

Episodic and Continuous Monazite Growth within an Orogenic Cycle: A Monazite Petrochronology Case Study in the Central Damara Orogen



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1. Introduction:

Monazite petrochronology is an advancing research field which is widely applied to orogens to unravel details of metamorphic pressure-temperature-time (P-T-t) paths and gain insights into tectonic evolution. Detailed monazite petrochronology work has not been done in Damara Orogen, and more arguments and debates regarding correlations of monazite chemical zonation and U-Pb dates are emerging. In this study, we collected monazite-bearing metamorphic rocks from the central zone of Damara Orogen at different structural levels to 1) disentangle monazite chemical zonation and Th-U-Pb ages correlations; 2) understand monazite growth mechanisms and improve the understanding of monazite petrochronology; 3) unravel details of metamorphic events and Damara Orogen evolution from monazite perspective.

2. Sampling Sites and Analytical Methods

Monazite-bearing migmatite and amphibolite-granulite-facies metapelites were collected from the central zone of Damara Orogen (Fig. 1), from deepest level (lower plate) and shallowest level (upper plate). Systematic EPMA X-ray mapping were done on representative monazites for Th-Y-U-Ce-Ca-P elements. High spatial resolution (5µm), high precision LA-MC-ICP-MS U-Th-Pb isotopic dating was done to unravel correlations of monazite growth with chemical zonation.

3. Timeframe of the Damara Orogenic Cycle

- Pre-Damara Subduction: ~580-570 Ma
- Early-phase Collision: ~555-550 Ma
- High-P low-T (HPLT) Metamorphism (prograde): 550-535 Ma
- Damara Main Peak Metamorphism: 535-518 Ma
- High-T/low P (HTLP) Metamorphism (post-peak): 515-505 Ma
- Exhumation: 500-480 Ma
- Post-orogenic Alteration: ~460 Ma or younger

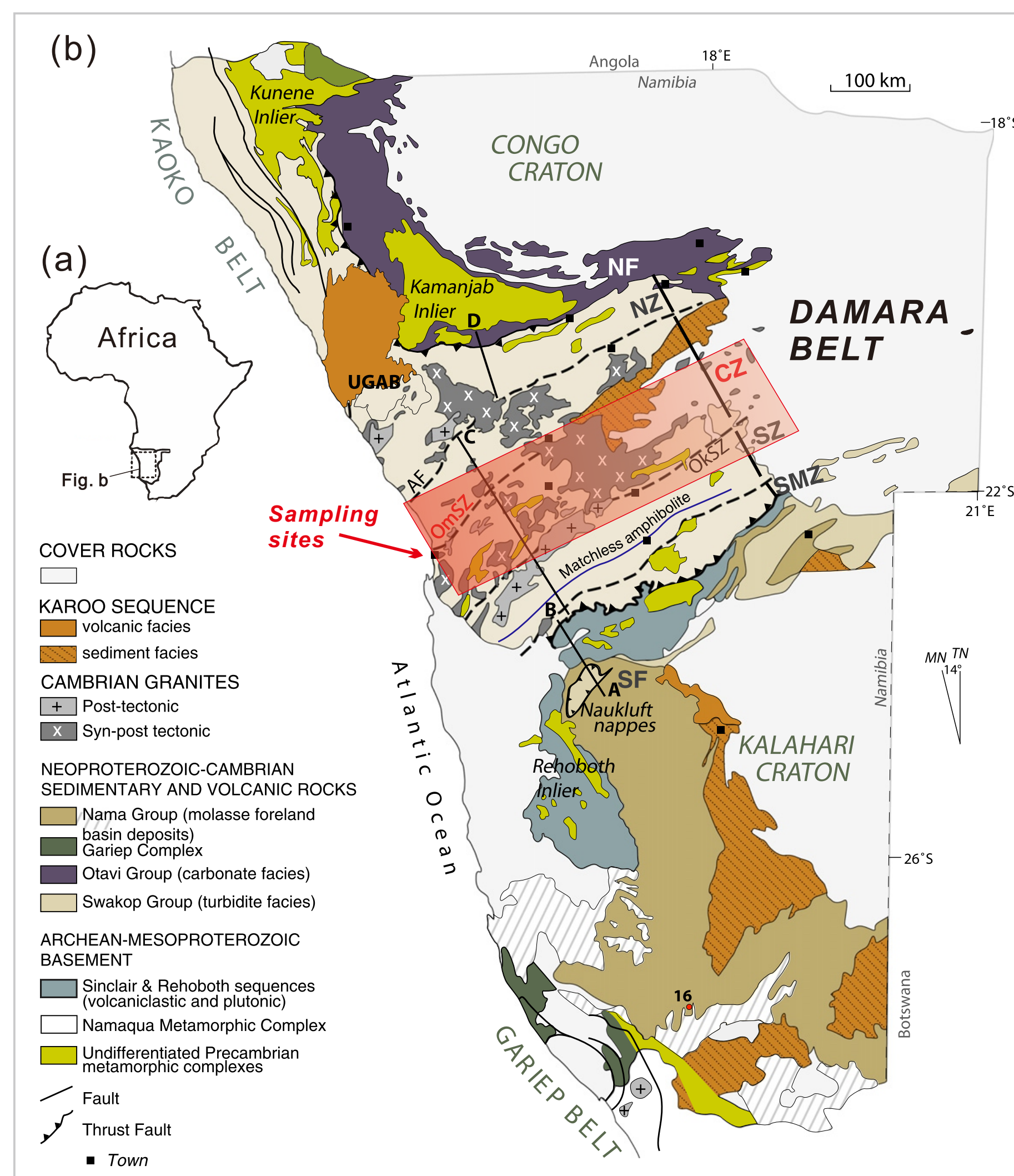
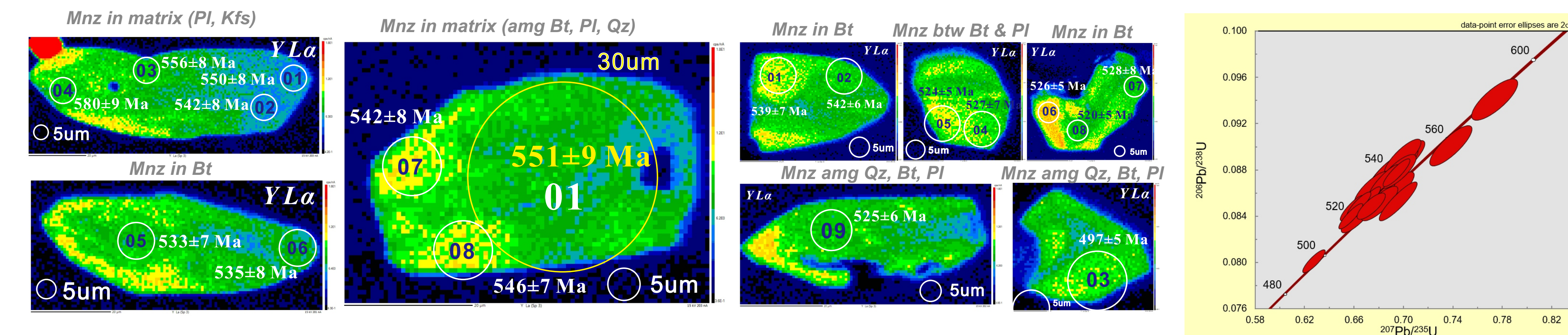


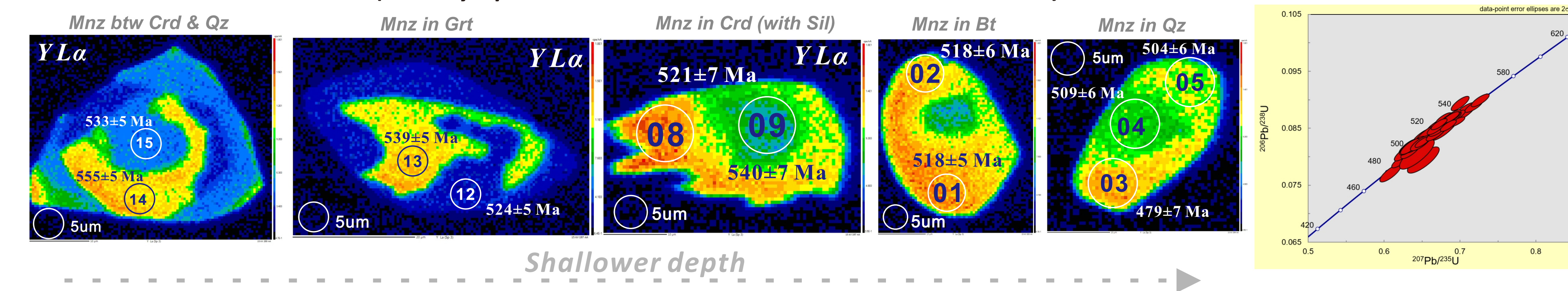
Fig. 1. Geological map of the Damara Orogen, showing the main geological units, the major faults, and the distribution of plutonic rocks and Swakop Group turbidites. Note: OmSZ, Omaruru Shear Zone; OKSZ, Okahandja Shear Zone; NZ, Northern Zone; CZ, Central Zone; SZ, Southern Zone; SMZ, Southern Margin Zone (Damara Belt). The figure was modified after Foster et al (2015).

4. Varying Monazite Growth Patterns at Different Structural Levels

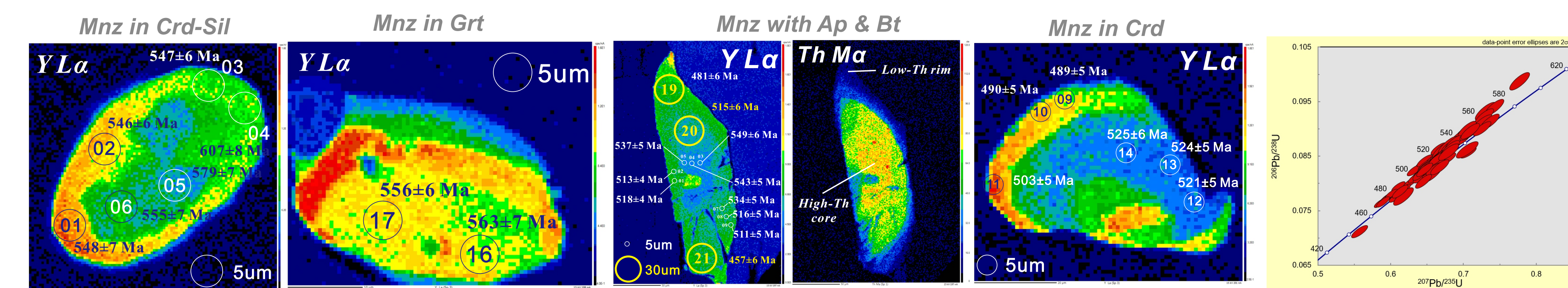
The Shallowest Levels (Pre-Damara subduction --> Damara main peak, HTLP missing)



The Middle Levels (Early-phase Collision --> Exhumation)

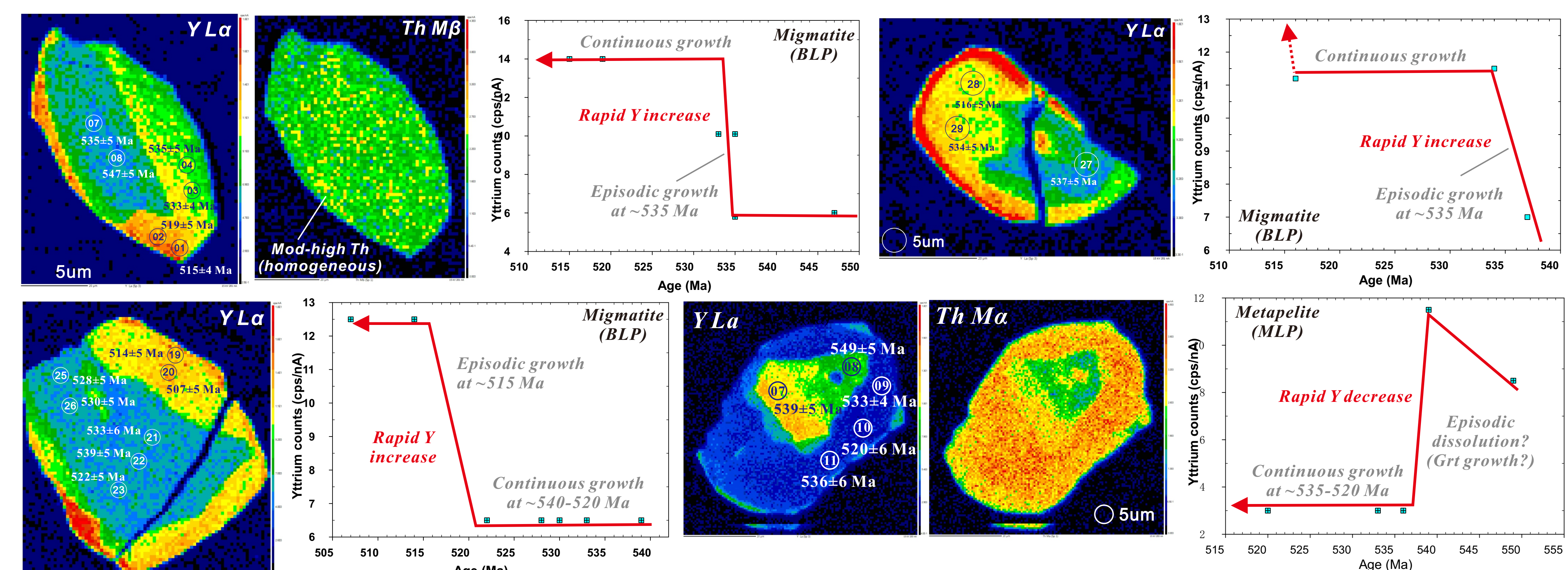
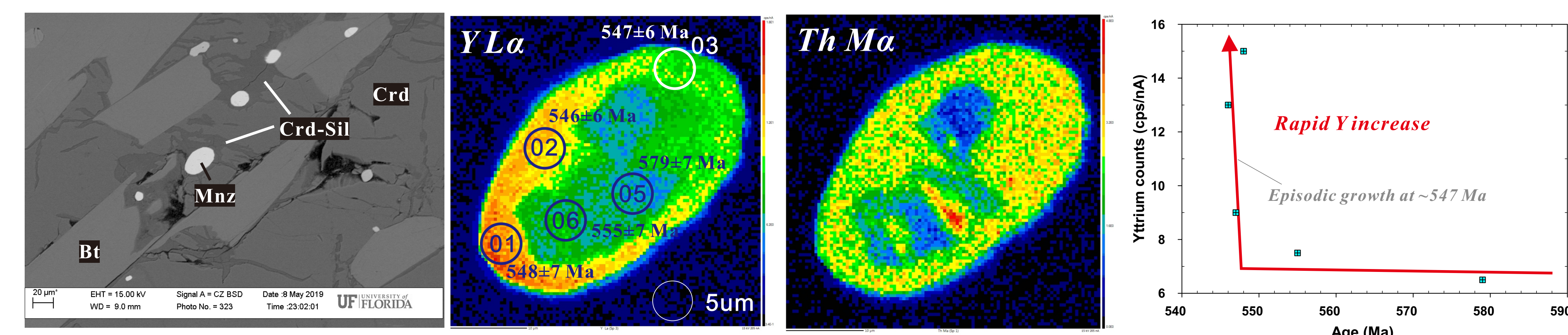


The Deepest Levels (Pre-Damara subduction --> Exhumation)

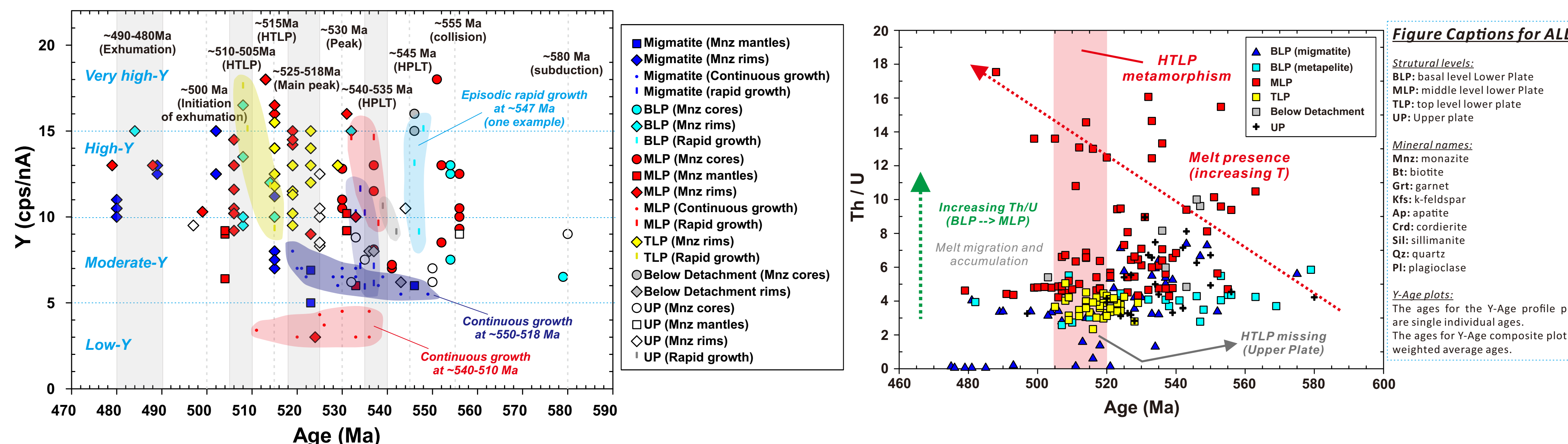


5. Episodic and Continuous Monazite Growth Within an Orogenic Cycle

Despite the varying age patterns of monazites at different structural levels, they overall reveal protracted growth during the entire orogenic cycle (>100 m.y.). As monazite Y content is closely correlated with garnet (and other Y-bearing minerals) growth or breakdown, Y-Age variations can provide direct constraints on metamorphic processes. Based on our systematic X-ray maps, U-Pb dates, and typical profile analyses, we have deciphered episodic and continuous monazite growth within the orogenic cycle.



Monazites in migmatite and mid-level lower plate both preserve grains showing **continuous growth at ~540-515 Ma**, as indicated by nearly homogeneous Th and Y contents, suggesting **monazite growth with presence of melt**. **Episodic** monazite growth at ~545 Ma, ~535 Ma, ~ 515 Ma was revealed by rapid Y increase, which could be correlated with garnet breakdown due to decompression, heating, or melt fluxing during orogenic evolution. Other episodes of monazite growth were also revealed, such as ~580 Ma, ~555 Ma, ~530 Ma, ~525-518 Ma, 505 Ma, ~500 Ma, and 490-480 Ma.



6. Implications for Monazite Petrochronology and Damara Evolution

- Monazite growth can provide insights into the plate tectonic evolution during the orogenic cycle. **An over ~20 m.y. hiatus** for Upper Plate was revealed by the lack of HTLP metamorphism.
- **The Y-Age patterns** can provide significant constraints on monazite growth mechanism, as episodic or continuous, and its correlation with garnet breakdown or growth.
- Key elements such as **Th, U, REE need to be compared with Y growth zones** to better understand monazite growth mechanisms, and to conduct the monazite petrochronology work.

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