Evolution of mantle peridotite rocks - structures generated in a transition from the ductile-brittle regime in the Equatorial Atlantic

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Introduction

The exhumation of peridotite rocks in oceanic transform zones passes by the rheological transition between the ductile-brittle deformations until the complete emplacement in the oceanic lithosphere. The São Pedro and São Paulo Archipelago (SPSPA), located about 1000km from the Brazilian coast, positioned approximately 1° north of the Equator Line (Fig.1A,B). Ten isles compose the archipelago with a total exposed area of 17 km². Those isles record the deformational products of ductile, brittle and rocks/fluid interaction. The deformational stages are related to the transpressional and transtensional geodynamics of São Paulo Transform Fault(Fig 1B).The ductile-brittle fabrics were observed in a multiscale context in this work (Barão et al., 2020).

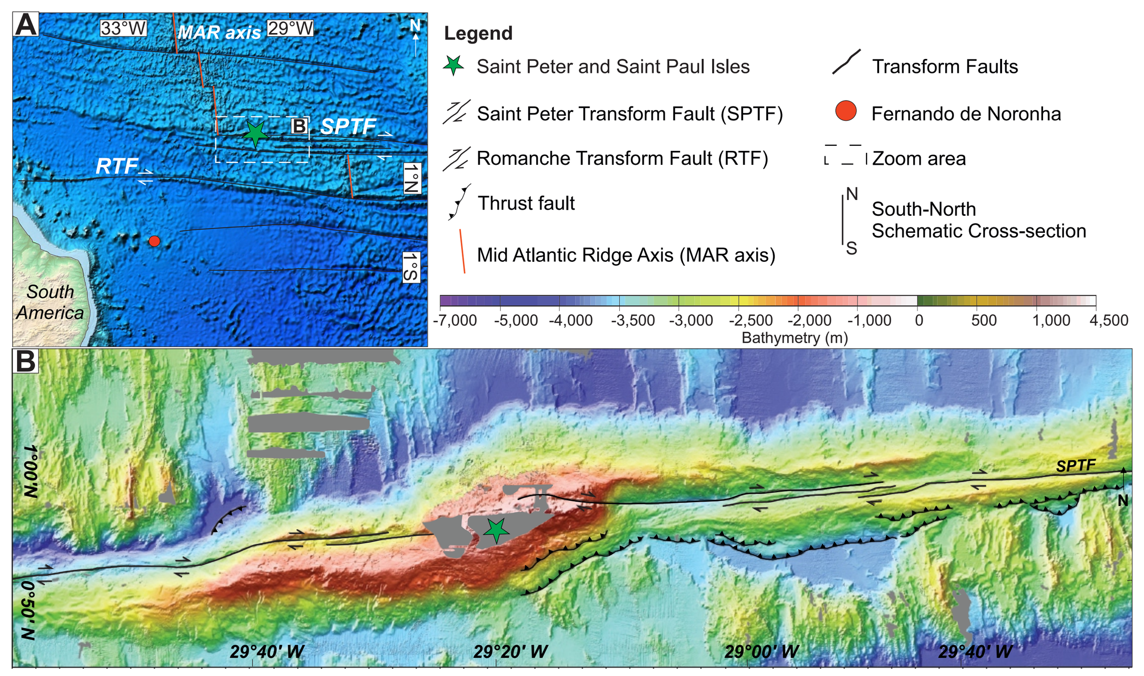


Figure 1 - Location of the St. Peter and St. Paul Archipelago (SPSPA) in the Mid-Atlantic Zone. (A) Location of the SPSPA, with indication of the São Paulo (SPTF) and the Romanche Transform Faults (modified from Sandwell and Smith, 1997); (B) Shaded bathymetric relief map of the SPTF where it intersects the SPSPA (modified from Maia et al., 2016).

Geological Settings

The SPSPA is composed by ultramylonite peridotite with mylonitic foliation (Fig. 2). On these rocks also observes cataclastic flow, this fabric are sectioned by fractures networks some of those are filled by sediments.The most prominent structure observed was the primary structure of peridotite rocks, it is mylonitic foliation (Fig.2). This foliation has anastomosed fabric, marked by the development of serpentine parallel to the foliation.

These structures are orientated NNW-SSE (Fig. 2) directions and it is penetrative over the isles. The mylonitic foliation (Fig. 3B) oriented to NE30-20W, with different orientations in the SPSPA isles (Fig. 2). Also, the foliation is gently folded with axis oriented to the northeast (Fig. 2).

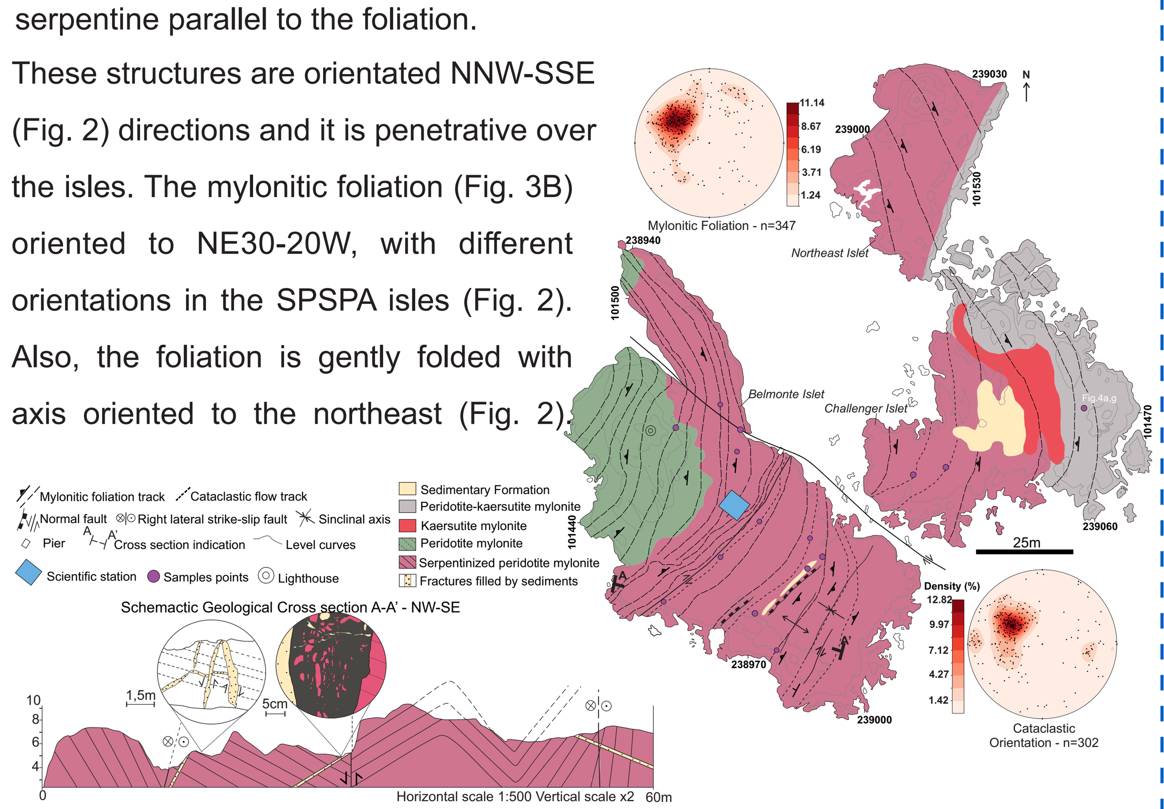
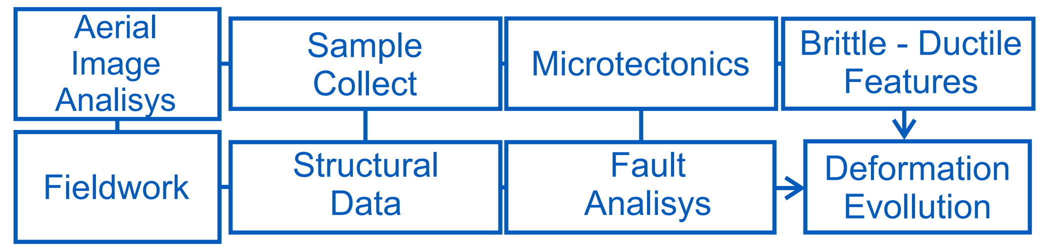


Figure 2 - Geological map (modified from Campos et al., 2003) and geological cross-section A-A' of the Belmonte, Challenger and Northeast islets of the SPSPA; and lower-hemisphere, equal-area projections, indicating the trending of the mylonitic foliation and the cataclastic orientation in the SPSPA.

Methods



Results

Field mapping allowed us to estimate the main deformational domains that the rocks of the SPSPA passed through (Fig. 3A). These domains involve the abrupt transition from ductile to the brittle regime, initially forming peridotite mylonites to ultramylonites (Fig. 3B), and later cataclasites and breccia faults (Fig. 3C).

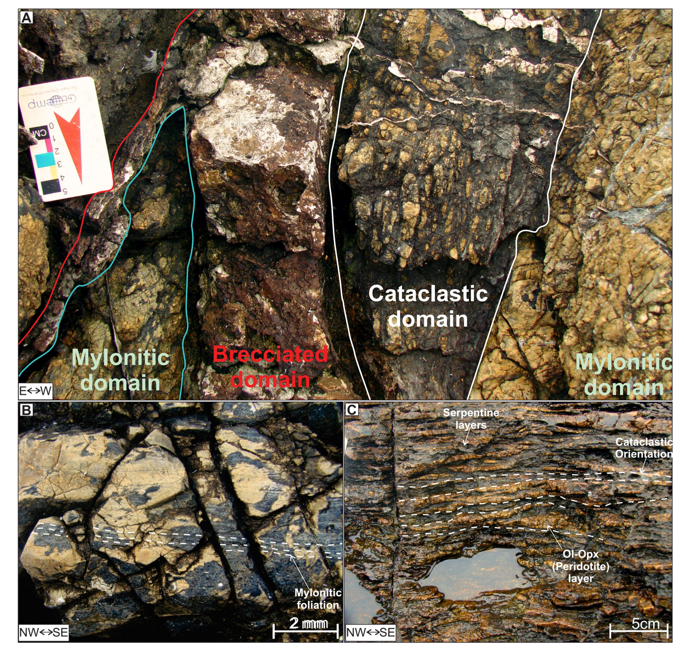


Figure 3 - (A)Tectonic domains; (B)Mylonitic Domain; (C)Cataclastic Domain.

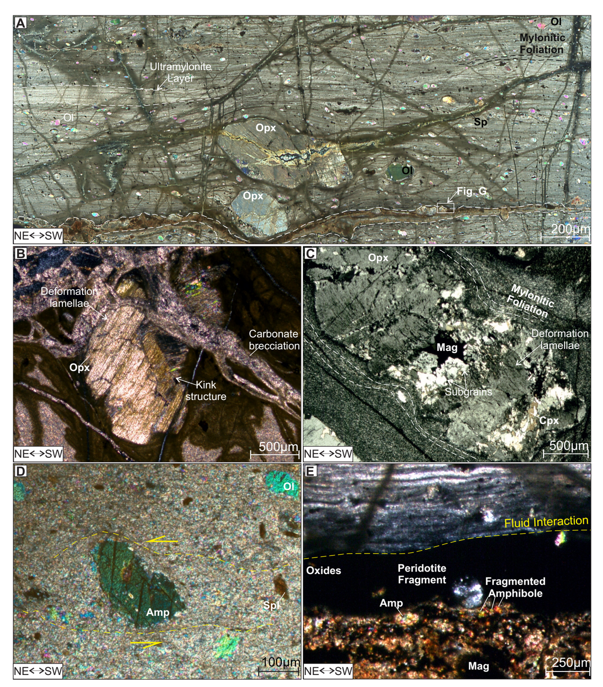


Figure 4 - (A) Overview of the ultramylonites to mylonites bands; (B) Opx porphyroclast with kink structure and Cpx exsolution lamellae; (C) Opxporphyroclasts bypassed by mylonite foliation. It is observed the formation of subgrains associated to Mag and Op minerals; (D) Amp bypassed by the mylonitic foliation; (G) Fluid Reaction Band.

Mylonitic Domain

- It's observed in the very fine mylonitic matrix, composed of minerals such as a Ol, Opx, Spl and Amp (Fig. 4A-E);
- The Ol and Opx porphyroclasts indicate their predominantly left-lateral kinematics. Also the crystals exhibit pressure shadows (Fig.4A);
- The Opx internally exhibits deformation lamellae (Fig. 4D, E), with Cpx exsolution lamellae and kinks (Fig. 4D), also subgrains of Opx may occur (Fig. 4E);
- Reacting layer intercalated with the mylonitic levels, marks fluid penetration may have been facilitated by the mylonitic foliation (Figs. 4A,G);
- Fluids interact with the rock, forming Amp, Mag, and oxides (Fig. 4G). Locally, there is the formation of porphyroblasts of amphibole without orientation (Fig. 4G).

Cataclastic Domain

- Marked by cataclastic orientation and cataclasites associated with serpentine (Fig. 2,3). The serpentine fill fractures (Fig. 3A), which may divides the rock into serpentinite bands and bands with elongated peridotite fragments (Fig.3C);
- Also observed angular-shaped, asymmetrical domino boudins (Spr2) along a shear band (Fig. 5A) indicate right-lateral kinematic;
- The serpentine-filled microfaults (Fig. 5C - Spr3) have different generations overlapping each other. The serpentine gashveins take place (Fig. 5B);
- The last vein phase (Srp4) crosscuts all previously formed phases (Fig. 5D). These veins are 100 to 200μm wide and the crystals are coarser-grained. The morphology is that of granular-shaped and isotropic crystals

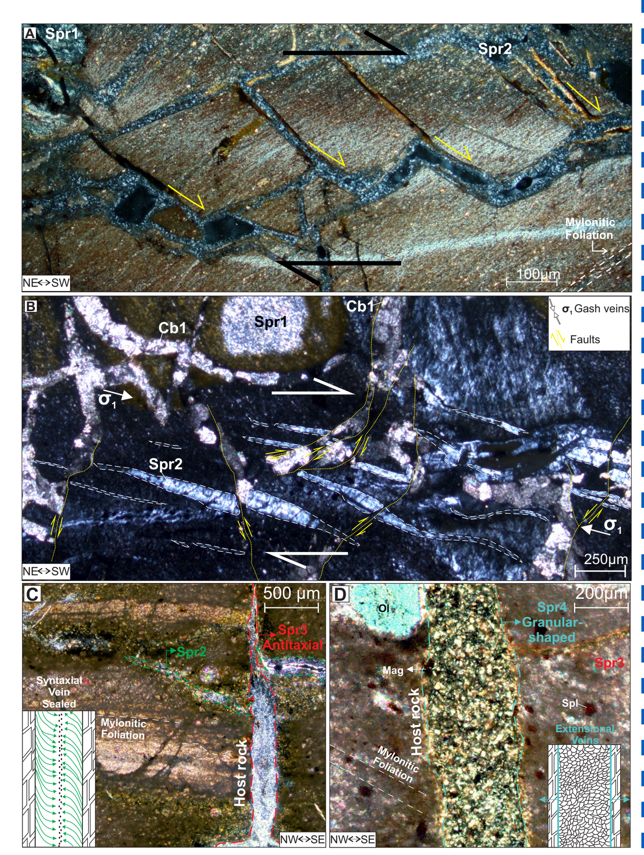


Figure 5 - .(A)Domino faults formed; (B)Serpentine gash veins formed by the crack-seal process (Srp2); (C)Type Srp3, with very micro crystals of serpentine (1 to 5μm) (D)Type Srp4, with granular-shaped serpentine infill and disoriented pattern.

Brecciated Domain

- Brecciated domain is highlighted by peridotite fragments and carbonate cement that fill previous structures;
- Sedimentary bodies are elongated and randomly arranged (Fig. 6A); they are composed of conglomerate with peridotite clasts, shell fragments bounded by a carbonate-rich matrix;
- Shear zones seem to have facilitated the sedimentary bodies formation (Fig. 7B).
- Two different phases of carbonate veins idetifyed. They were named Cb1 and Cb2 (Fig. 8) due to their temporal and crosscutting
- First phase (Cb1) directly crosscuts serpentinite veins, in some cases forming gash veins with the indication of right-lateral kinematics can be classified as syntaxial
- Cb2 veins, crosscut the other veining phases observed in the SPSPA (Figs. 8B and C). Those veins are related to carbonate fluids, facilitating the brecciation process and formation of angular fragments (Fig. 7B).

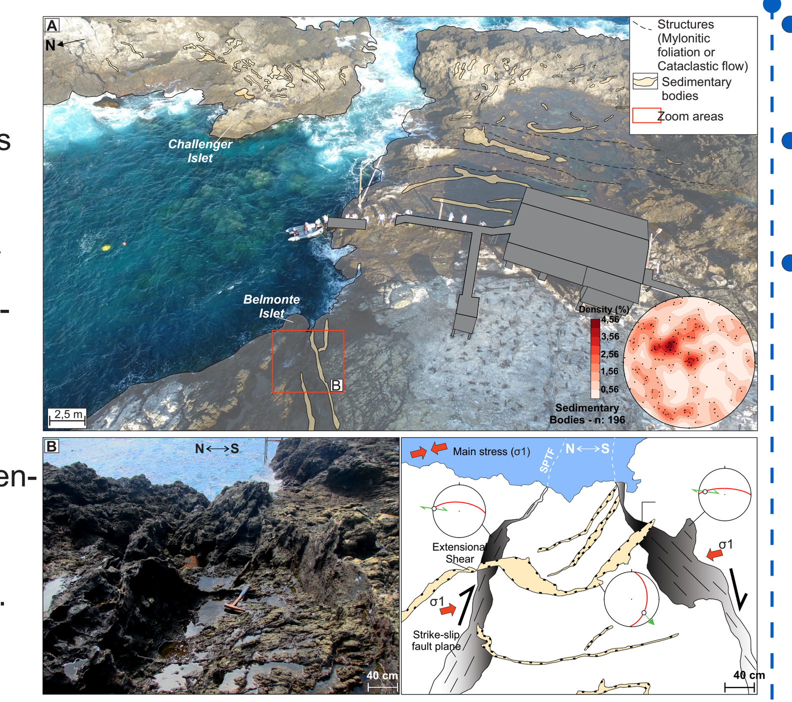


Figure 6 - (A) Drone photographs, outlining some sedimentary bodies. Lower-hemisphere, equal area projection indicating the direction of sedimentary bodies (B) Zoom area of the strike-slip fault zone with a oblique component, alongside extensional shears oblique to the main fault zone.

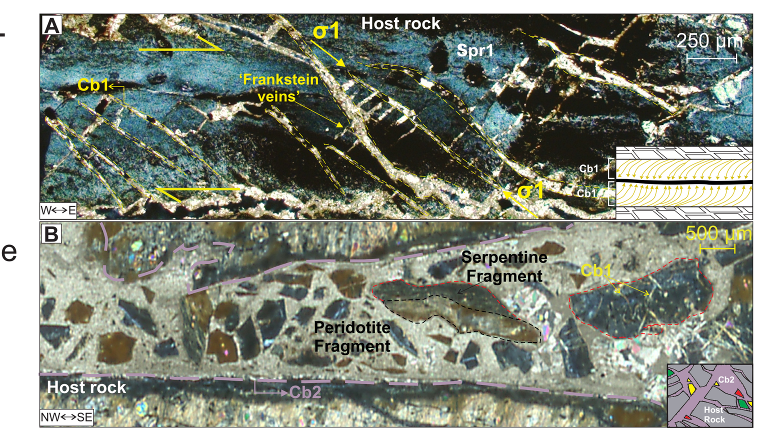


Figure 7 - (A) Cb1 veins marked by gash veins with right-lateral kinematics; (B) Cb2 veins, associated with fluid brecciation process, creating fragments of peridotite.

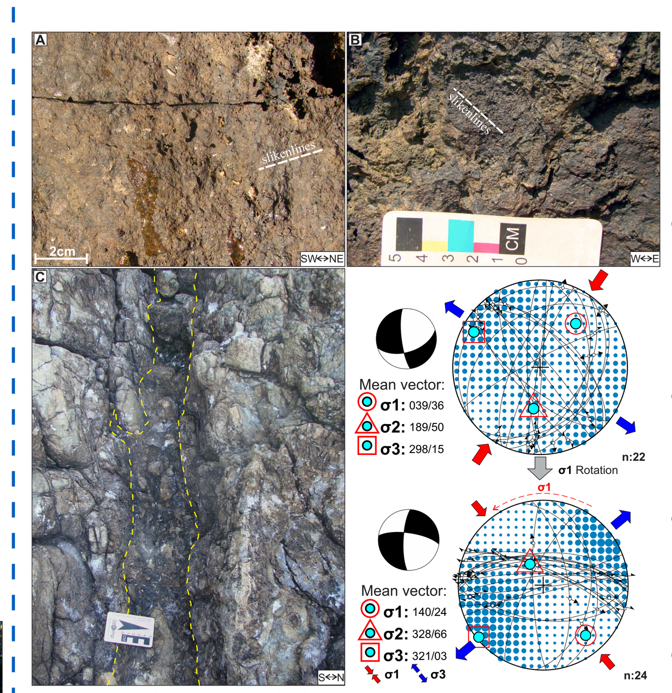


Figure 8 - (A) and (B) Fault planes observed in sedimentary bodies (C) Breccia fault (15cm); (D) straight dihedral-angle method, showing the two different main shortening direction

Fault Analysis

- Predominance of strike-slip faults (Fig.2,8), associated with oblique components. The fault planes are mainly related to sedimentary bodies;
- Kinematic indicators are right-lateral (Fig. 8A,B). These structures are linked to EW-directed fault planes (Fig. 2);
- Locally, these features can produce breccia faults (Fig. 8C), and not associated with the cataclastic domain;
- Fault plane data collected in the field and processed by the straight dihedral-angle method suggest that the main tensor has an approximate direction of NW-SE and a marked extension trending NE-SW (Fig. 8D)

Discussions

- The transition has been demonstrated in deformed rocks along shear high-angle zones and locally associated with hydrothermal fluids (Fig.9)
- Rocks were affected by the ductile to semi-brittle deformation, which caused intense recrystallization of minerals such as Ol and Opx and the formation of ultramylonitic features, associated with temperatures ranging between 700-800°C;
- The continuous and rapid uplift led to the superposition of deformation mechanisms, with reactivation of pre-existing structures and predominance of semi-brittle to brittle deformation;

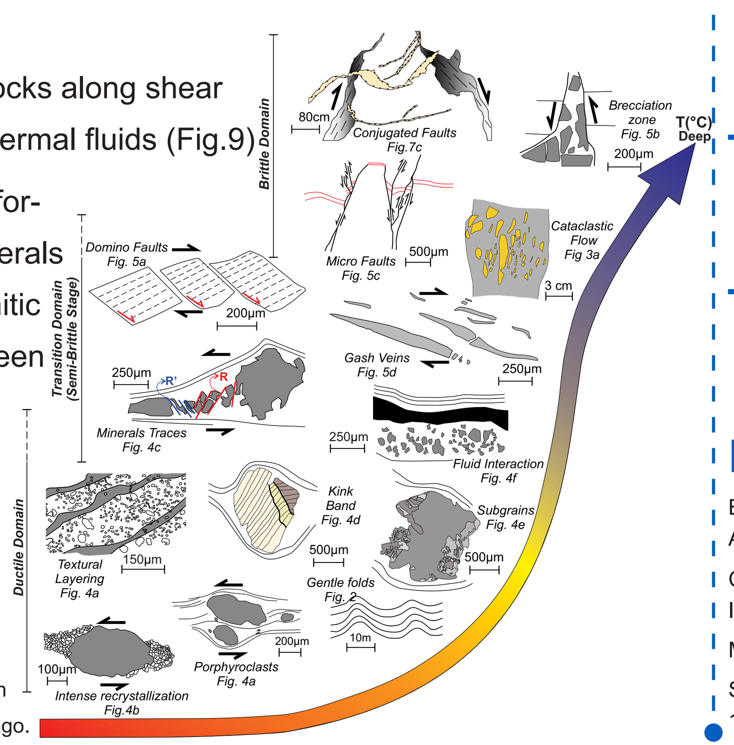


Figure 9 - Table of microstructures and structures observed in peridotites in the SPSPA. These structures describe the ductile-brittle transition in the archipelago.

- The transition to the semi-brittle regime leads to the formation of Srp2 and Spr3 veins (Fig. 10). The Srp2 veins tend to run parallel to the mylonitic foliation, isolating fragments of peridotite and olivine crystals from the rock matrix;
- Srp4 veins (Fig. 10) show a fracture-filled with fluid, evidencing continuous deformation, without kinematic variation during crystal growth, corresponding to the complete hydrothermal system opening
- The last phase of serpentinization (Srp4) are time-equivalent to the carbonatation phases (Cb1 and Cb2) (Fig.10) and marks a progressive change to the carbonatation process predominance and peridotite exhumation to the surface.

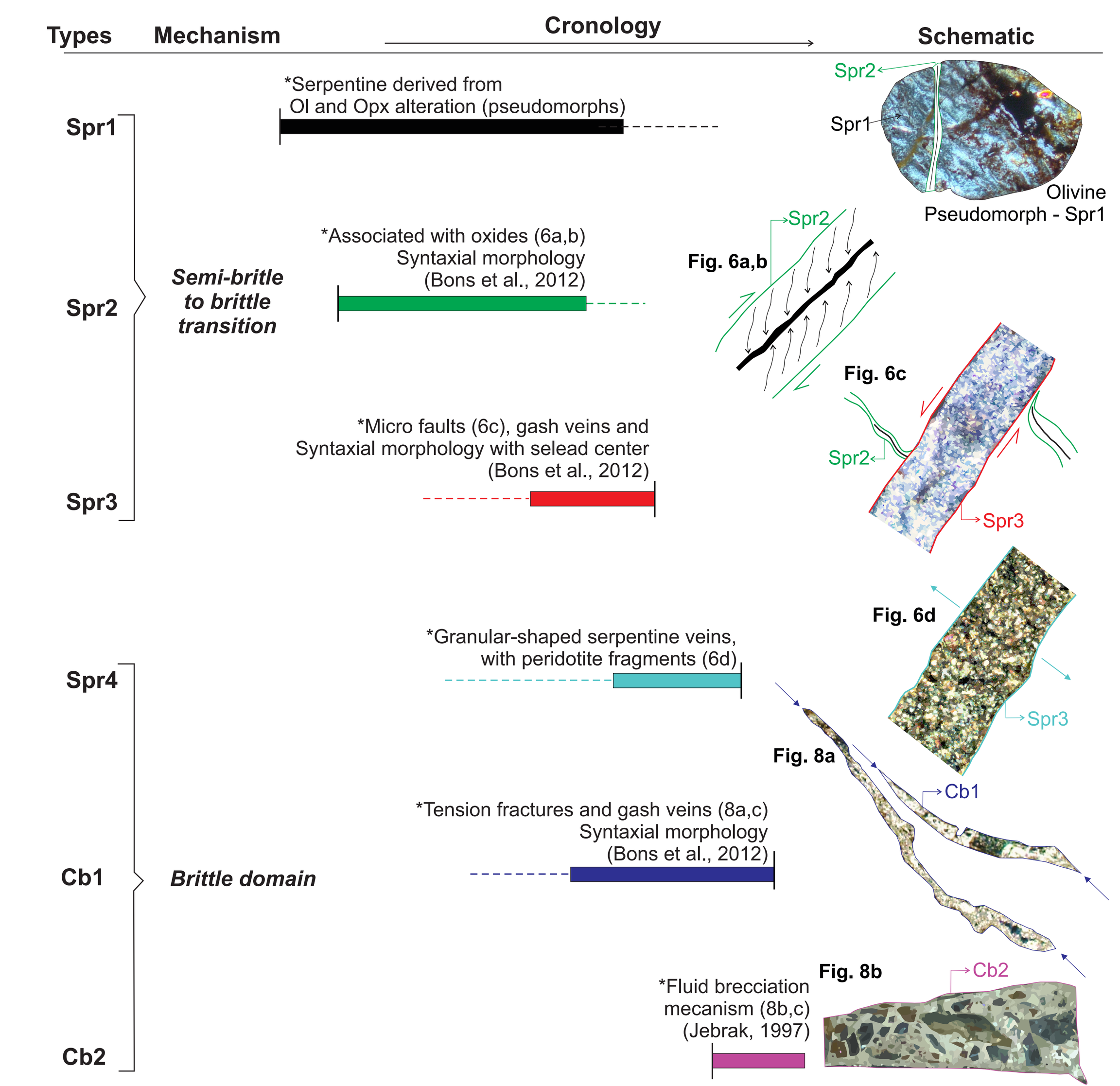


Figure 10 - Chronology of the formation of serpentine and carbonate phases in the SPSPA and their relation to the ductile-brittle transition.

Conclusions

- The SPSPA evolutionary history shows different deformational styles during peridotite exhumation, varying from ductile to brittle regimes and it's resumed in four deformational stages (Fig.11):
- **Stage I:** comprises the ductile to semi-brittle deformational phases (Fig.10) of the SPTF,involving transtension to transpression. The mylonitization between the temperatures of ~700 – 800°C, causing Ol and Opx recrystallization;
- **Stage II:** refers to the semi-brittle to brittle transition of rocks in the SPSPA, with the formation of cataclastic features and it is mainly associated with cataclastic flow process;
- **Stage III:** marks deformation under brittle regime (Fig. 11), where we observe the presence and intensification of faults,
- **Stage IV:** final phase of deformation which faults and fractures oriented E-W and filled with carbonate-rich fluids. The direction of NW-SE of their main tensor is compatible with the current compressive field observed in earthquakes nearby SPSPA.

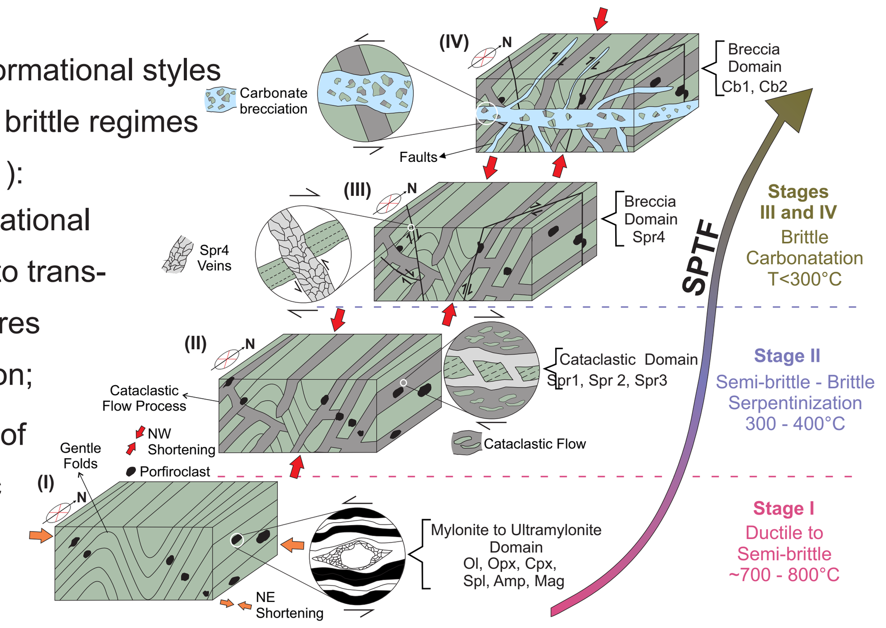


Figure 11 - Evolutionary models of the deformation of the SPSPA (I) to (IV), marking the ductile-brittle deformational transition.

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