Pergamon

Journal of Structural Geology, Vol. 18, No. 12, pp. 1493 to 1497, 1996

0191-8141/96 $15.00+0.00

PII: S0191-8141(96)00067-3

Brevia

SHORT NOTE

Leucoxene fish as a micro-kinematic indicator

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(*Received* 12 *February* 1996; *accepted in revised form* 1 *August* 1996)

Abstract—Asymmetric aggregates of fine-grained leucoxene and quartz are reported from siliceous *L–S* tectonites deformed by progressive simple shear. The leucoxene fish, morphologically similar to mica fish, consistently yield shear senses in agreement with other kinematic criteria. We interpret the leucoxene as a pre- or early syntectonic alteration product of detrital heavy-minerals in a siliciclastic protolith. The leucoxene fish behave as passive markers, and they record kinematics by modification of pre-existing aggregates rather than syndeformational mineral growth. For siliceous metasedimentary rocks otherwise lacking in micro-kinematic indicators, leucoxene fish may provide an alternative to quartz *c*-axis analysis. Copyright © 1996 Elsevier Science Ltd

INTRODUCTION

Many microshear-sense indicators have been proposed for the kinematic analysis of ductilely deformed rocks that have experienced non-coaxial progressive deformation (Simpson & Schmid 1983, Simpson 1986, Hanmer & Passchier 1991, Passchier & Trouw 1996). However, most *L–S* tectonites lack shear-sense indicators and remain unconstrained with respect to kinematics. This paper reports a previously undescribed micro-kinematic indicator, leucoxene fish, from the Teslin suture zone of northwest Canada. Because these microstructures occur primarily in quartzites, they may provide a less time-consuming alternative to quartz petrofabric analysis for siliceous tectonites.

GEOLOGIC SETTING

The Teslin suture zone in Yukon Territory, Canada, is a major tectonic boundary separating ancestral North American rocks from younger, allochthonous terranes to the west (Tempelman-Kluit 1979). Sedimentary, volcanic and intrusive protoliths were ductilely deformed at lower greenschist to amphibolite facies conditions and contain isolated eclogites and blueschists (Erdmer 1987, Hansen 1992). *L–S* tectonites with elongation lineations (L_e) both parallel and perpendicular to strike characterize the Teslin suture zone (Hansen 1989).

At Little Salmon Lake (62.2°N, 134.5°W) the sequence of deformation is complex (Oliver & Hansen 1994). Quartz *c*-axis fabric analysis, used in conjunction with sparse micro-indicators, shows that individual tectonites containing a dip-slip L_e record either SW- or NE-vergent shear. Top-to-the-NW shear locally overprints the dip-slip fabrics. $^{40}Ar/^{39}Ar$ thermochronology at Little Salmon Lake constrains the penetrative deformation to be pre-196 Ma (Oliver & Hansen 1994). Discordant $^{40}Ar/^{39}Ar$ cooling ages for muscovite–biotite pairs indicate that the tectonite assemblage underwent slow cooling ($<5\,°C\,m.y.^{-1}$) after ductile deformation. NW-trending folds at Little Salmon Lake also postdate *L–S* tectonite formation.

EASTERN STRIKE-SLIP DOMAIN

Three strike-slip L_e domains transect the Little Salmon Lake area. Poor-quality microshear-sense indicators hampered kinematic analysis in the eastern strike-slip domain. An assortment of indicators are locally present including *S–C* fabrics, grain-shape preferred orientation, mica fish, σ-porphyroclasts, asymmetric microfolds, and pressure shadows around pyrite, but they are of low confidence. Similarly, quartz *c*-axis fabrics from this domain are poorly developed relative to those observed elsewhere at Little Salmon Lake. In part, the poor quality of the kinematic indicators in this domain is a function of lithology as graywackes are the dominant protolith. However, the nearly orthogonal overprinting of strike-slip shear on the pre-existing dip-slip fabrics may also be a factor. Despite the weak fabric development, a top-to-the-NW sense of tectonic transport is indicated for this domain by the preponderance of quartz *c*-axis and micro-kinematic data. This agrees with other strike-slip L_e domains at Little Salmon Lake where quartz *c*-axis fabrics are better developed.

A discontinuous quartzite and stretched-pebble conglomerate unit exposed within the eastern strike-slip domain typifies the kinematic difficulties. The quartzites were extensively annealed during slow cooling and lack a grain-shape preferred orientation. Although they display a lattice-preferred orientation, quartz *c*-axis analysis yielded either ill-defined or symmetric patterns. In particular, the *c*-axis fabric of one sample (NS-59d) relative to the structural reference frame (X, parallel to L_e; Z, normal to foliation; and Y, perpendicular to X and Z) consists of a single maximum at X.

Sample NS-59d displays a pronounced tectonic foliation and a weakly developed L_e defined by streaked mica. The orientation of both foliation and L_e are consistent with adjacent samples from this strike-slip domain. Quartz grains, commonly pinned by mica, show straight contacts and weak undulatory extinction. Fine-grained muscovite, generally concordant with foliation, is hosted within many of the larger quartz grains—a feature consistent with grain-boundary migration during slow, post-tectonic cooling (Hansen & Oliver 1994). Muscovite and calcite together comprise ~15% of this sample with chlorite, apatite, euhedral pyrite, and fluoro-phlogopite present in trace amounts.

Table 1. Microprobe analyses[a]

SiO_2	46.44
TiO_2	38.61
Al_2O_3	3.19
FeO	0.77
MnO	0.01
MgO	3.17
CaO	1.43
K_2O	0.45
Na_2O	0.03
F	0.16
Total	94.26

[a]Weight percent of oxides except fluorine. Average of five analyses. Analyses determined on a JEOL-733 Superprobe at Southern Methodist University.

LEUCOXENE FISH

Sample NS-59d also contains aggregates of opaque sooty material intergrown with fine quartz (Fig. 1). We identified the opaque material as leucoxene based on its light gray color under reflected light and its Ti-rich composition as determined by electron microprobe analysis (Table 1). Because of the extremely fine grain size of the mineral aggregates, the broad-beam (10 μm) spot analyses contain significant Si, Al and Mg contributed from adjacent phases.

The leucoxene aggregates are lenticular in cross-section when viewed in either the *XZ* (motion plane) or *YZ* sections. Their maximum dimension, averaging 0.21 mm, is parallel to *Y*. However, within the *XZ* section the major and minor axes are inclined at an average angle of 18° to *X* and *Z*, with mean dimensions of 0.17 and 0.05 mm, respectively (Fig. 2). In this regard the leucoxene aggregates are morphologically similar to mica fish described from siliceous tectonites (Eisbacher 1970, Lister & Snoke 1984). Of ~300 leucoxene fish observed in the motion-plane section of NS-59d, virtually all are aligned with their major axis plunging to the SE. Using the convention for interpreting shear-sense from mica fish (Simpson & Schmid 1983), the leucoxene fish uniformly indicate top-to-the-NW shear. This is consistent with other kinematic criteria.

ORIGIN OF LEUCOXENE FISH

Because leucoxene is ill-suited for sedimentary transport, we propose that the leucoxene aggregates represent an alteration product of primary detrital constituents in the siliciclastic protolith. Although the aggregates are distributed throughout sample NS-59d, they are more abundant in some layers than others. We interpret these and other compositional variations in the quartzite as relict, albeit transposed, bedding within a sandstone protolith that contained the leucoxene heavy-mineral precursor. Given the low Fe and Ca content of the aggregates, rutile is a likely candidate although ilmenite and titanite are also possibilities.

Alteration of the primary titanium mineral probably occurred during metamorphism. Quartz veinlets that cross-cut the foliation yield a *c*-axis pattern indistinguishable from their host indicating they are either pre- or early synkinematic. The quartz veinlets and the high fluorine content of the fluoro-phlogopite (~3%) suggest that temperatures and fluid activities were sufficiently high to alter the Ti-rich detrital grains.

Unlike mica fish whose formation remains obscure (Hanmer & Passchier 1991, Passchier & Trouw 1996), leucoxene fish can be explained by non-coaxial deformation of a spherical marker. Alteration of the primary titanium mineral (former sand grains) would most likely produce radially-symmetric aggregates of leucoxene if fluid migration was homogeneous. Deformation of an equidimensional aggregate by simple shear would result in an ellipsoid whose major axis rotates towards *X* with increasing strain. Thus, the leucoxene fish are passive features in a quartz-rich matrix that record kinematics by the modification of pre-existing mineral aggregates.

UTILITY FOR KINEMATIC AND STRAIN ANALYSIS

It is tempting to use the leucoxene fish to quantify bulk strain as their discoidal shape puts them within the flattening field of a Flinn diagram (Flinn 1962). Similarly, the aspect ratio of the major and minor axes could be used to estimate the shear strain (Ramsay & Huber 1983). However, this is unwarranted for several reasons. The original shape of the leucoxene aggregates is unknown and they may have been oblate prior to deformation, particularly if the leucoxene preferentially migrated along bedding/foliation surfaces during alteration. Similarly, the timing of alteration of the primary titanium mineral is uncertain. If alteration was syndeformational, the leucoxene fish would record only a portion of the total strain. Finally, kinematic analysis indicates a polyphase deformational history at Little Salmon Lake with two nearly orthogonal shear events affecting the tectonites in the vicinity of NS-59d. Because it is not possible to quantify strain during *either* of these events, an infinite number of deformation paths could be invoked to produce the present state.

We limit leucoxene fish to kinematic analysis, a role for which they appear well-suited. Of 10 tectonite samples

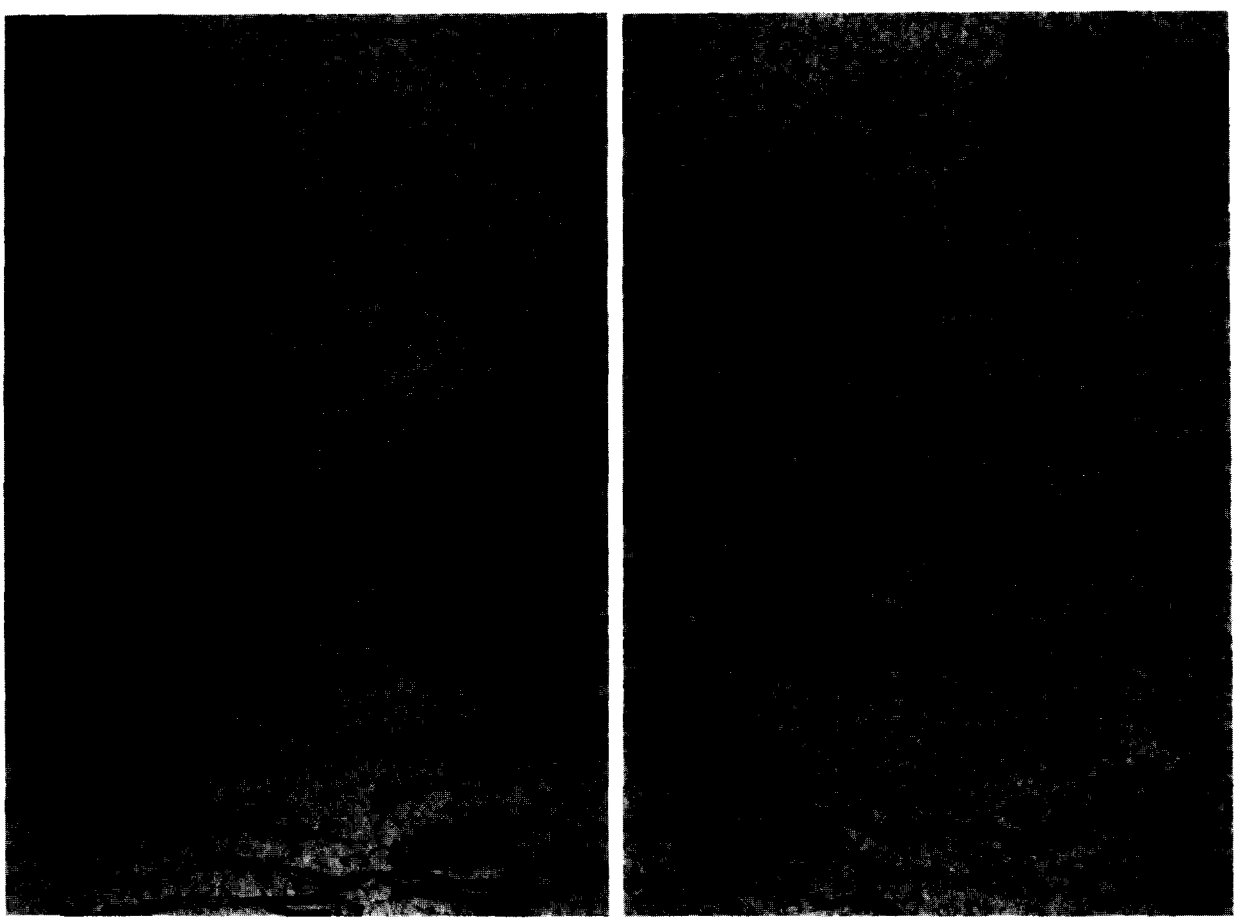

Fig. 1. Photomicrographs of leucoxene fish in plane polarized light. (a) *X-Z* (motion-plane) view. *X* is parallel to L_e (N59W), and *Z* is normal to foliation. Shear sense is top-to-the-NW (to the right in photomicrograph). Cal, calcite; Qtz, quartz; Ms, muscovite. (b) *YZ* view. *Y* is perpendicular to *X* and *Z*.

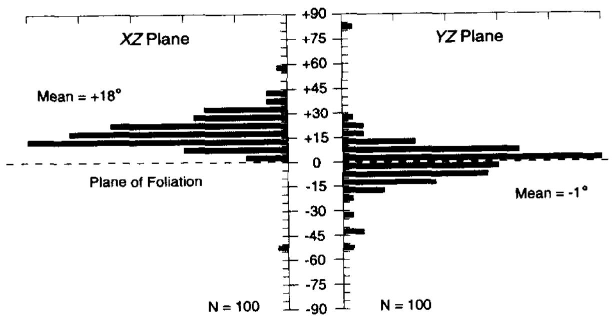

Fig. 2. Angular relationship of the major axes of the leucoxene fish with respect to foliation in the *XZ* and *YZ* planes. Positive inclination in the *XZ* plane corresponds to SE plunge direction for axis, and negative inclination plunges NW.

from Little Salmon Lake containing leucoxene fish, all record a shear-sense in agreement with the local kinematic domain as established by either quartz *c*-axis analysis and/or other micro-structures. Where present, leucoxene fish are the *most reliable* kinematic indicator at Little Salmon Lake based on the number per thin-section, the consistency of shear-sense, and their degree of asymmetry.

A potential factor inhibiting the use of leucoxene fish is their size. Whereas most micro-kinematic indicators have dimensions in the millimeter or even centimeter range, the leucoxene fish are a full order of magnitude smaller. Consequently, they may be easily overlooked, particularly if a wide-field microscope is used to scan for more conventional shear-sense indicators at low-magnification. In this regard they underscore the need to evaluate information at all scales when conducting kinematic analysis, from macroscopic observations at the outcrop-scale (or larger) down to sub-millimeter features.

Acknowledgements—Supported by National Science Foundation grant EAR-9103531 to Vicki L. Hansen. We thank Vicki Hansen and James Willis for comments on an early version of this paper, Art Snoke and an anonymous reviewer for suggesting improvements, and Cees Passchier for editorial assistance.

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