Eventlike exhumation of high-grade blocks in the young Franciscan subduction zone

Daniel Rutte[1,2,3], Joshua Garber[4], Andrew Kylander-Clark[5], Paul R. Renne[1,2]
[1] Earth and Planetary Science, University of California, Berkeley
[2] Berkeley Geochronology Center
[3] University of Bonn
[4] Penn State University
[5] Department of Earth Science, University of California, Santa Barbara

Introduction

The metamorphic history of high-grade rocks provides invaluable insight into the thermomechanical processes of subduction zones. While subduction in most orogens is terminated by continent collision entailing variably strong overprint of related units, the Franciscan Complex of California allows studying a >150 Myr long subduction history that started at ~175 Ma and ended by transformation into a transform plate boundary (San Andreas fault) without significant metamorphic overprint. The highest grade metamorphic rocks of the Franciscan Complex of California are found as blocks in serpentinite and shale matrix mélanges. They include amphibolites, eclogites, blueschists, and blueschist facies metasediments. These Franciscan mélanges inspired the subduction channel return-flow model, but other processes e.g., buoyancy-driven serpentinite diapirism have been argued to be concordant with our current understanding of their metamorphic history, too.

Hypothesis 1: Continuous Subduction Channel Return Flow (Cloos 1982)

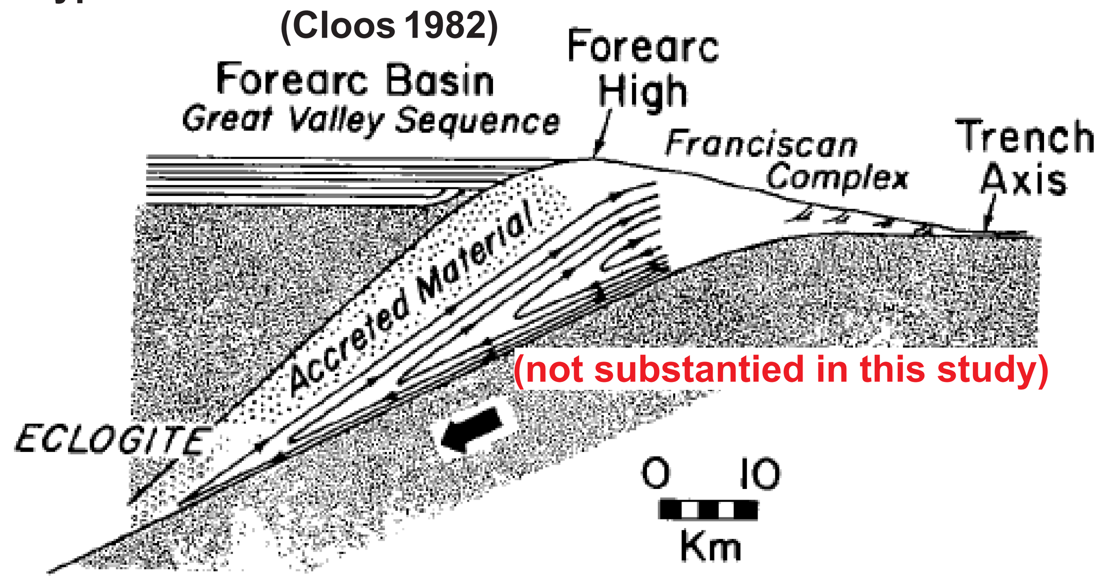


Figure 1. Early proposed model of subduction channel return flow (Cloos 1982). Main prediction of this continuous process model: Prograde and retrograde metamorphism occur at all grades at all times.

Hypothesis 2: Cooling of the Subduction Zone after Subduction Initiation (Anczkiewicz et al., 2004)

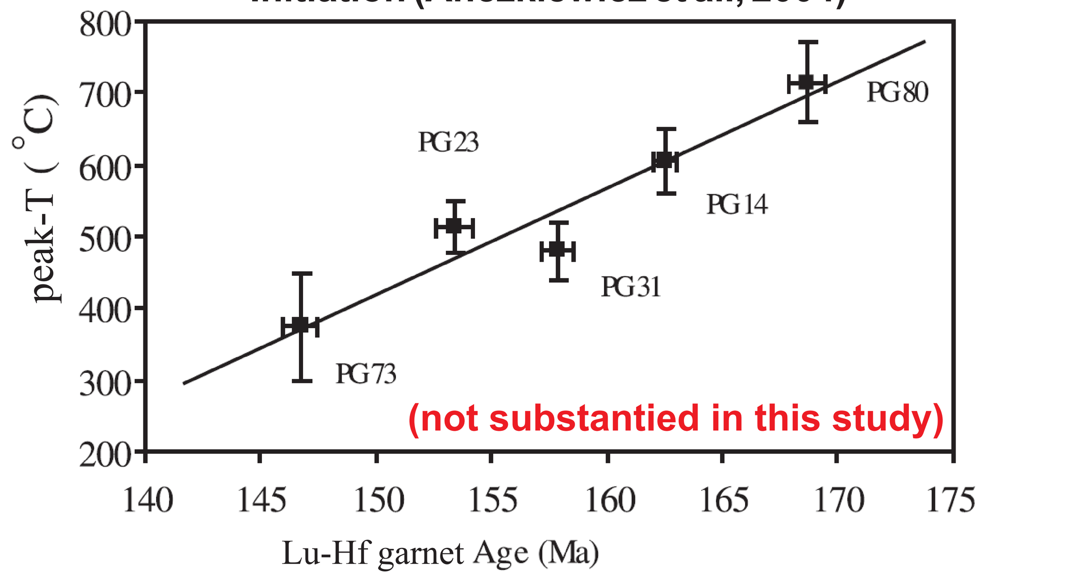


Figure 2. Geothermometric estimates vs. age diagram for analyzed samples. Slope of the regression line suggests ca. 15 °C/Ma cooling rate for the Franciscan subduction (Anczkiewicz et al., 2004).

Study Setup

We sampled high-grade blocks from serpentinite and serpentinite-shale mélanges. We focused on eclogite-amphibolites that were previously investigated petrologically and geochronologically (primarily Lu-Hf garnet). We dated amphibole, phengite, and zircon using the $^{40}Ar/^{39}Ar$ and U-Pb systems, respectively.

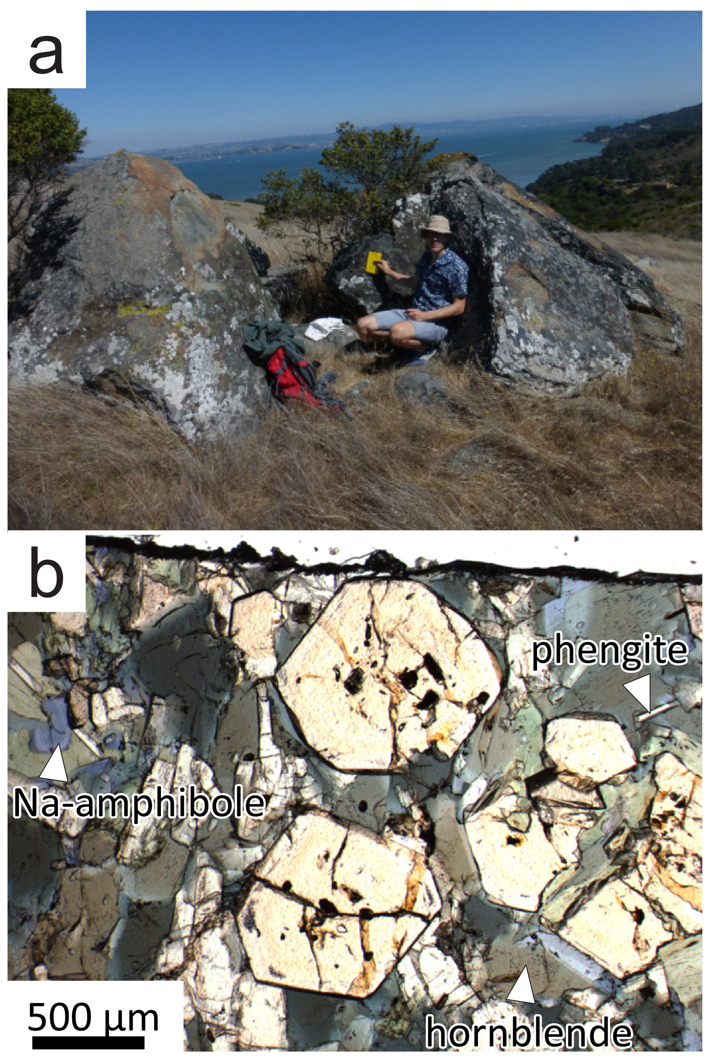


Figure 3 (↑): Exemplary high-grade block TIBB in the field (a) and in thin section (b).

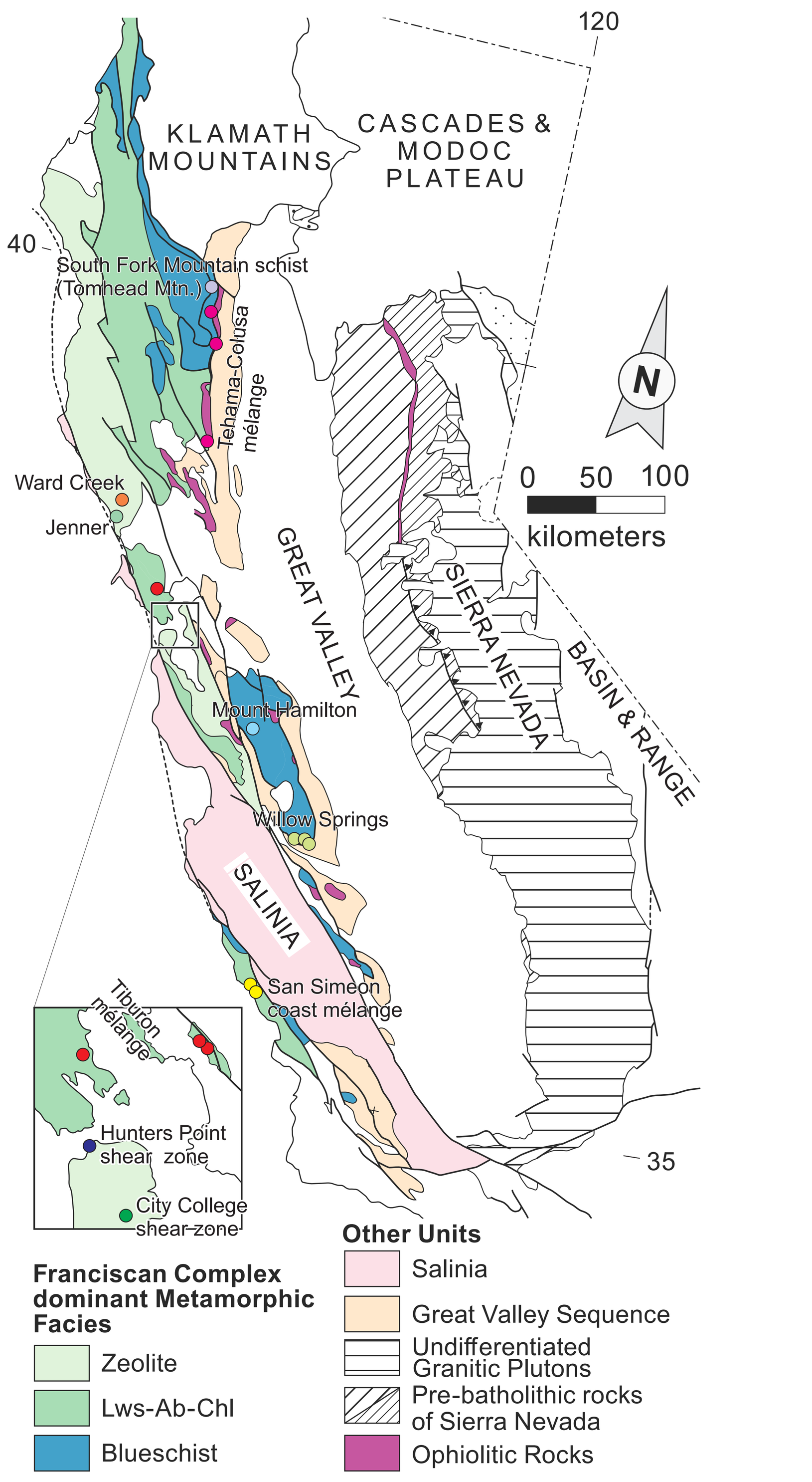


Figure 4 (↑): Tectonic and metamorphic overview map of northern and central California. Investigated locals in the Franciscan complex are color coded in conjunction with figure 5. Modified from Mulcahy et al. (2018).

Results 1 - Timescales of Metamorphism

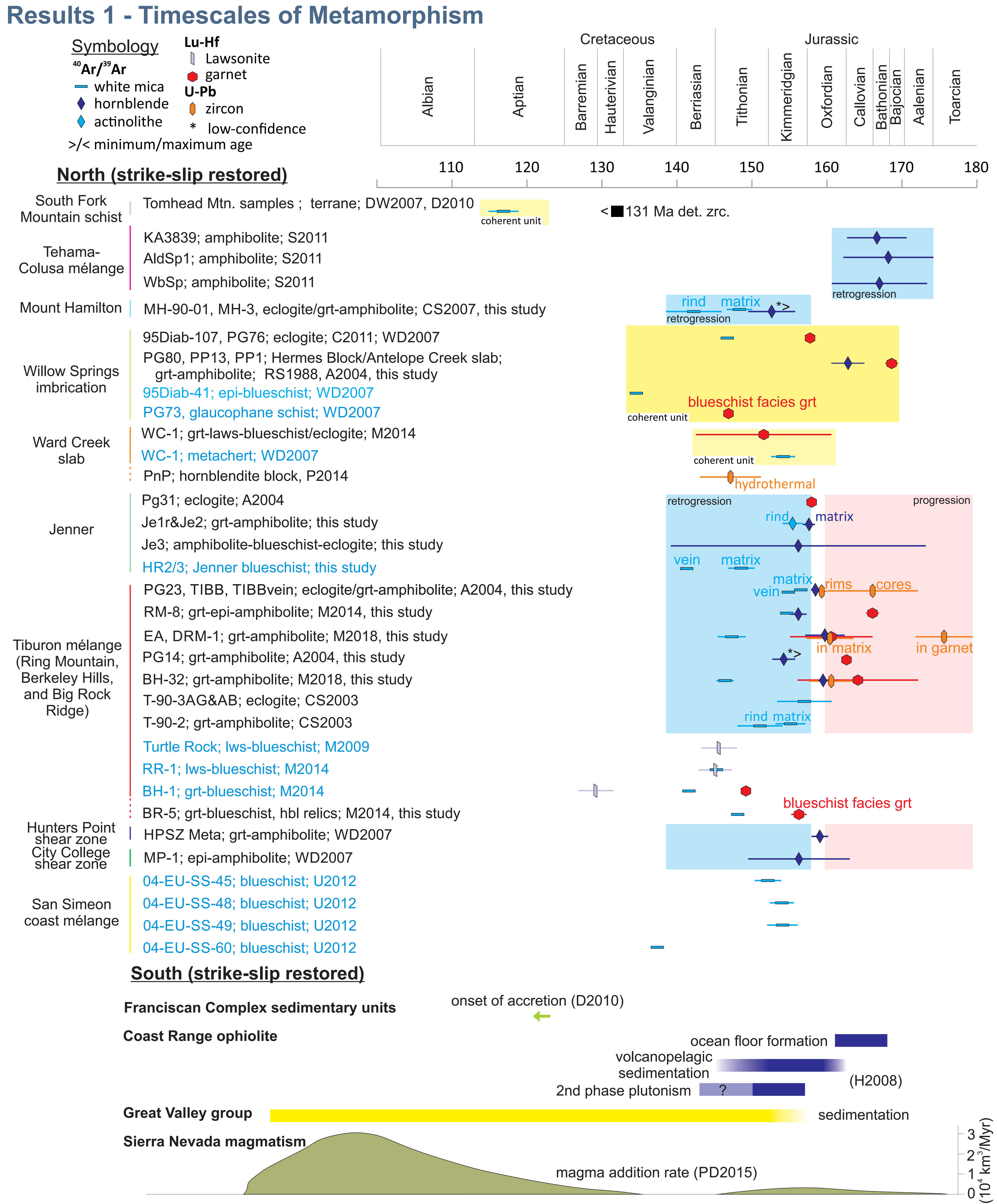


Figure 5 (↑). Summary of geochronologic data for Franciscan high-grade bocks and coherent units and comparison with chronology of accretion of Franciscan Complex sedimentary units, Coast Range ophiolite genesis, Great Valley group sedimentation, and Sierra Nevada magmatism. Samples described in black font experienced eclogite-amphibolite facies and variable blueschist facies overprint while those in blue font experienced only blueschist facies metamorphism. Abbreviations: A2004 - (Anczkiewicz et al., 2004); CS2007 - (Catlos & Sorensen, 2003); C2011 - (Cooper et al., 2011); D2010 - (Dumitru et al., 2010); H2008 - (Hopson et al., 2008); M2009 - (Mulcahy et al., 2009); M2014 - (Mulcahy et al., 2014); M2018 - (Mulcahy et al., 2018); P2014 - (Page et al., 2014); PD2015 - (Paterson & Ducea, 2015); RS1988 - (Ross & Sharp, 1988); S2011 - (Shervais et al., 2011); U2012 - (Ukar et al., 2012); WD2007 - (Wakabayashi & Dumitru, 2007).

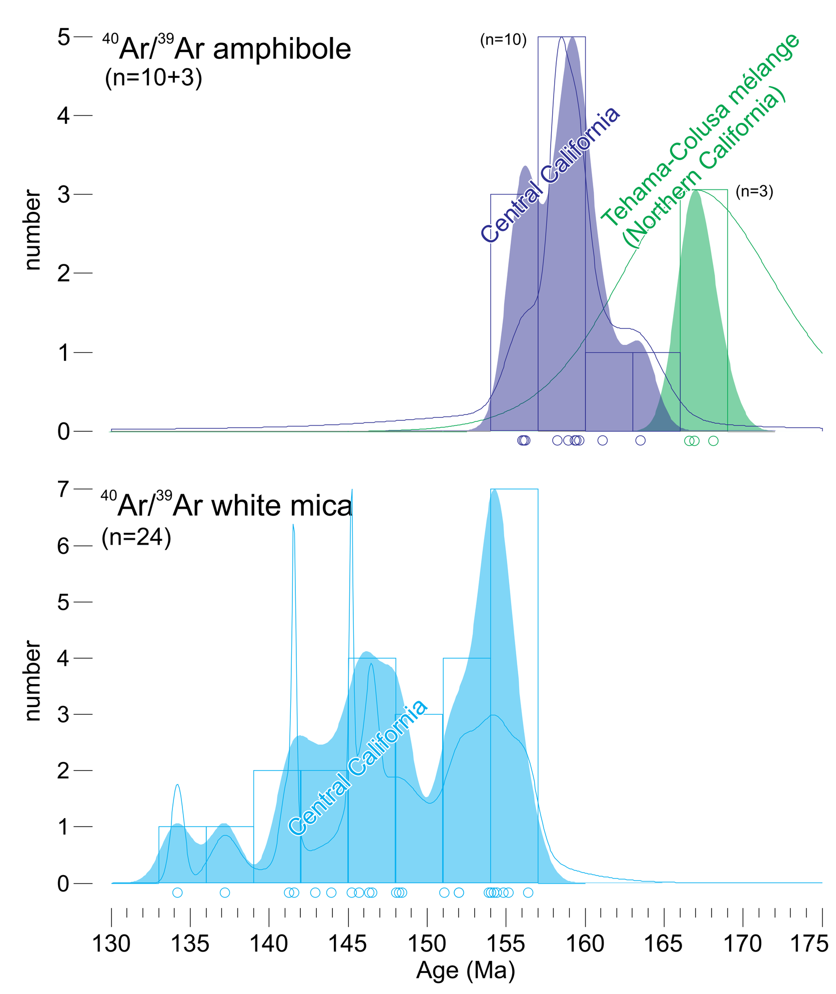
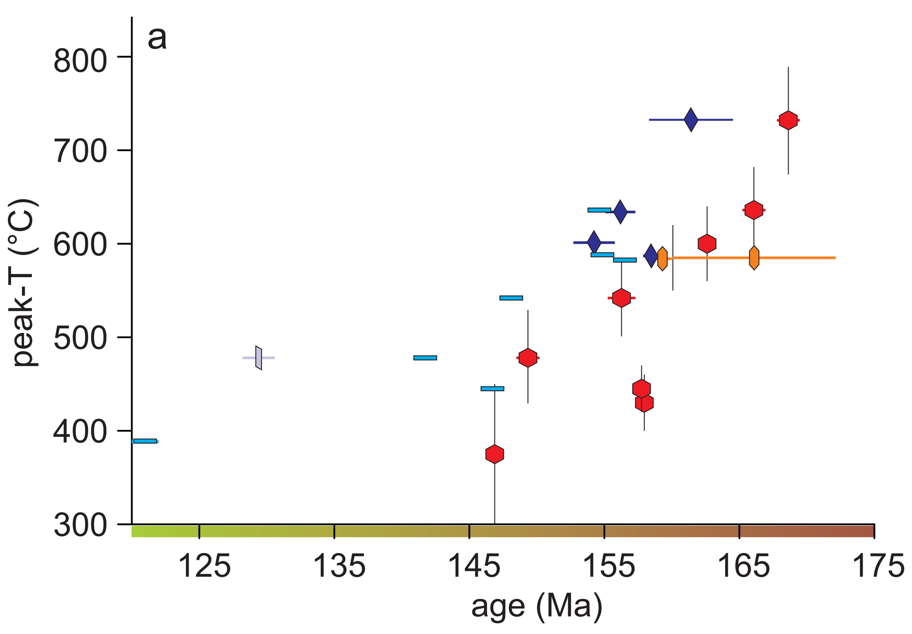


Figure 6 (→): Published and new $^{40}Ar/^{39}Ar$ amphibole and white mica ages from high-grade blocks and eclogite-amphibolite facies coherent units displayed in histograms, probability density functions (line), and kernel-density estimate curves (area).

Key Findings:

- Prograde metamorphism appears temporally variable, but geochronometers may date variable PT conditions
- $^{40}Ar/^{39}Ar$ amphibole ages cluster at 165-159 Ma with a N-S younging trend
  - high-T retrograde metamorphism of eclogite-amphibolite was fast and uniform
- Duration between $^{40}Ar/^{39}Ar$ amphibole and white mica dates ranges 2–14 Myr
  - Exhumation rates of eclocite-amphibolite slowed in the blueschist facies and became more variable

Results 2 - Thermokinetic Evolution of the Subduction zone



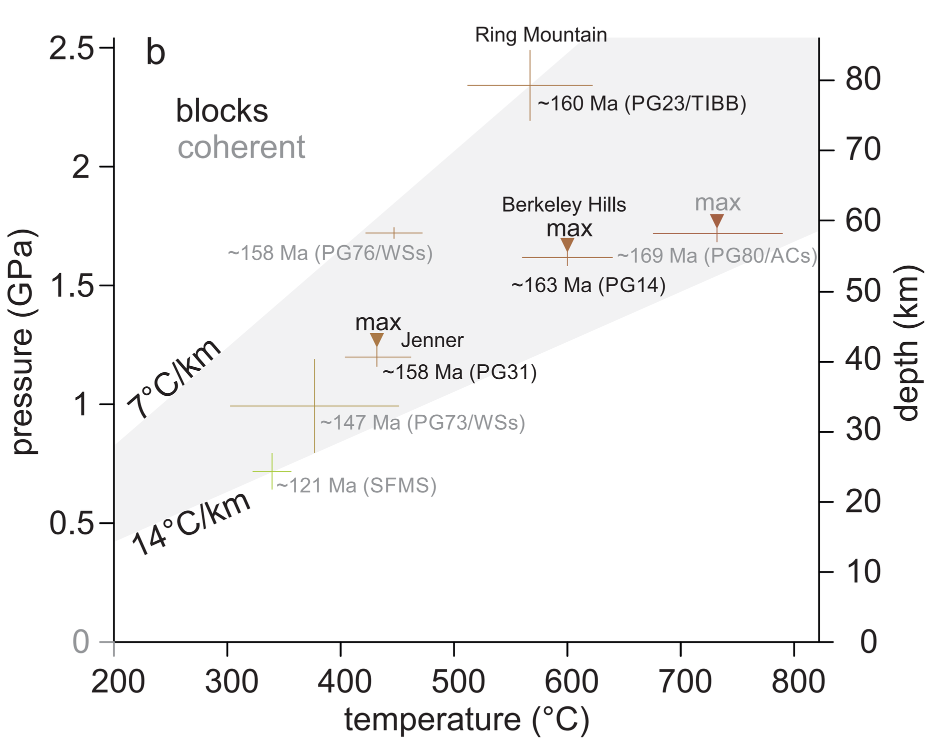


Figure 7. (a) Tt diagram showing dates of geochronometers of individual blocks as a function of the peak-T determined for the block.
(b) PT diagram showing peak-PT data of blocks and coherent units along with the approximate age of peak metamorphism, estimated between prograde Lu-Hf garnet or U-Pb zrc and retrograde $^{40}Ar/^{39}Ar$ hornblende or phengite dates. The arrows indicate maximum pressure estimates.

Key Findings:

- Geothermal gradients ranged 7-14°C/km.
- Younger metamorphism was rather hotter than cooler.

References
Anczkiewicz, R., Platt, J. P., Thirlwall, M. F., & Wakabayashi, J. (2004). Franciscan subduction off to a slow start: Evidence from high-precision Lu-Hf garnet ages on high grade-blocks. Earth and Planetary Science Letters, 225(1–2), 147–161. https://doi.org/10.1016/j.epsl.2004.06.003
Catlos, E. J., & Sorensen, S. S. (2003). Phengite-based chronology of K- and Ba-rich fluid flow in two paleosubduction zones. Science (New York, N.Y.), 299(January), 92–95. https://doi.org/10.1126/science.1076977
Cloos, M. (1982). Flow melanges: numerical modeling and geologic constraints on their origin in the Franciscan subduction complex, California. Geological Society of America Bulletin, 93(4), 330–345. https://doi.org/10.1130/0016-7606(1982)93<330:FMNMAG>2.0.CO
Cooper, F. J., Platt, J. P., & Anczkiewicz, R. (2011). Constraints on early Franciscan subduction rates from 2-D thermal modeling. Earth and Planetary Science Letters, 312(1–2), 69–79. https://doi.org/10.1016/j.epsl.2011.09.051
Dumitru, T. A., Wakabayashi, J., Wright, J. E., & Wooden, J. L. (2010). Early Cretaceous transition from nonaccretionary behavior to strongly accretionary behavior within the Franciscan subduction complex. Tectonics, 29(5). https://doi.org/10.1029/2009TC002542
Hopson, C. A., Mattinson, J. M., Pessagno, E. A., & Luyendyk, B. P. (2008). California Coast Range ophiolite: Composite Middle and Late Jurassic oceanic lithosphere. Special Paper 438: Ophiolites, Arcs, and Batholiths: A Tribute to Cliff Hopson, 2438(01), 1–101. https://doi.org/10.1130/2008.2438(01)
Mulcahy, S. R., King, R. L., & Vervoort, J. D. (2009). Lawsonite Lu-Hf geochronology: A new geochronometer for subduction zone processes. Geology, 37(11), 987–990. https://doi.org/10.1130/G30292A.1
Mulcahy, S. R., Vervoort, J. D., & Renne, P. R. (2014). Dating subduction-zone metamorphism with combined garnet and lawsonite Lu-Hf geochronology. Journal of Metamorphic Geology, 32(5), 515–533. https://doi.org/10.1111/jmg.12092
Mulcahy, S. R., Starnes, J. K., Day, H. W., Coble, M. A., & Vervoort, J. D. (2018). Early Onset of Franciscan Subduction. Tectonics, 37(5), 1194–1209. https://doi.org/10.1029/2017TC004753
Page, F. Z., Essene, E. J., Mukasa, S. B., & Valley, J. W. (2014). A garnet-zircon oxygen isotope record of subduction and exhumation fluids from the Franciscan complex, California. Journal of Petrology, 55(1), 103–131. https://doi.org/10.1093/petrology/egt062
Paterson, S. R., & Ducea, M. N. (2015). Arc magmatic tempos: Gathering the evidence. Elements, 11(2), 91–98. https://doi.org/10.2113/gselements.11.2.91
Ross, J. A., & Sharp, W. D. (1988). The effects of sub-blocking temperature metamorphism on the K/Ar systematics of hornblendes: 40Ar/39Ar dating of polymetamorphic garnet amphibolite from the Franciscan Complex, California. Contributions to Mineralogy and Petrology, 100(2), 213–221. https://doi.org/10.1007/BF00373587
Shervais, J. W., Choi, S. H., Sharp, W. D., Ross, J., Zoglman-Schuman, M., & Mukasa, S. B. (2011). Serpentinite matrix melange: Implications of mixed provenance for melange formation. Geological Society of America Special Papers, 480(01), 1–30. https://doi.org/10.1130/2011.2480(01).
Ukar, E., Cloos, M., & Vasconcelos, P. (2012). First 40 Ar- 39 Ar Ages from Low-T Mafic Blueschist Blocks in a Franciscan Mélange near San Simeon: Implications for Initiation of Subduction. The Journal of Geology, 120(5), 543–556. https://doi.org/10.1086/666745
Wakabayashi, J., & Dumitru, T. a. (2007). Ar Ages from Coherent, High-Pressure Metamorphic Rocks of the Franciscan Complex, California: Revisiting the Timing of Metamorphism of the World's Type Subduction Complex. International Geology Review, 49(August 2016), 873–906. https://doi.org/10.2747/0020-6814.49.10.873