Shear-zone controls on giant spodumene-bearing pegmatite deposits in the northern Pilbara Craton, Western Australia

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1. Background

- Giant spodumene ($LiAlSi_2O_6$) -bearing pegmatite deposits are located along regional shear zones in the Archaean northern Pilbara Craton (Fig. 1), yet were formed at ca. 2845 Ma (Kendall-Langley et al., 2020), after documented orogenic episodes (Hickman, 2021). The 2860-2830 Ma Split Rock Supersuite is considered to be the only viable source region to pegmatite deposits, and both the granites and pegmatites have been attributed to a single, post-tectonic magmatic event (Sweetapple and Collins, 2002).
- The popular model for rare-metal pegmatite genesis contends that, whilst pegmatite deposits are most commonly hosted in orogenic belts near crustal-scale structures, pegmatite-forming magmas are the products of fractional crystallisation in large scale (~1000 km^3), late- to post-tectonic granite bodies, and that pegmatite-forming magmas are passively emplaced along "structures of convenience" into surrounding country rocks (London, 2018; Bradley et al., 2017; Černý, P., 1991).
- Structural mapping and drill-core logging, petrography and targeted whole-rock geochemistry have been undertaken to determine the role of deformation in the genesis of pegmatite deposits in the northern Pilbara Craton.

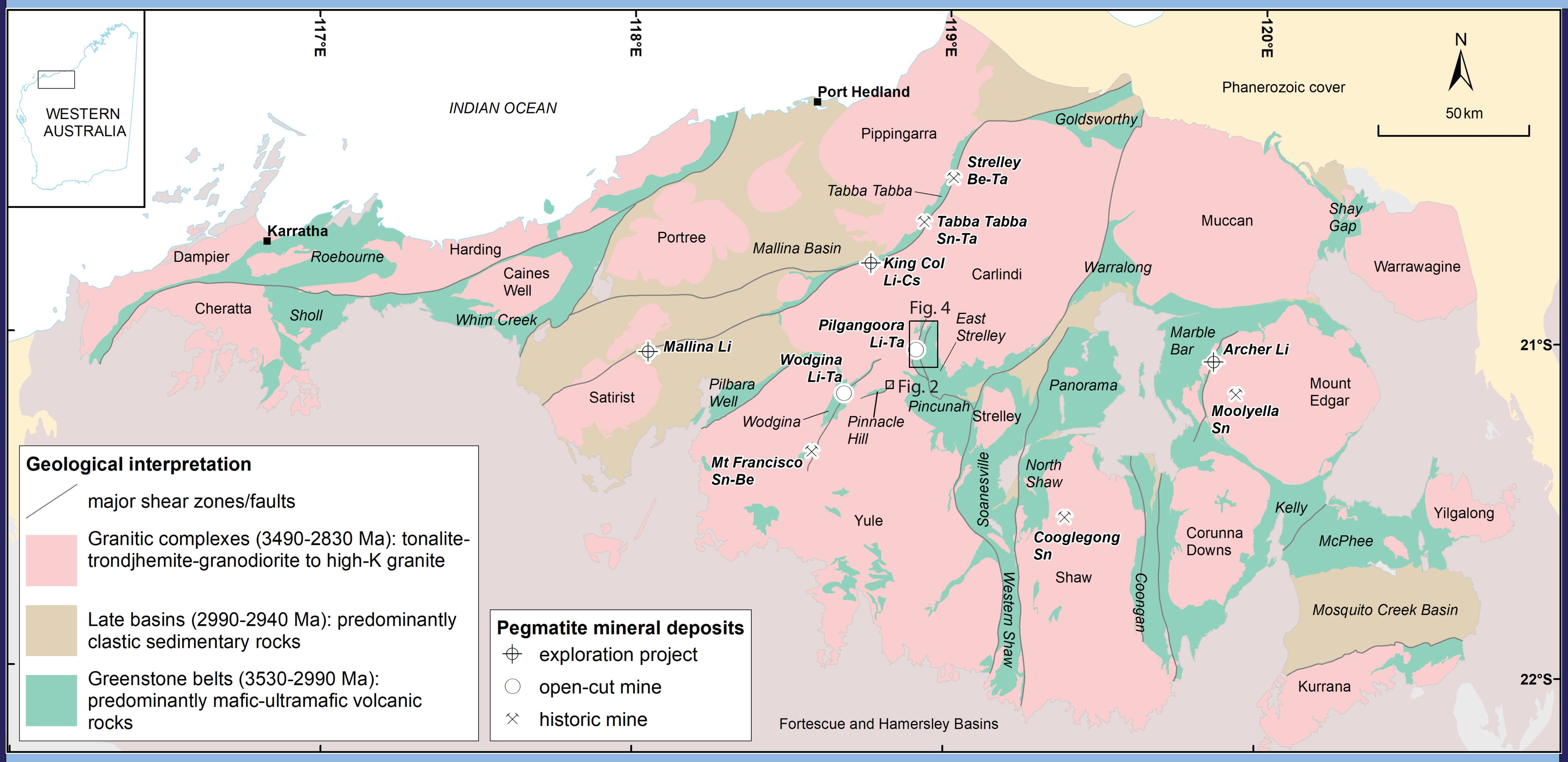
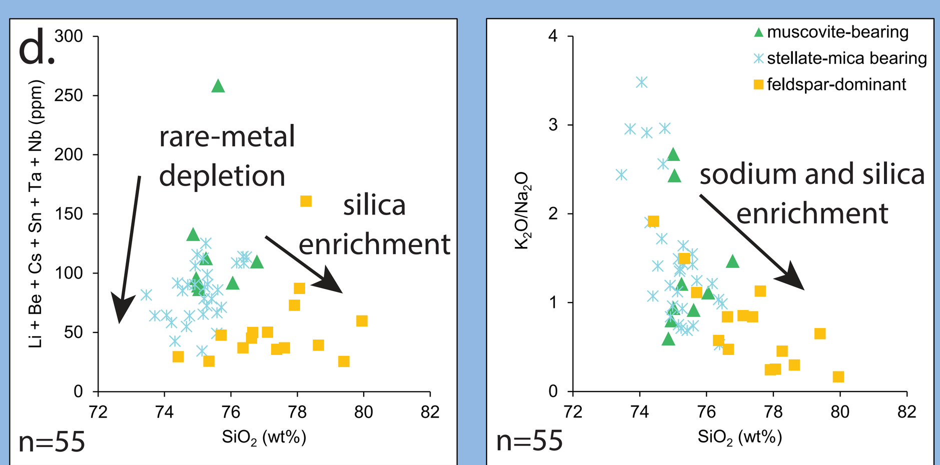
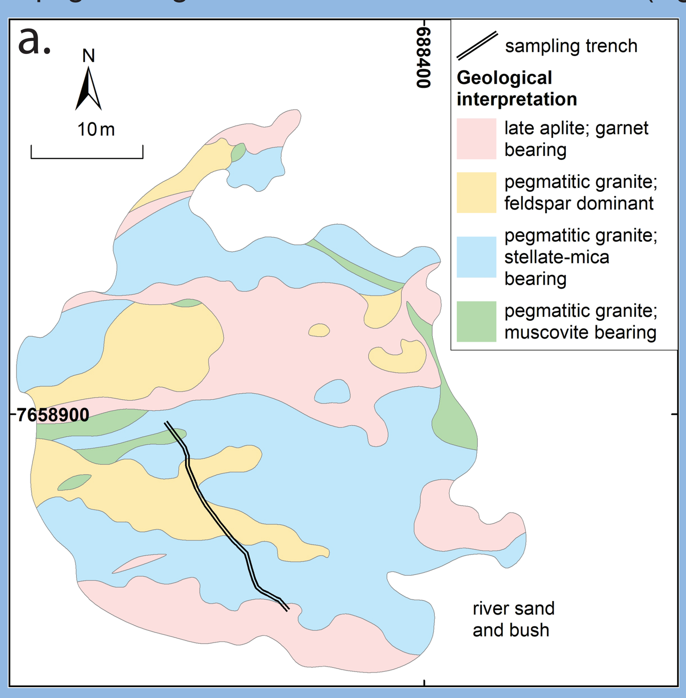


Fig. 1. Simplified geological map of the Archaean northern Pilbara Craton showing: i) the individual greenstone belts and late clastic basins (italics), and granitic complexes, and; ii) distribution and metallogenic associations of pegmatite mineral deposits. Redrawn and modified after GSWA 1:2,500,000 Geological Map of Western Australia GIS layer.

2. Textural and compositional evolution of Split Rock Supersuite pegmatitic granite during ductile shear-zone deformation, Pinnacle Hill district

- Split Rock Supersuite pegmatitic granite (Fig. 2a,b,c): i) megacrystic muscovite-bearing pegmatitic granite with euhedral magmatic texture; ii) deformed stellate-mica bearing pegmatitic granite in which former muscovite books are cataclastically disaggregated and replaced by stellate patches of an optically distinct, phengitic white-mica; iii) strongly deformed feldspar-dominant pegmatitic granite comprised of medium-grained albite-quartz intergrowths enveloping relic microcline crystal fragments, which likely represent deformation induced myrmekite (Menegon et al., 2006), and; iv) late garnet-bearing aplite which cross-cuts the previous lithologies.
- Transition from muscovite-bearing to stellate-mica bearing pegmatite: rare-metals (Li, Be, Cs, Sn, Ta, Nb) and potassium depletion, sodium enrichment (Fig. 2d).
- Transition from stellate-mica bearing to feldspar-dominant pegmatitic granite: silica and sodium enrichment (Fig. 2d).





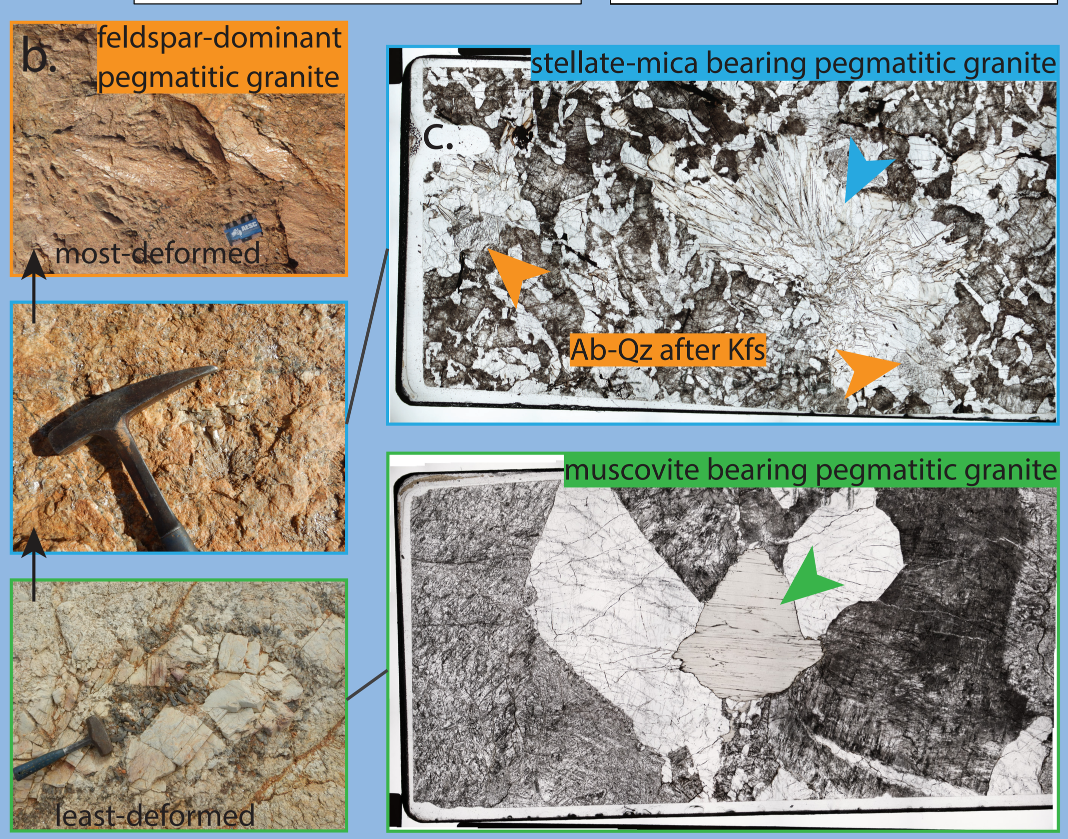
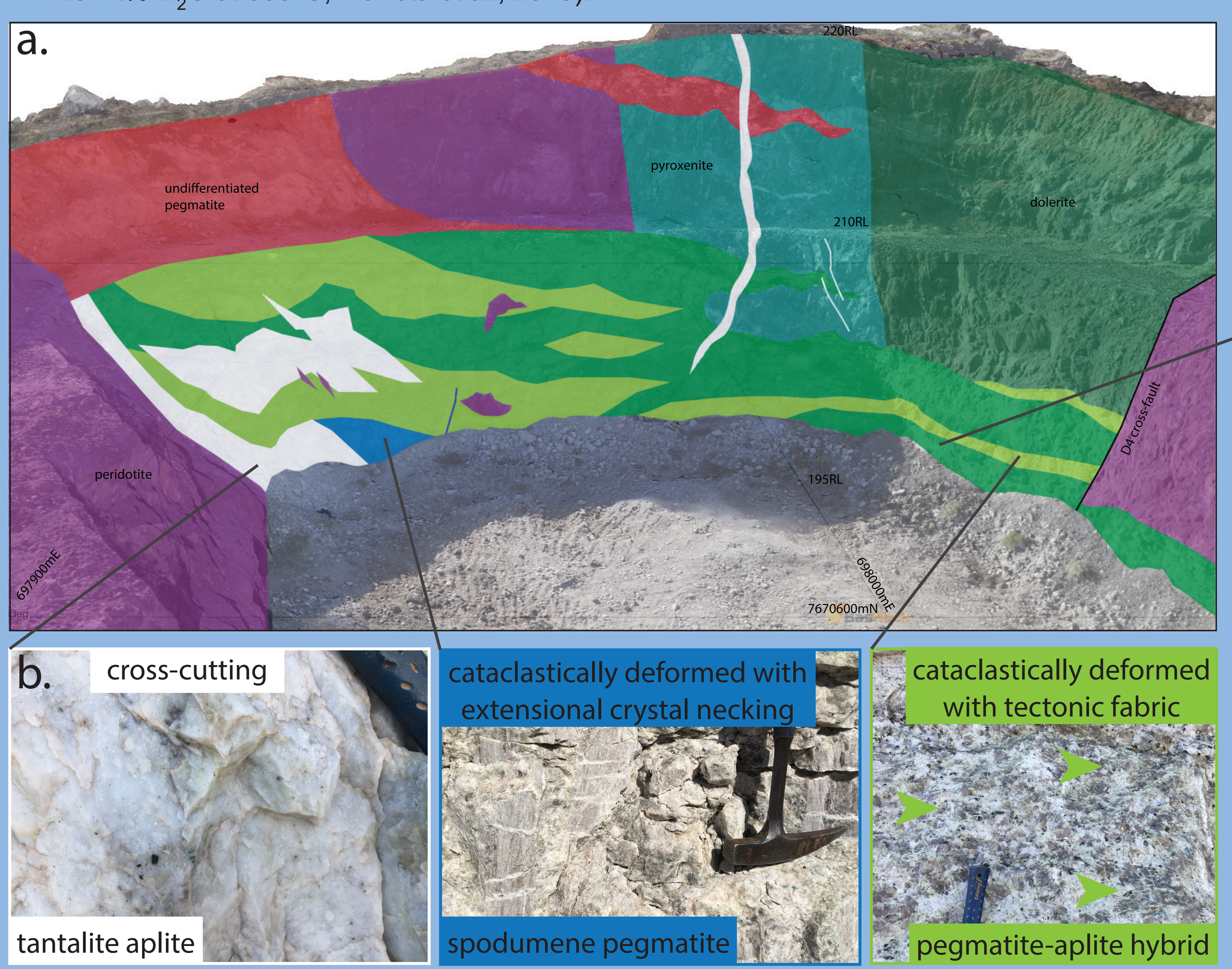
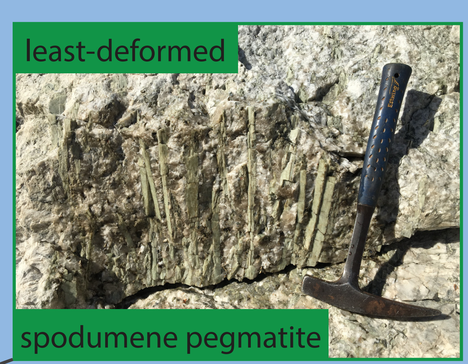


Fig. 2. (a) Simplified geological map of river-cut pavement in Pinnacle Hill district showing pegmatitic granite lithologies. (b) outcrop photographs of pegmatitic granite lithologies. (c) PPL microphotographs of pegmatitic granite lithologies (1x magnification, 2-inch field of view). (d) total rare-metals (Li,Be,Cs,Sn,Ta,Nb) vs. SiO2 and K2O/Na2O vs. SiO2 binary plots from whole-rock geochemical data of pegmatitic granite trench samples.

3. Textural and compositional evolution of pegmatite and aplite during ductile shear-zone deformation, Pilgangoora district

- Pilgangoora pegmatite lodes are complexes of distinct lithologies (Fig. 3a,b): i) megacrystic spodumene-quartz pegmatites which preserve unidirectional solidification texture of spodumene growth normal to intrusion contacts; ii) cataclastically deformed, coarse- to fine-grained spodumene-quartz pegmatites with grain-scale infiltrations of aplite, in which spodumene best defines the effects of solid-state flow by extensional necking of crystals and line-rotation towards L-S fabrics, and; iii) fine-grained, cleavelandite-rich, tantalite-bearing aplite which variably cross-cuts or intrudes parallel to pegmatite sheets.
- Magmas forming the spodumene-quartz pegmatites were saturated in lithium greater than required to crystallise spodumene (Fig. 3c; ~1.3 wt% Li_2O at 600°C, Maneta et al., 2015).





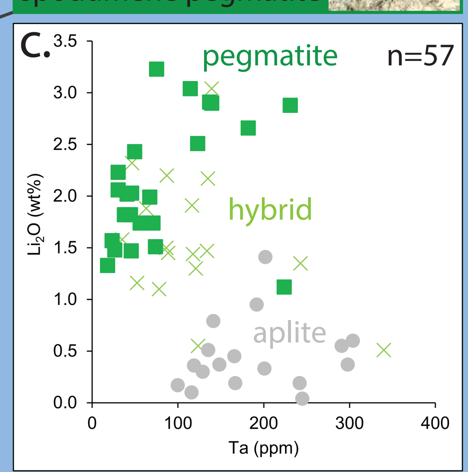


Fig. 3. (a) North-looking face sketch of the Domain-1 pegmatite lode in the Pilgangoora district showing pegmatite and aplite lithologies. (b) outcrop photographs of pegmatite and aplite lithologies. (c) Li vs. Ta binary plot from whole-rock geochemical data of 57 diamond drill-core samples (PQ quarter core) taken through the Domain-1 pegmatitie lode.

4. Geometric characterisation of shear zones and pegmatite intrusions in the Pilgangoora district, northern East Strelley greenstone belt

- Kinematically distinct D4 Pilgangoora shear zone (Fig. 4a) comprises both strike-slip and normal-slip strain compartments which: i) influence the en-echelon geometry of steeply ESE-dipping and gently ESE-dipping pegmatite sheet-intrusions, and; ii) resolve to overall sinistral and west-side (granitic complex) down, trantensional strain.
- Beneath the spodumene-bearing pegmatite sheet-intrusions, there are two styles of spodumene mineralisation where crystals are not set in a pegmatite matrix: i) spodumene-quartz veins (in ultramafic schist) that are largely coplanar with respect to the S4 foliation, and; ii) zones of abundant augen-like spodumene crystals (in ultramafic schist) which have a coplanar relationship with NE-trending cross-faults in the Pilgangoora shear zone (Fig 4, 4c).

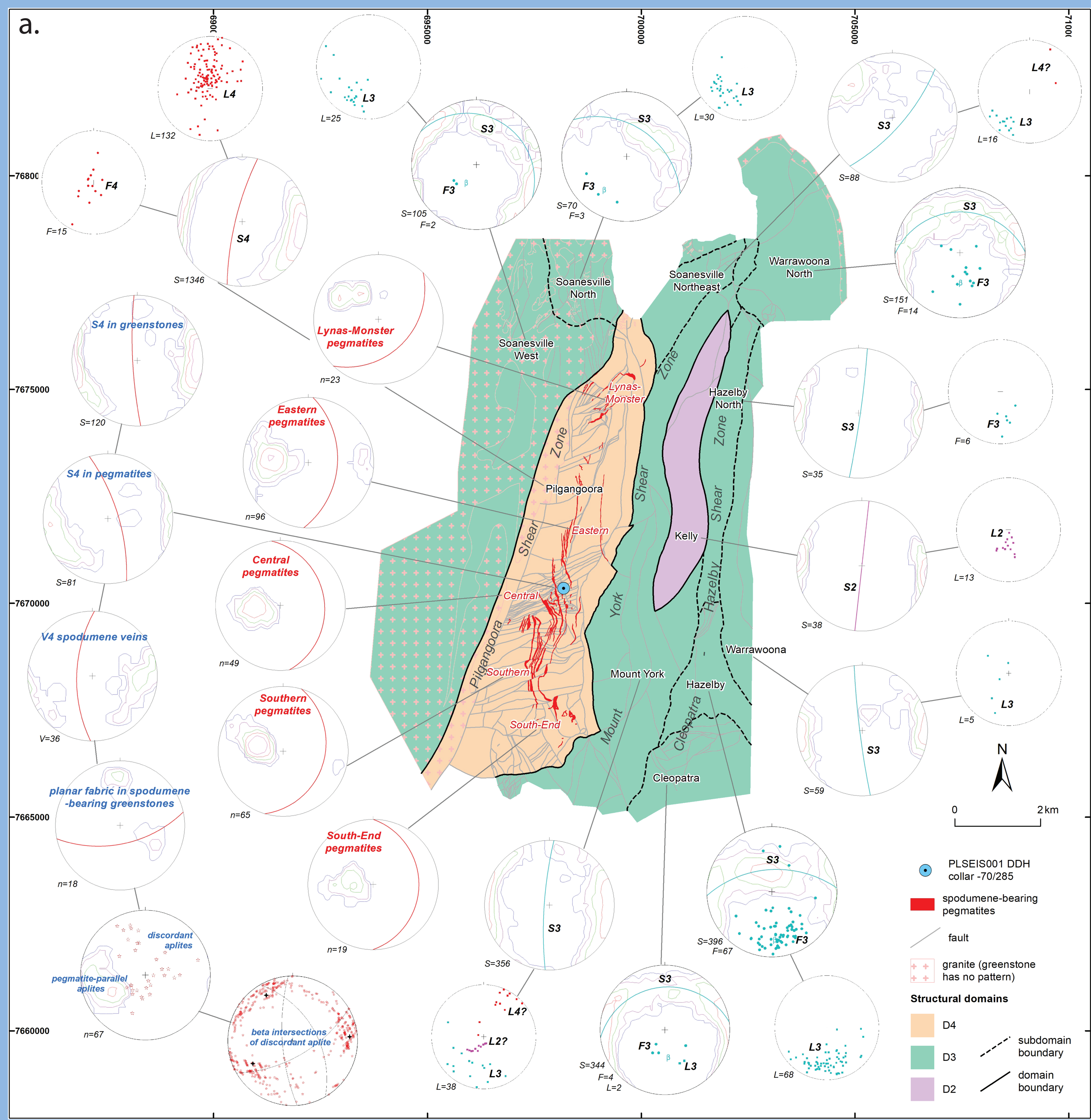
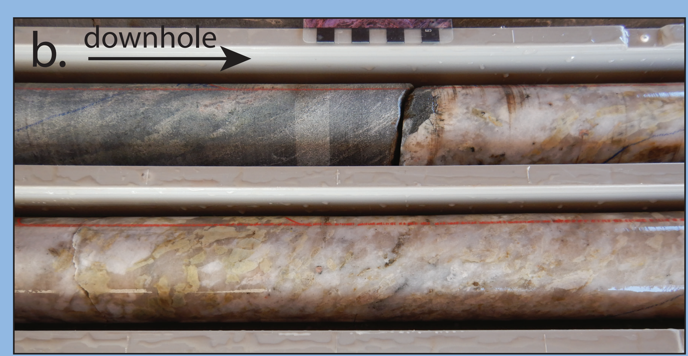
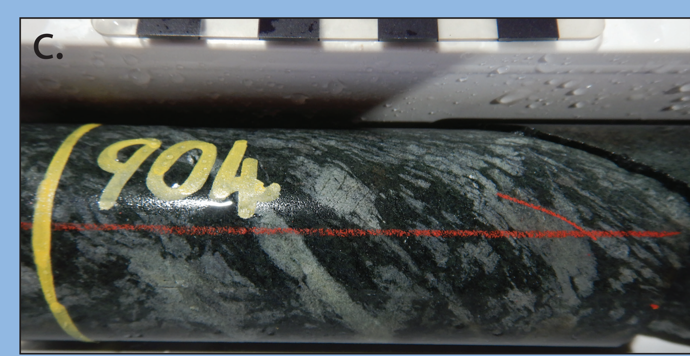


Fig. 4. (a) Geological map and deformation history of structural domains and subdomains recognised in the northern East Strelley greenstone belt. The Kelly domain preserves D2 strain defined by steep N-trending S2 foliation and steeply S-plunging L2 mineral stretching lineations. Most of the greenstone belt comprises a broad domain of D3 strain that is subdivided into subdomains that exhibit steep N- to NE-trending S3 foliation and gently S- to SW-plunging L3 mineral stretching lineations, and subdomains that exhibit F3 folding of an earlier foliation and both L3 mineral stretching lineations on the folded foliation surfaces and F3 fold axes that are gently to moderately SW- to SE-plunging. D3 strike-slip shear zones host lode-Au mineralisation dated at 2888±6 Ma (Pb-Pb isochron on hydrothermal microcline, titanite and pyrrhotite; Neumayr et al., 1998). The Pilgangoora shear zone comprises a 2km by 10km NNE-trending corridor of D4 strain in the greenstone belt which extends up to 500m into the adjacent Carlindi granitic complex. The Pilgangoora shear zone comprises a sub-vertical NNE-trending S4 foliation and variable gently to steeply N- to NNW-plunging L4 mineral stretching lineations, a pervasive network of N-trending strike faults and NE-trending cross-faults, and hundreds of spodumene-bearing pegmatite sheet-intrusions with variable gently to steeply ESE-dipping en-echelon array geometry. (b) DDH PLSEIS001 at 313.5m showing S4 foliation developed in both ultramafic schist and Domain-37 pegmatite lode where S4 (and likely L4) are defined by fragments of cataclastically deformed spodumene crystals. (c) DDH PLSEIS001 at 904m showing (strongly altered-) spodumene-bearing ultramafic schist which has a coplanar relationship with the NE -trending cross-faults in the Pilgangoora shear zone.





5. Take home message: Syn-tectonic generation, transport, and trapping of lithium-saturated pegmatite magmas

- Turner River Orogeny, a hitherto unrecognised tectonometamorphic event in the northern Pilbara Craton, occured concomitantly with the emplacement of 2860-2830 Ma Split Rock Supersuite granite and ca. 2845 Ma pegmatite. During this event:

1. Fertile muscovite-bearing pegmatitic granite of Split Rock Supersuite experienced deformation-assisted selective melting;
2. Mobile lithium and other rare-metal rich magmas escaped from their granitic source region along active shear-zone conduits, and;
3. Pegmatite-forming magmas, saturated in lithium and other rare-metals, were syn-tectonically emplaced at higher levels of the shear-zones within greenstone belts.

Future work: EPMA mineral chemistry of mica species and further immobile-element mass balance modelling in pegmatitic granites to complement petrography and whole-rock geochemistry studies, and; absolute timing constraints on the magmatic and/or metamorphic events through U-Pb SHRIMP zircon, U-Th-Pb LA-ICPMS monazite and U-Pb LA-ICPMS tantalite and cassiterite geochronology.

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