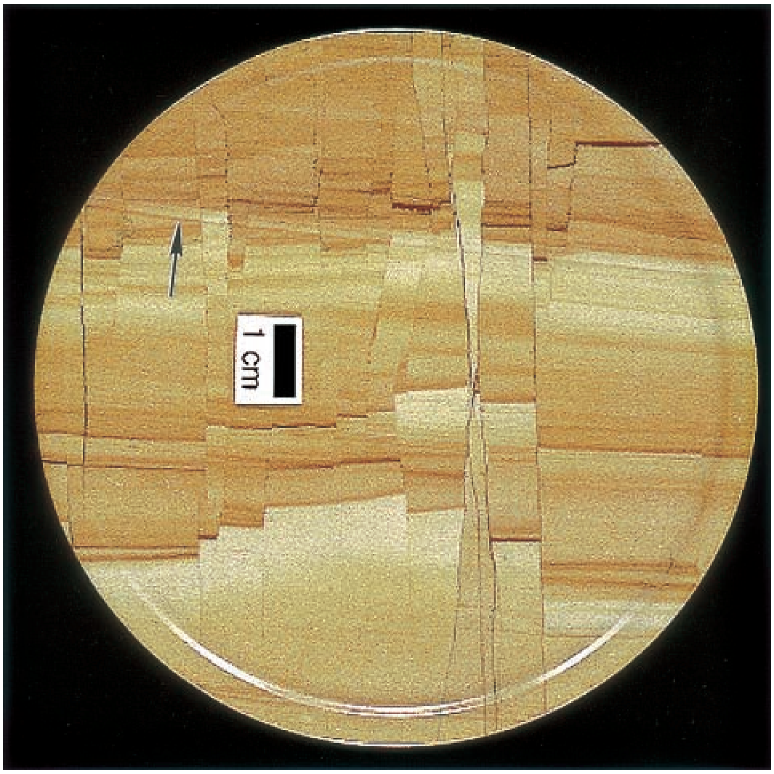

Fig. 2. Pattern of Liesegang bands in a calcisiltite of an unknown formation, Pakistan. Sample has been carved into a drink coaster. Arrow identifies a lamination that is visible after enhancing the colour contrast by computer.

of the Dimple is along US Highway 90 ≈ 34 km east of the town of Marathon, and the other locality is 10 km to the south along a ranch road. The Dimple at these localities is composed of calcisiltite and calcarenite turbidites rhythmically interbedded with calcitic pelagic shale, rocks that were deposited in a slope-to-basinal setting (Thomson & Thomasson, 1969). The rocks were structurally deformed during the Late Pennsylvanian–Early Permian Ouachita Orogeny (King, 1937; Tauvers, 1988). Liesegang-banded beds are composed of graded sedimentation units (event beds) at the centimetre scale and are locally laminated at the millimetre scale (Fig. 3). Beds are composed chiefly of micrite (≈ 30%) and sand- and silt-sized allochems (micrite clasts,

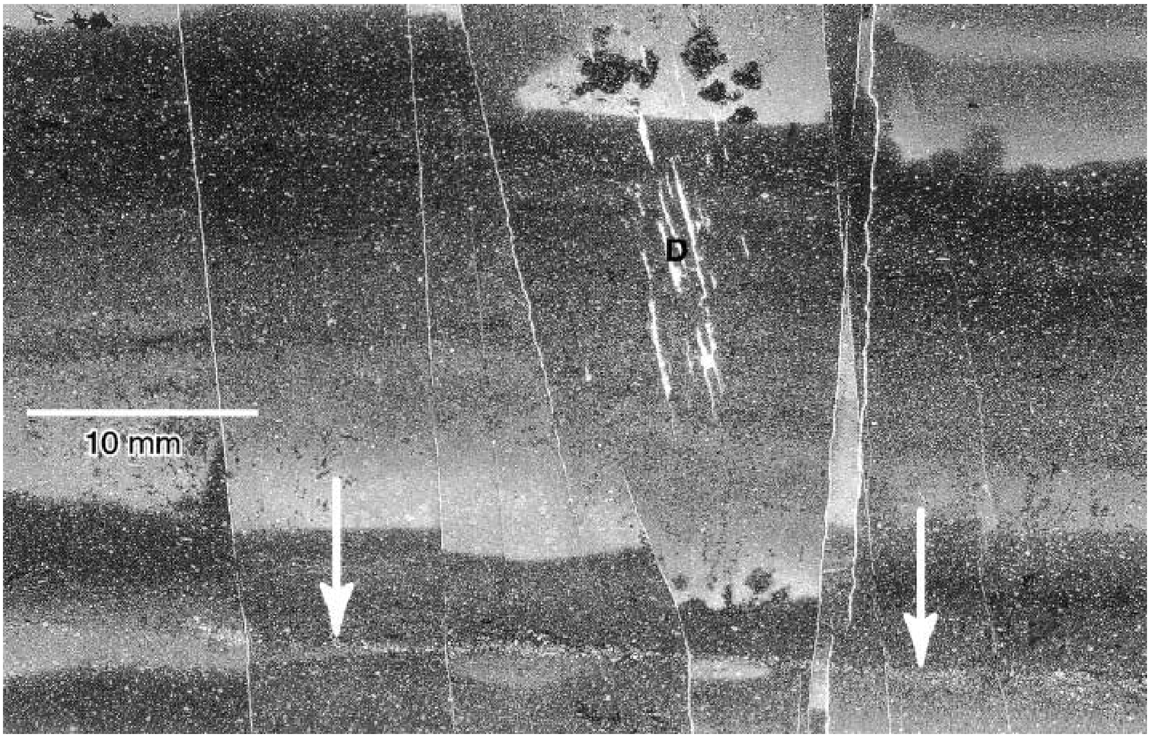

Fig. 3. Photomicrograph of a thin section of the Dimple Formation. White vertical lines are calcite-filled fractures; arrows identify a lamination that extends unbroken across the field of view; white streaks at D are thin-section flaws. Bands rich in iron oxide give the impression of being offset along fractures.

Table 1. Weight percentage Fe_2O_3 of Liesegang bands.

	Dark band	Light band
Dimple	7·43	2·39
Pakistan	1·96	1·32

Wt% iron in samples obtained by microdrilling iron-rich (dark) and iron-poor (light) Liesegang bands; values are percentage of whole rock.

pellets and fossil debris), siliceous sponge spicules and clay clasts with a trace of quartz silt. Iron oxide is goethite with minor haematite; these oxides overprint much of the rock and reach 7·4 wt% Fe_2O_3 in the iron-rich bands (Table 1). Grains of haematite pseudomorphous after pyrite are scattered (< 3%) throughout the calcisiltite; some crystals reach 2 mm in diameter.

The second example is an unknown formation from an unknown locality in Pakistan. The samples are labelled 'picture jasper' and were shaped into drink coasters (Fig. 2). This rock is composed of micrite and compacted micrite pellets (55%), fossils (chiefly spherical foraminifers up to 0·15 mm in diameter; 35%) and terrigenous clay clasts (10%). Laminated sedimentation units are at the centimetre scale (Fig. 4); graded layers are rare. Iron oxide overprints these limestone beds also, but to a lesser degree than in the Dimple. Fe_2O_3 reaches only 2 wt% in the iron-rich bands (Table 1). Possible oxidized pyrite grains are minute and rare.

LIESEGANG BANDS AND JOINTS

Bands are manifested as alternating dark brown and very light brown zones that are richer and poorer, respectively, in iron oxide (Table 1). Dark bands contain 1·5–3 times the amount of iron oxide of light bands. Bands are mostly between 1 and 5 mm in thickness and lack any particular sequential thickness patterns. In the Pakistan calcisiltites, all bands are parallel or subparallel with laminations, of which the latter differ slightly in the relative amounts of silt vs. micrite. The samples, however, are only 12 cm in diameter, so the larger scale configuration of bands in the parent beds is unknown. In the Dimple calcisiltites, bands formed within polyhedral blocks with borders that are defined by joints and bedding planes at contacts with shale beds (Fig. 1; cf. Shahabpour, 1998). Several joint sets with spacings of centimetres and oriented at high

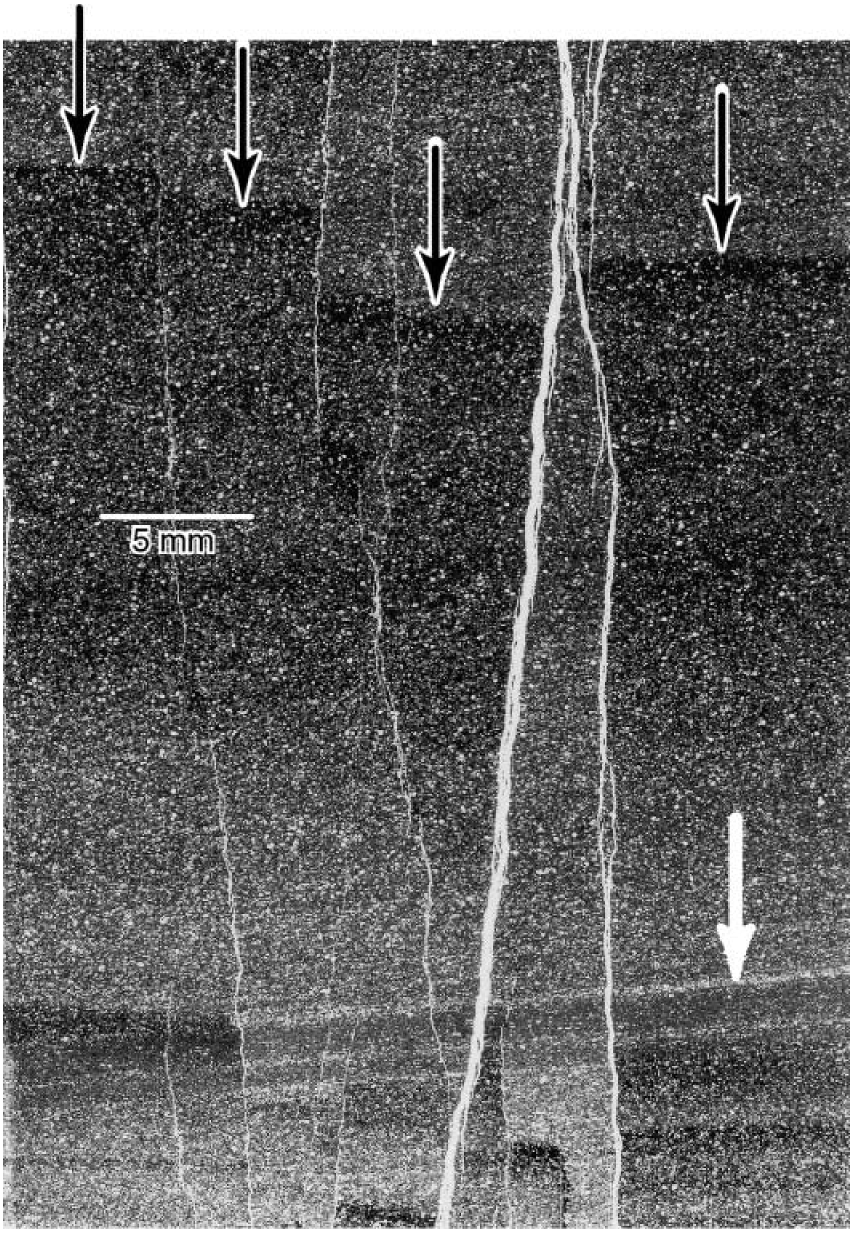

Fig. 4. Photomicrograph of a thin section of the Pakistani formation. Black arrows identify the top of a Liesegang band rich in iron oxide that appears to be offset along calcite-filled fractures (white). The white arrow points to a lamination that extends unbroken across the field of view.

angles to bedding form the vertical elements of the polyhedra. Joints die out in the shale interbeds. Bands are generally parallel or nearly parallel with bedding, but some curve around to conform to the attitude of joint faces (Fig. 5). The Pakistan beds are cut by a similar system of joints at a high angle to bedding, but Liesegang bands do not follow joints. In both stratigraphic units, joints are < 1 mm wide and have been cemented by sparry calcite.

Samples sawn perpendicular to bedding in both rock units show Liesegang bands parallel with bedding, which appear to be offset at joints (Figs 1 and 2). Bands of nearly identical thickness and spacing are commonly offset several millimetres on opposite sides of joints. The megascopic view suggests that Liesegang bands formed before deformation of the rock, and that bands are offset along faults with millimetre-scale displacement. However, thin sections show that laminations within a bed are not offset at the joints (Figs 3 and 4), and hand specimens of the Dimple show no offset of upper and lower bedding planes of individual beds. No offset of laminations is found in thin sections cut at various orientations perpendicular to bedding, so banding offset

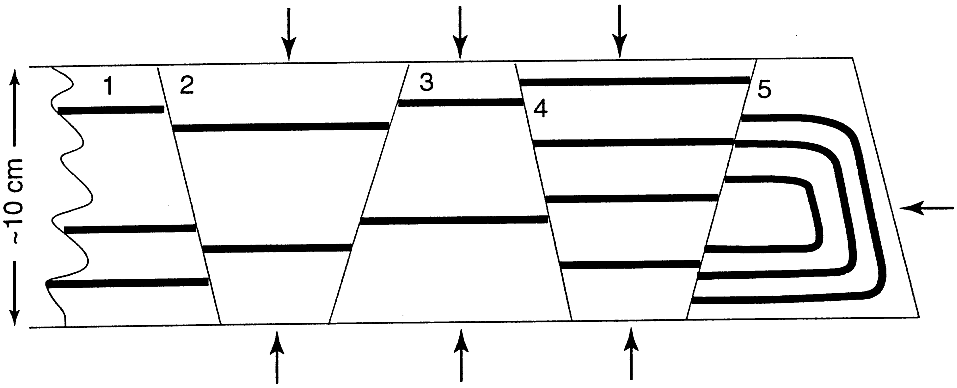

Fig. 5. Schematic view of Liesegang bands in Dimple calcisiltites. Arrows show the inferred diffusion paths of oxygenated ground water that led to generation of the bands. Some adjacent compartments have identical numbers and thicknesses of bands (polyhedra 2 and 3), whereas other adjacent compartments differ in the number and spacing of bands (polyhedra 1 and 2; 3 and 4). Some bands conform with joints that leaked oxygenated ground water (compartment 5).

cannot be explained by strike-slip faulting in which lamination continuity might be preserved but not banding. Thus, the veins demarcate joints and not faults.

INTERPRETATION

Civitelli *et al.* (1970) reported that previous workers considered the offset colour bands in the *pietra paesina* to mark small faults and that iron was introduced into the bands in solution from an outside source. Civitelli *et al.* (1970) documented the absence of offset along joints and attributed the dark bands to the oxidation of ferrous iron in the rock to ferric iron in the presence of oxygenated meteoric water. They also noted, from chemical analyses, that there was some substitution of Mg by Ca in the dark bands. They did not address the origin of the rhythmicity of the bands, nor did they describe them as a manifestation of the Liesegang phenomenon.

Liesegang bands form as precipitates in gels and porous media (Henisch, 1988) by one or more diffusional processes, although the details of their formation in rocks remain uncertain. The Liesegang–Ostwald model (Liesegang, 1913; Ostwald, 1925) explains the bands as the result, in a zone of diffusional mixing, of the repeated sequence of supersaturation of reactants, nucleation and local precipitation and depletion of reactants. This model was modified by Sultan *et al.* (1990) to account for an apparent mathematical deficiency in the Liesegang–Ostwald model. An alternative model is that a uniformly distributed precipitate undergoes dissolution in rhythmically spaced zones to produce the bands (Carl & Amstutz, 1958; Ortoleva, 1984). Arguments have been made for diffusion from inside cells to the outside (Liesegang, 1913), outside to inside (Carl & Amstutz, 1958) and in opposing directions (Sarracino *et al.*, 1987; Shahabpour, 1998). All models have elements of some self-organizational process (Merino, 1984; Ortoleva, 1984, 1993; Krug & Jacob, 1993; Fu *et al.*, 1994).

The dominance of bands parallel to bedding in both units indicates that most bands formed during diffusion perpendicular to bedding, although diffusion from joint surfaces into beds also occurred in the Dimple (Fig. 5). Liesegang (1913) showed by experiments using salts and gels that rhythmic bands form perpendicular to the path of diffusing salts. Oxygenated pore water probably diffused into cemented, low-permeability calcisiltites, reacted with soluble ferrous iron and, through some self-organization mechanism, precipitated iron oxides in rhythmic patterns. Oxygenated ground water apparently entered the Dimple Formation chiefly along weathered shale beds, the interbeds to the calcisiltites. Shale beds in drainages where the Liesegang bands occur show various degrees of calichification, attesting to their permeability near the surface. The specific mechanism of origin of the Liesegang bands found in the samples is unclear, in part because it is uncertain whether the iron was precipitated microbially or inorganically (cf. Nordstrom, 1982; Moses *et al.*, 1987). The source(s) of iron in pore water of the two formations is uncertain, but pyrite and siderite are present in fresh samples of the Dimple and were potential sources.

The time of Liesegang band generation cannot be constrained closely. Meteoric water could not have invaded the Dimple before deformation, but may have invaded the Dimple after uplift in the Late Palaeozoic, at any time before marine transgression over the bevelled Palaeozoic fold-thrust belt during the Cretaceous and during Tertiary to Holocene weathering. The Dimple is a ridge-forming unit, which has been followed on foot for many kilometres. Liesegang bands have been found only in modern drainages, which suggests, as in the example of Shahabpour (1998), that band formation is a near-recent event. Liesegang bands in a Pennsylvanian sandstone in Ohio, USA, are also interpreted to have a recent origin (Law & White, 2000).

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