Kilometre-scale folding in the Teslin zone, northern Canadian Cordillera, and its tectonic implications for the accretion of the Yukon–Tanana terrane to North America: Discussion[1]

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Despite the often divergent opinions regarding the evolution of the Teslin suture zone (TSZ), previous tectonic models broadly agree that the TSZ comprises a ductile shear zone that constitutes a fundamental crustal boundary (e.g., Tempelman-Kluit 1979; Erdmer 1985; Hansen 1989; Stevens and Erdmer 1996; Hansen and Dusel-Bacon 1998). In contrast, de Keijzer et al. (1999) offer a radical model in which the TSZ is a rootless polydeformed nappe obducted onto North America. According to their interpretation the TSZ does not represent a shear zone. Although the influx of new ideas in science is always commendable, the methodology by which de Keijzer et al. (1999) arrive at their interpretation is scientifically flawed; they ignore or arbitrarily dismiss published TSZ data, and they fail to present evidence in support of key elements of their model. Although their data may be valid, we question: (1) their interpretation of linear fabric elements, (2) the existence of kilometre-scale folding, and (3) evidence for North American rocks in the western TSZ.

Linear fabric elements

de Keijzer et al. (1999) discard the interpretation of the TSZ as a complex ductile shear zone and assert that, apart from the western TSZ, most lineations represent crenulations and bedding–cleavage intersections. They state that they did not observe stretching lineations or fabric asymmetries. In contrast, previous workers (Erdmer 1985; Hansen 1989, Hansen et al. 1989, 1991; Stevens and Erdmer 1996; Oliver 1996; Hansen and Dusel-Bacon 1998) describe numerous structural domains within the TSZ and correlative L–S tectonites in east-central Alaska, based on elongation lineation orientation and microstructural asymmetry, which they attribute to widespread ductile shear across the entire TSZ. Thus, knowledge of whether or not the TSZ represents a zone of ductile shear deformation is critical to models of TSZ evolution.

The presence and nature of quartz lattice-preferred orientation (LPO) can preserve a record of ductile shear history. Quartz *c*-axis LPO data plotted relative to foliation and lineation indicate whether the ductile deformation is dominantly pure shear, simple shear, or more complex monoclinic or triclinic shear (Lister et al. 1978; Lister and Price 1978; Lister and Williams 1979; White et al. 1980; Simpson and Schmid 1983; Schmid and Casey 1986, Law 1990; Passchier and Trouw 1995; Passchier 1998). Quartz *c*-axis analyses have been conducted for numerous L–S tectonites from the TSZ and correlative rocks in Alaska. Hansen (1989, fig. 8) presented quartz LPO diagrams for nine TSZ and Cassiar tectonites, including two samples of de Keijzer et al.'s (1999) micaceous quartzite (MQ) unit. Oliver (1996) documented quartz LPO fabrics for 47 L–S tectonites from the Glenlyon area north of de Keijzer et al.'s (1999) study area. Hansen and Dusel-Bacon (1998) present 36 quartz LPO plots from TSZ correlative tectonites in Alaska. All the LPO diagrams indicate a ductile deformation history, and most of the LPO patterns also indicate monoclinic geometries, consistent with noncoaxial ductile shear in Y_I-type shear zones (Passchier 1998, fig. 13). The quartz LPO plots provide strong evidence that (1) TSZ tectonites record ductile shear, and (2) the lineations are indeed elongation lineations and not crenulation or intersection lineations, as asserted by de Keijzer et al. (1999). Additionally, microstructural asymmetries within TSZ tectonites are consistently preserved in the plane normal to foliation and parallel to lineation (Hansen 1989; Stevens and Erdmer 1996; Oliver 1996; Hansen and Dusel-Bacon 1998), further supporting the interpretation that TSZ tectonites record widespread ductile shear.

TSZ tectonites and correlative rocks preserve kinematic domains based on lineation orientation and associated shear fabrics in four distinct regions. These regions include east-central Alaska (Hansen and Dusel-Bacon 1998) and regions north of (Oliver 1996), south of (Stevens and Erdmer 1996), and enclosing (Hansen 1989) the area examined by

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de Keijzer et al. (1999). In each region, workers interpreted the shear deformation as having occurred within a transpressional tectonic environment. Recent studies indicate that caution must be exercised in interpreting the direction of tectonic transport within transpressional environments, because complex monoclinic and triclinic shearing may result in lineations not aligned with the shear direction (Jiang and Williams 1998; Lin et al. 1998). However, the kinematic data suggests that TSZ tectonites record dominantly monoclinic-type Y_I-shear (Passchier 1998), although the shear is apparently partitioned into dip-parallel and strike-parallel domains (Hansen 1989; Stevens and Erdmer 1996; Oliver 1996; Hansen and Dusel-Bacon 1998). In this regard, the TSZ may be more similar to the transpressional Rosy Finch – Gem Lake shear zone in the Sierra Nevada, where both shallow and steeply plunging lineations occur (Tikoff and Greene 1997). However, in the Sierra Nevada example, dextral strike-parallel asymmetries occur with steeply plunging elongation lineations, and thus represent X_I-shear zones of Passchier (1998). No such discrepancies between fabric asymmetry and elongation lineation are noted in TSZ tectonites. A variety of microkinematic indicators are found across the TSZ, including quartz grain-shaped preferred orientation (e.g. Hansen 1989, fig. 7*b*), pyrite pressure shadows (e.g. Hansen 1989, figs. 6*c* and 7*a*), mica “fish” (e.g. Erdmer 1985, fig. 11), leucoxene “fish” (e.g. Oliver and Goodge 1996, fig. 1), and S–C and C’ fabrics (e.g. Hansen 1989, fig. 6*a*; Stevens and Erdmer 1996, fig. 3*e*). In all cases, the fabric asymmetries occur in planes normal to foliation and parallel to lineation. Consequently, TSZ tectonites record relatively simple monoclinic fabrics at least to a first-order approximation, despite their transpressive deformation history.

The asymmetric quartz LPO girdles and microshear indicators together provide important kinematic constraints for TSZ evolution. de Keijzer et al. (1999) ignore previous kinematic data and restrict their analysis to the westernmost margin of their project area and the Dunite klippe. Although de Keijzer et al.’s (1999) limited kinematic interpretations agree with the previous studies noted above, these studies document shear across a vastly larger area encompassing all of de Keijzer et al.’s (1999) field area and extending to the south, north, and into east-central Alaska. The kinematic domains record regionally consistent patterns of dextral or top-to-the-NW shear within the strike-parallel domains and apparent normal and apparent reverse shear in the dip-parallel domains (see Hansen and Dusel-Bacon 1998 for discussion). Indeed, the interpretation of these multiple kinematic domains has been a key factor in the proliferation of TSZ tectonic models (Erdmer 1985; Hansen 1989; Stevens 1994; Stevens and Erdmer 1996; Oliver 1996; Hansen and Dusel-Bacon 1998).

Kilometre-scale folding

de Keijzer et al. (1999) propose the presence of a regional overturned east-vergent fold—the Grizzly synform—as the dominant structure in their study area. The purported hinge lies just west of the d’Abbadie fault, with the overturned limb occupying much of the TSZ, and the shallow limb occurring mostly east of the d’Abbadie fault within rocks of the parautochthonous Cassiar terrane.

Kilometre-scale folding in the TSZ was described previously in the Glenlyon area, where the tectonite foliation is warped into two broad synclines with an intervening anticline (Campbell 1967; Oliver 1996). An apparent lithologic succession is preserved on both limbs of the eastern-most syncline and includes a repetition of distinctive lithologies, such as greenstone, marble, calc-silicate schist, and volcanogenic sulphide mineralization (Oliver and Mortensen 1998; Colpron 1999*a*,*b*).

In contrast to the Glenlyon folds, evidence for the Grizzly synform is lacking. Distinctive western TSZ lithologies do not occur east of the purported synform axis, and evidence for the shallow limb is lacking. The westerly dips of the tectonite foliation gradually change from steep to moderate from west to east across the TSZ (Tempelman-Kluit 1979; Erdmer 1985; Hansen 1989). Comparison of foliation orientation reported by de Keijzer et al. (1999) across the synform axis is hindered due to intense small-scale folding east of the fold axis in their domain IV. However, the effects of domain IV small-scale folds should not be mistaken for regional shallowing of foliation—small-scale folds within a steep west-dipping foliation would produce the distribution shown by de Keijzer et al. (1999). de Keijzer et al.’s (1999) data show that truly shallow westerly dips are uncommon in domain IV and are generally restricted to domain V, the Dunite klippe. However, the Dunite klippe and the underlying parautochthonous Cassiar tectonites, the dominant assemblage east of the d’Abbadie fault, record distinctly different tectonic histories from TSZ tectonites (Tempelman-Kluit 1979; Erdmer 1985, Hansen 1989, 1992*a*, *b*; Hansen et al. 1989, 1991). Indeed, the juxtaposition of lithologies on opposite sides of the d’Abbadie fault occurred after cooling of the TSZ tectonites (Hansen et al. 1991).

Evidence for the Grizzly synform centers largely on geometric arguments, including asymmetric fold vergence domains and cleavage–bedding relations (de Keijzer et al. 1999, fig. 6); F_3-folds with S-asymmetries (looking northwest) occur west of the synform axis whereas F_3-folds with Z-asymmetries occur to the east. However, alternate interpretations can accommodate these fold patterns. Z- and S-folds could be products of reverse and normal ductile shear, respectively, within steeply southwest-dipping tectonites—consistent with structural and kinematic data (Erdmer 1985; Hansen 1989; Stevens and Erdmer 1996).

Evidence of North American rocks in the western TSZ

de Keijzer et al. (1999) assert that autochthonous North American rocks underlie the TSZ and that the quartzofeldspathic schist that outcrops west of Last Peak and extends to the Big Salmon fault constitutes North America. Thus, by their model, the TSZ is a nappe separated from the autochthonous basement by an inferred fault. This hypothetical fault takes on increasing significance as their discussion progresses and is described as a ductile thrust, an obduction boundary, and, ultimately, a possible terrane boundary.

de Keijzer et al. (1999) provide no data to support these claims. Rocks with pericratonic characteristics elsewhere in the TSZ are recognized based on evolved isotopic signatures and (or) Devono-Mississippian crystallization ages for orthogneiss bodies (Stevens et al. 1993; Creaser et al. 1997; Oliver and Mortensen 1998). de Keijzer et al. (1999) provide no such data for the quartzofeldspathic schist. Even if these rocks have pericratonic characteristics, such an affinity does not require them to be autochthonous to North America. Rocks with evolved isotopic signatures and (or) Devono-Mississippian crystallization ages occur in several terranes west of the TSZ including the Nisling and the Tracy Arm terranes. Although it could be argued on the basis of orogenic float that these continental assemblages together constitute autochthonous North America, other mechanisms capable of producing the observed distribution of pericratonic assemblages exist (Hansen and Dusel-Bacon 1998).

de Keijzer et al. (1999) do not provide evidence for a fault west of Last Peak that juxtaposes TSZ tectonites with North American assemblages. Their map provides little data in this region. The most compelling “evidence” for the assumed fault is the proposed existence of North American rocks west of the TSZ—an unsupported claim. Because the inferred fault constitutes a key element of de Keijzer et al.’s (1999) model, robust evidence of its existence is required.

That the history of the TSZ remains controversial after 20 years is a testament to both its tectonic importance and enigmatic geology. Clearly, our understanding of its development is imperfect by any measure. However, only by building upon previous data can we hope to unravel the complex geology of this crustal entity. Models that explain only part of the data are inherently either overly simplistic or wrong. This is not to say that data cannot or should not be challenged, but data cannot be discarded lightly. We suggest that models capable of explaining all the data, including the structural observations presented by de Keijzer et al. (1999), exist. The subduction–accretion model initially proposed by Tempelman-Kluit (1979) is one such model; de Keijzer et al.’s (1999) model is not.

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