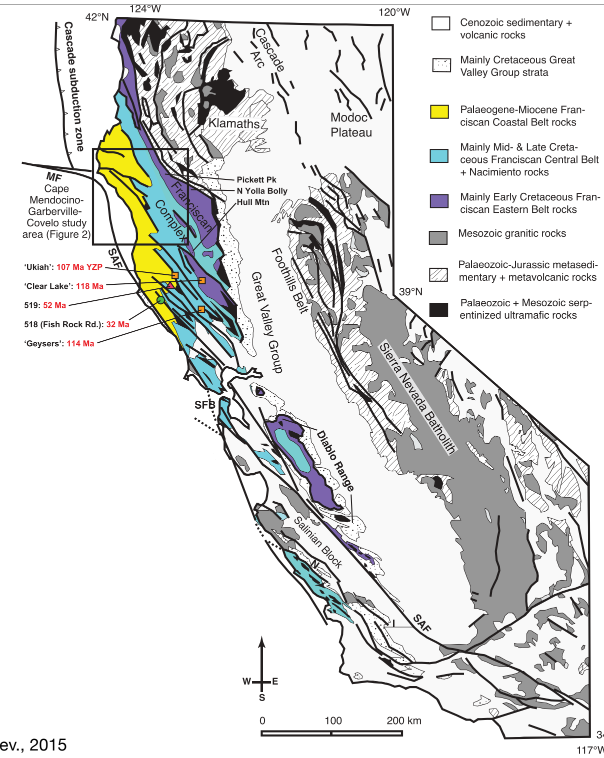
Franciscan Complex



Dumitru et al., Intl. Geol. Rev., 2015

"Franciscan lithologies are predominantly (a bit less than 90%) siliciclastic sedimentary rocks primarily consisting of sandstones (called 'greywackes' in most literature), shales (also referred to as mudstones), conglomerates, and sedimentary breccia, with subordinate serpentinite, basaltic volcanic rocks, chert, and rare limestone." [Wakabayashi, 2015]

Typical outcrop of blueschists…

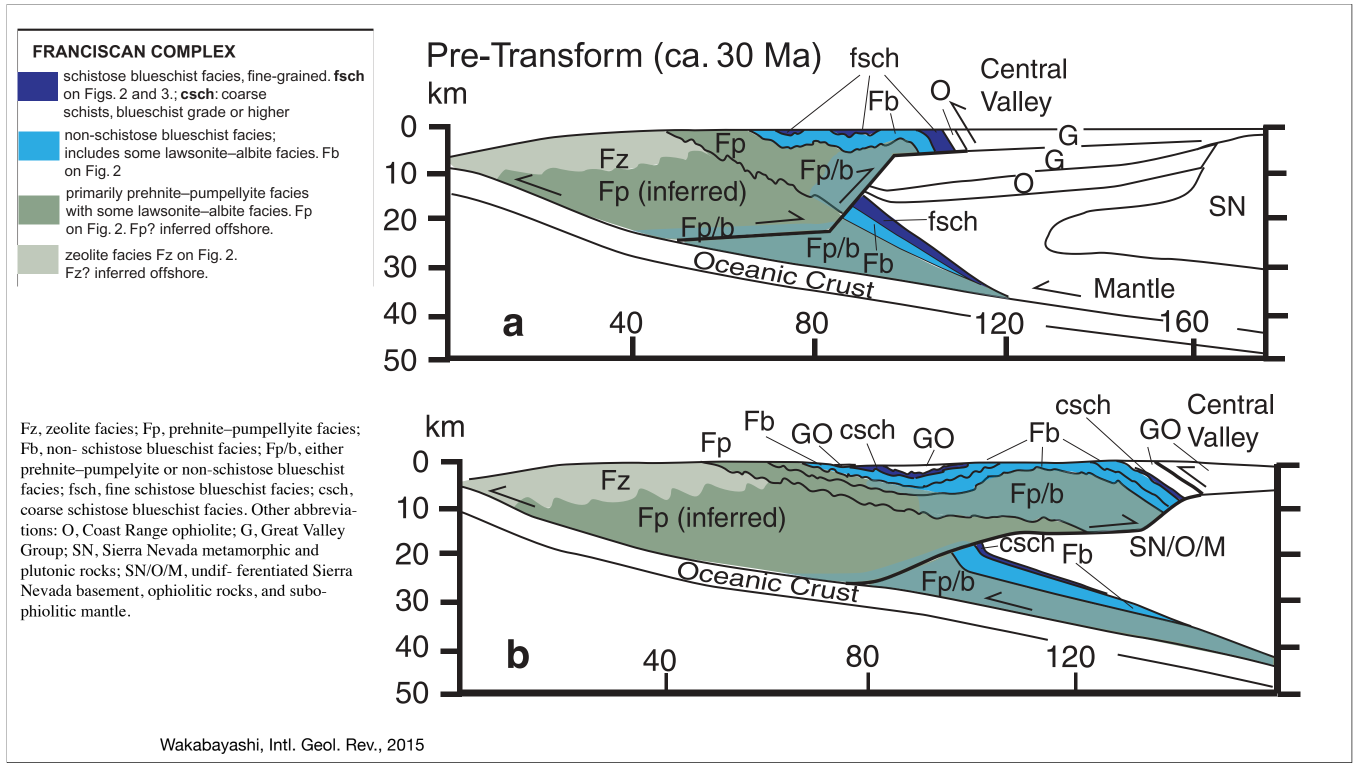
Here can see the serpentinite framework with a high-grade (blueschist?) boulder above

<Looking at blueschist up close

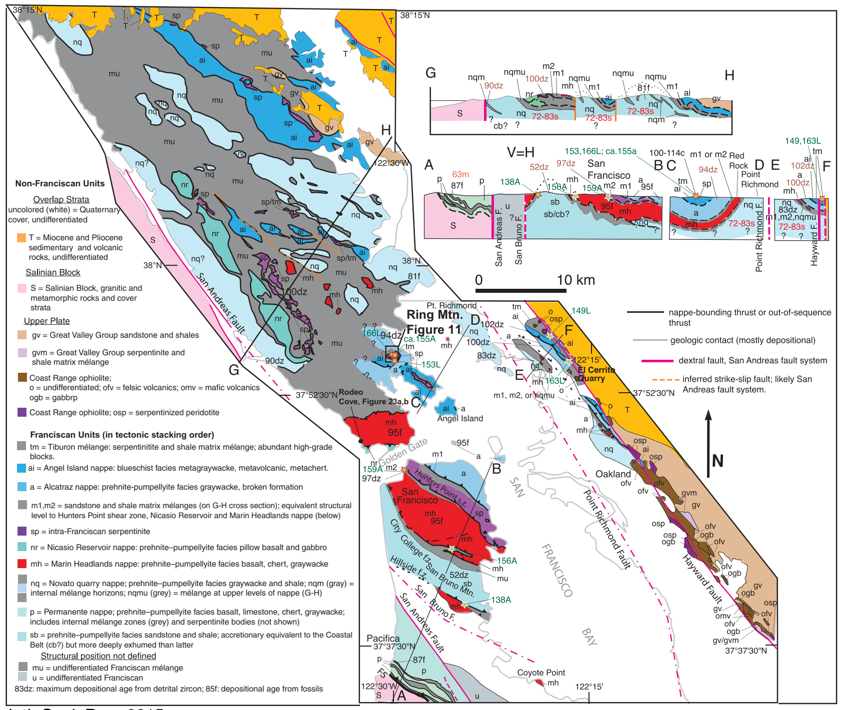
and closer.

Pillow basalts


Wakabayashi, Intl. Geol. Rev., 2015
Serpentinite Breccia
Serpentinite Breccia
Serpentinite Breccia
amphibolite
Serpentinite Breccia
Serpentinite Breccia
amph.
d
Serpentinite Breccia

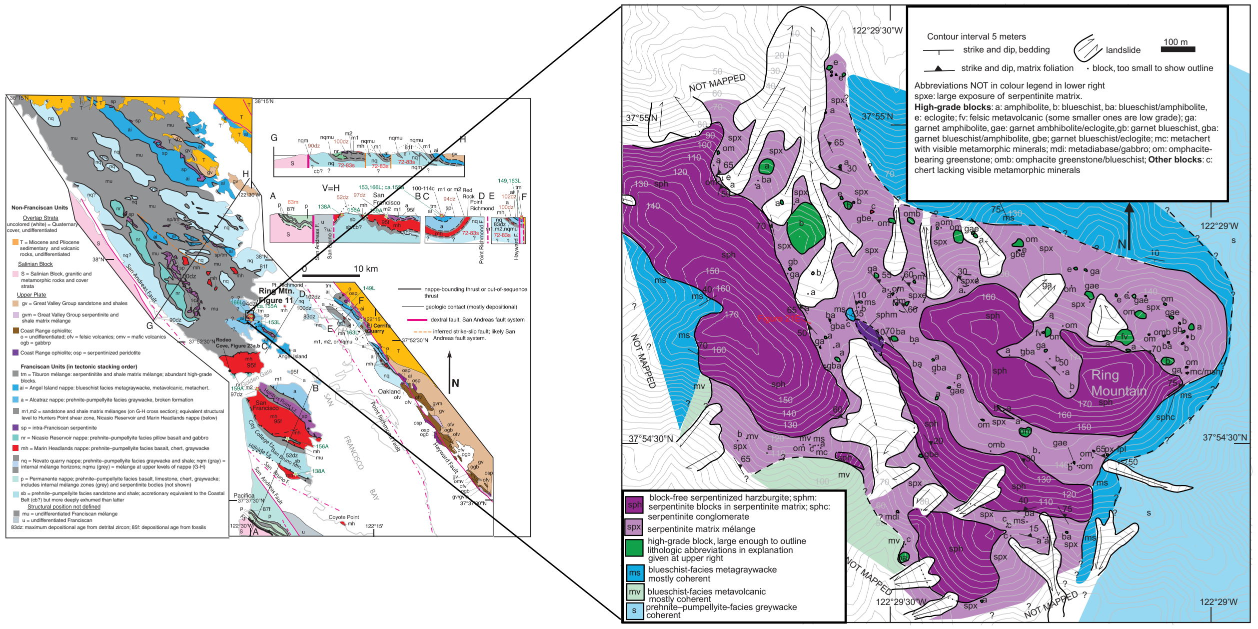


In general, young to lower left

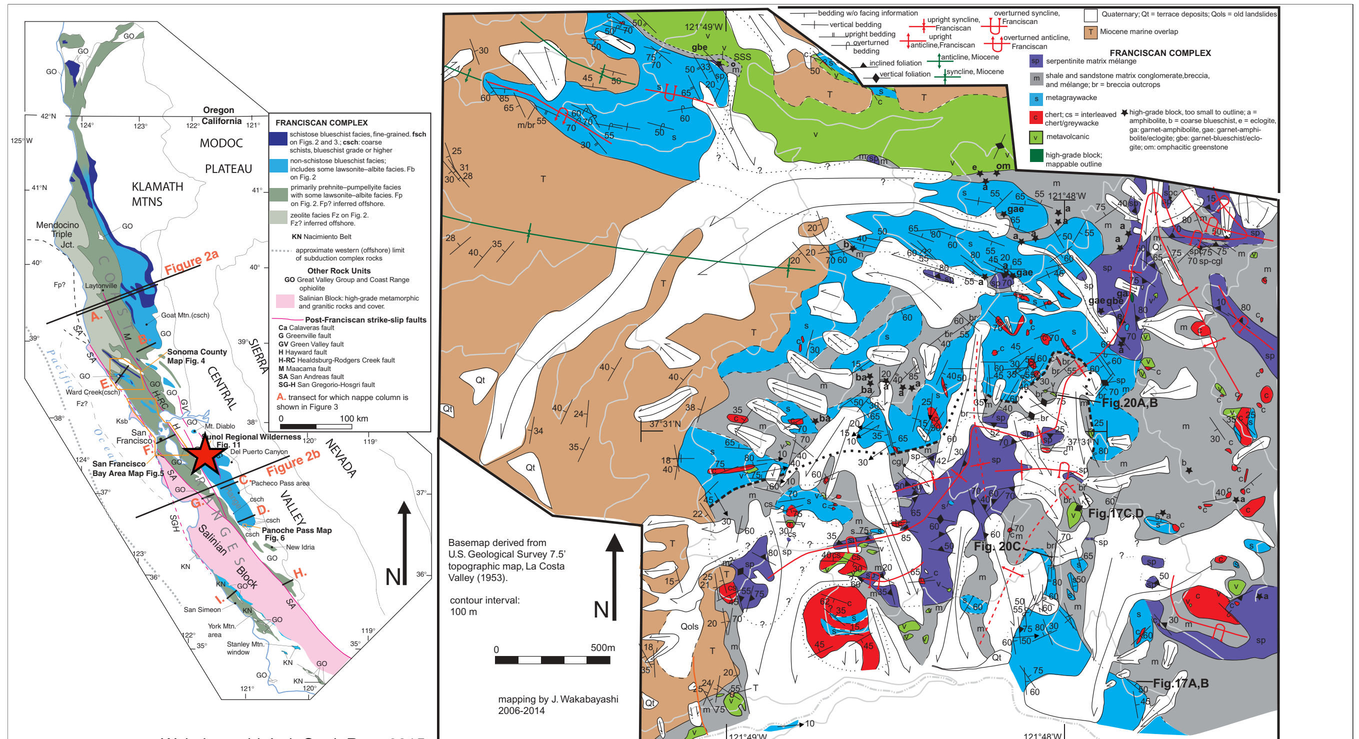


Wakabayashi, Intl. Geol. Rev., 2015

Why it is a “complex”: coherent chunks are lost in melange (grays here)

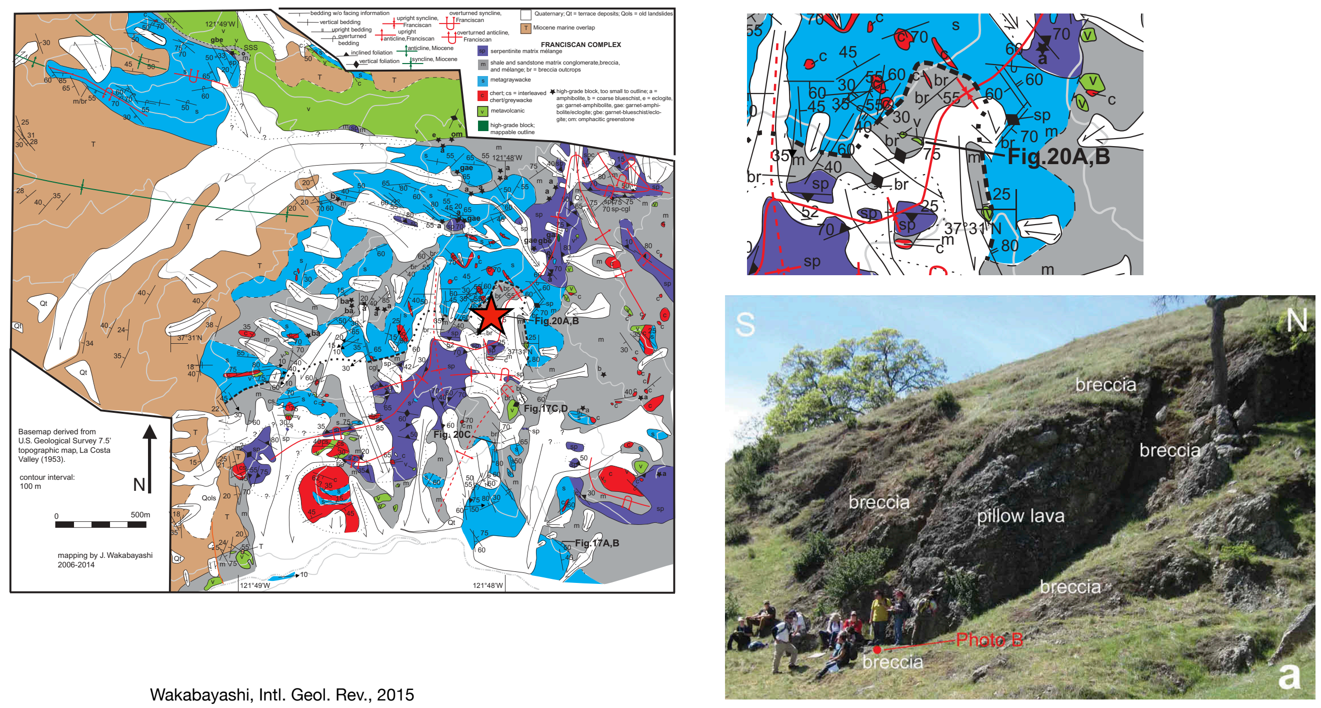


Wakabayashi, Intl. Geol. Rev., 2015



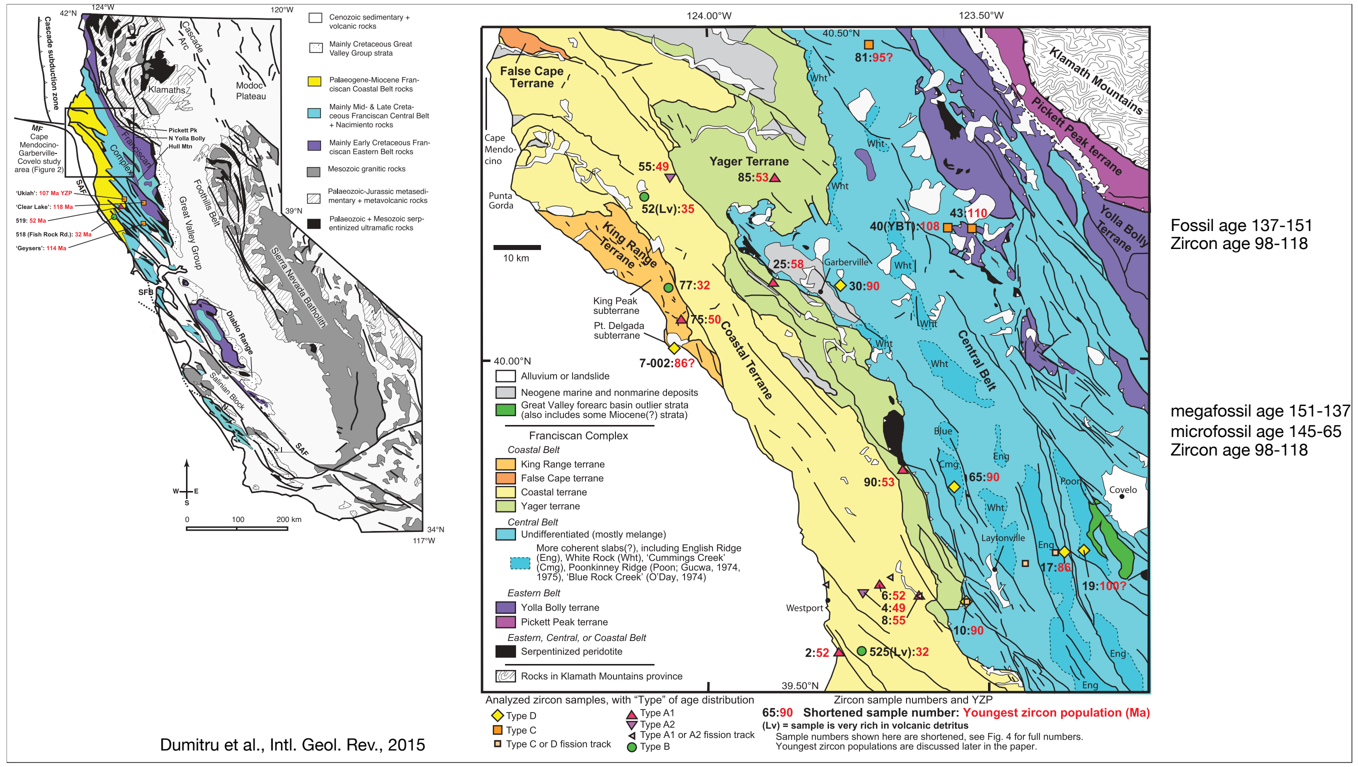
Wakabayashi, Intl. Geol. Rev., 2015

Gray on the map is melange



Wakabayashi, Intl. Geol. Rev., 2015

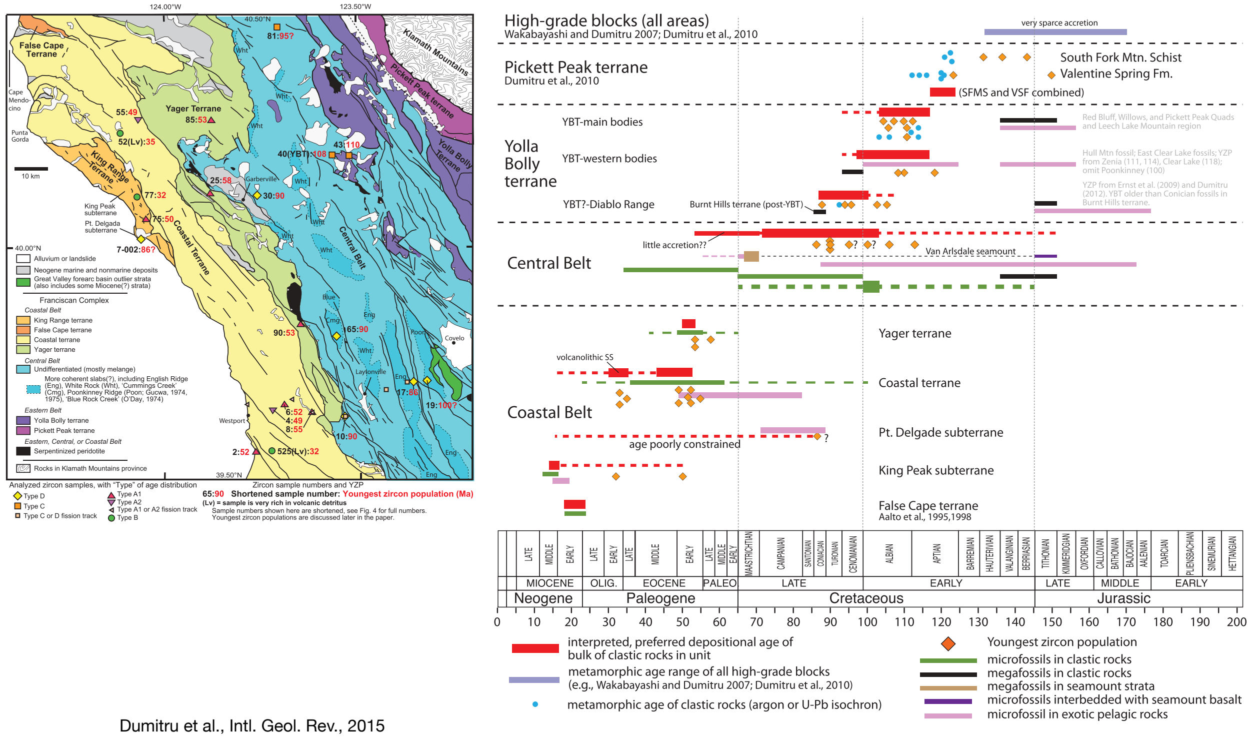
Gray on the map is melange



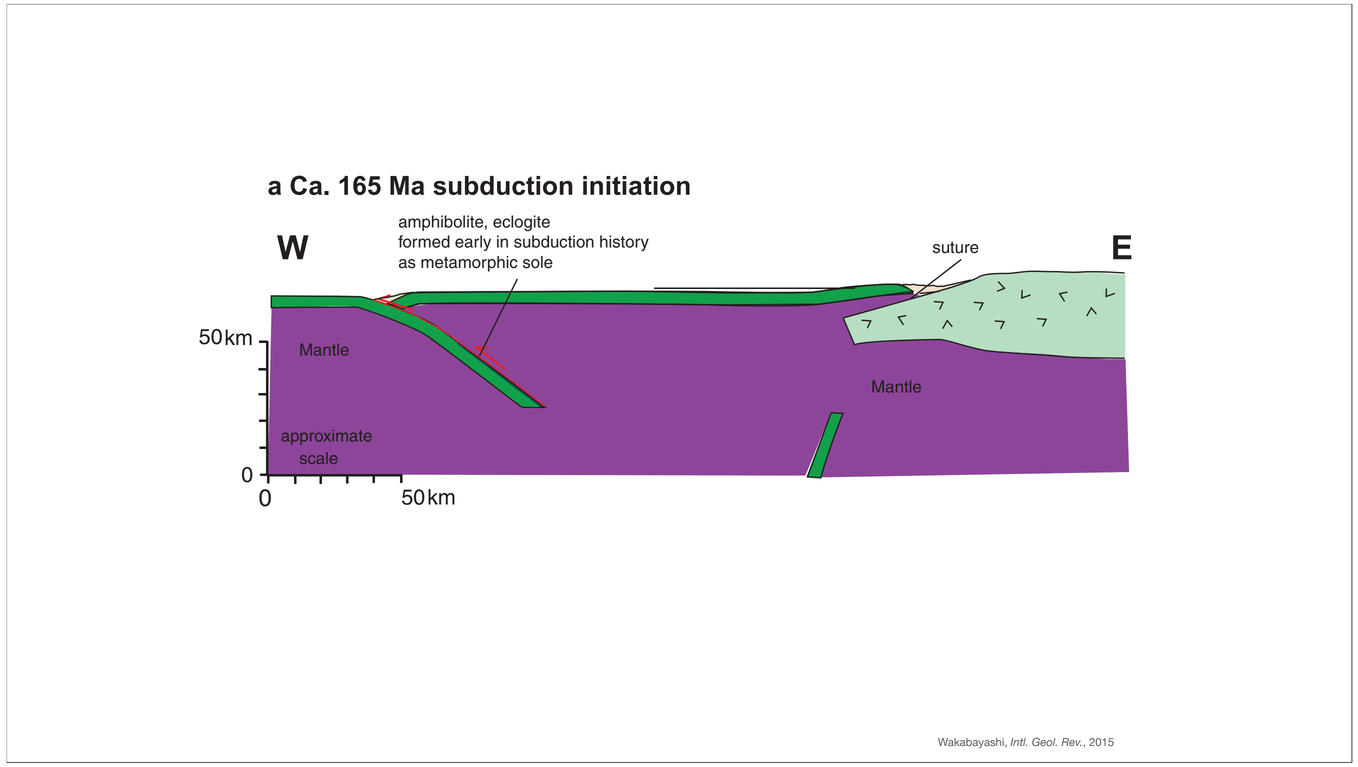
Fossil age 137-151
Zircon age 98-118

megafossil age 151-137
microfossil age 145-65
Zircon age 98-118

Dating is hard to do. Red numbers are ages youngest zircons. Note that zircon ages tend to be quite a bit younger, suggesting fossils are recycled…

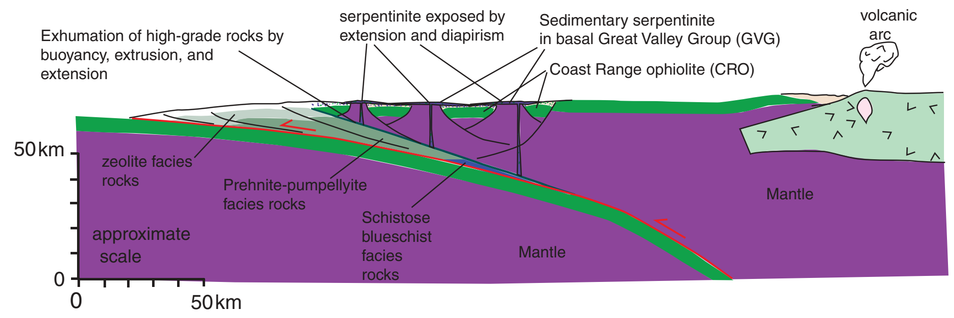


Dumitru et al., Intl. Geol. Rev., 2015



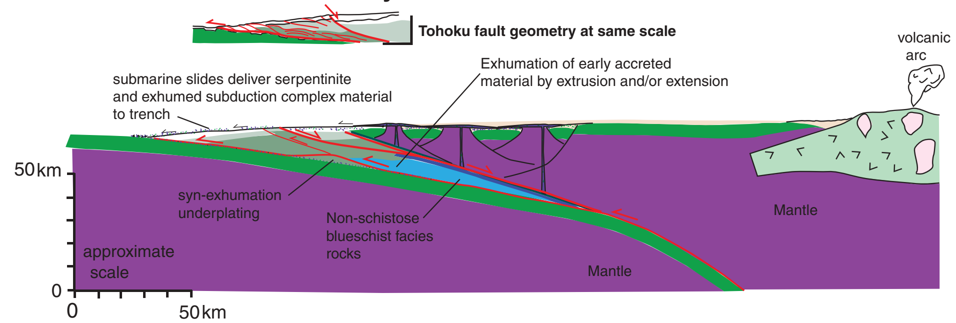
Cross-sectional cartoons showing the progressive evolution of the Franciscan. The Tohoku subduction zone insets are adapted from Tsuji et al. (2011). The colour scheme for Franciscan units follows the metamorphic grade scheme of Figures 1–3. Note that for simplicity the frames combine events that took place at slightly different times during the given period, and this simplification may distort the geometry of some of the features. In addition, all frames show net addition (accretion) of material to the subduction complex, although the net gain in frames (a) and (b) is very small. It is likely that all frames had shorter periods of accretion with intervening periods of subduction erosion that removed previously accreted material, with the final result of a net accretion (Sections 6.1.3.1, 6.1.3.2, and 6.2.1.2). (a) Initiation of E-dipping Franciscan subduction at ca. 165– 170 Ma in young island arc crust, following termination of west-dipping subduction to the east (Section 6.6.1). In the model shown here, the CRO, as well as the protoliths of the high-grade rocks of the Franciscan, formed over the earlier W-dipping subduction zone. In a more complex scenario, the CRO formed over the newly initiated Franciscan subduction zone that itself initiated in young arc crust as above. The ocean basin was starved of clastic sediments at the time of subduction initiation. The initially high geothermal gradient associated with subduction resulted in high-temperature metamorphism in the high-grade rocks of the Franciscan. (b) At the beginning of this 150–135 Ma period, there was little clastic delivery to the trench and nascent forearc basin. Serpentinite diapirs delivered serpentinite and included blocks, including high-grade blocks to serpentinite mud volcanoes in the forearc basin, forming the first deposits of the GVG (Sections 5.3.2.2 and 5.5). The level of exposure of the Franciscan for this time frame is very deep (corresponds to the dark blue colour), and there was little accretion taking place at this level, although the accretionary prism at higher levels was much thicker (see Section 6.5). See also parts of Section 6.6.3. (c) This shows the early stage of large-scale accretion in the Franciscan from 120 to 100 Ma. Current exposure corresponds to levels in the medium blue material. In addition to siliciclastic clastic sediments sourced from the magmatic arc to the east, serpentinite and high-grade blocks were shed into the trench as submarine landslides, having been sourced the basal olistostrome horizons of the GVG (Section 6.1.3.3). Some Franciscan material was far-travelled, derived from the downgoing plate (Sections 4.1 and 4.3), whereas some Franciscan material in mélanges and clastic rocks was derived as submarine landslides from Franciscan rocks exhumed and exposed on the sea floor (Section 5.8). The early exhumation of the Franciscan rocks took place by a combination of cross-sectional extrusion (megathrust below, landward-dipping normal fault above) and hanging wall extension, although the most significant extension of the hanging wall took place after 100 Ma. An inset of fault geometry associated with the 2011 Tohoku- oki earthquake (adapted from Tsuji et al. 2011) is shown for comparison and illustration of cross-sectional extrusion fault geometry. East and west are reversed on the Tohoku inset to make the fault dip directions similar to Franciscan geometry. (d) shows the major accretion that took place from 100 to 70 Ma (Section 6.6.4). Large-scale hanging wall extension along with cross-sectional extrusion contributed to critical path exhumation of Franciscan HP rocks (Sections 6.2.1.4 and 6.2.1.5). Mélange deposition as submarine landslides continued, and this may have been more voluminous towards the end of this period (Section 6.1.3.2). Sources of high-grade blocks and detrital serpentinite may have been from GVG basal horizons and/or exhumed Franciscan serpentinite mélanges (Sections 5.8.2 and 6.1.3.3). (e) Large-scale frontal accretion, including accretion of the Coastal Belt that began at about 53 Ma (Section 6.6.5). The early part of this period was associated with low-angle subduction. Arc (east)-vergent thrusting of the Franciscan over the forearc basin ('tectonic wedging') may have initiated early in this period, along with folding and out-of-sequence thrusting previously accreted nappes. (f) Current geometry, reflecting the post-subduction, dextral transform regime (Section 6.6.6). In addition to the dextral faults, the frame shows the emplacement magmatic arc basement, the Salinian Block, into the Coast Ranges along dextral faults. Also shown are some of the thermo-magmatic impacts of the slab window magmatism that resulted from subduction–transform transition. These include intrusion of plutons, mafic underplating, and thermal overprinting of the middle-to-lower levels of the Coast Range crust (none of which is exposed on the surface), shown by the transparent colours that show increasing metamorphic grade of post-subduction overprint with depth.

b Ca. 150-135 Ma early serpentinite sedimentation



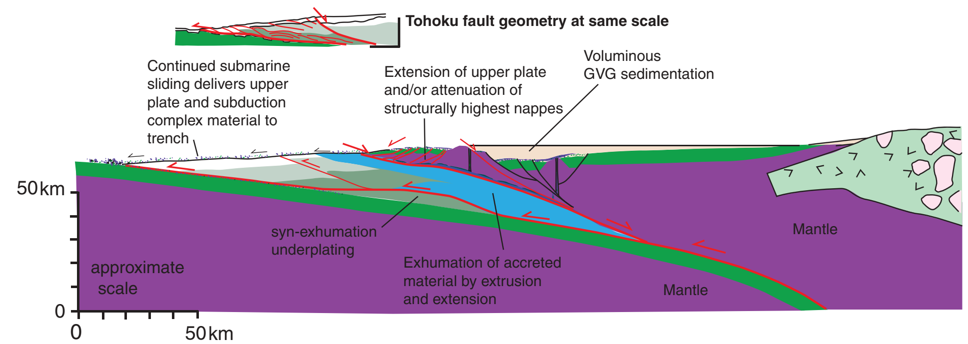
Wakabayashi, *Intl. Geol. Rev.*, 2015

c Ca. 120-100 Ma Early Clastic Accretion and Exhumation



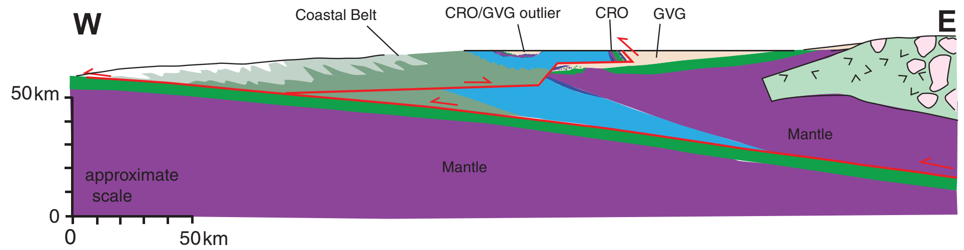
Wakabayashi, *Intl. Geol. Rev.*, 2015

d Ca. 100-70 Ma Clastic Accretion and Exhumation

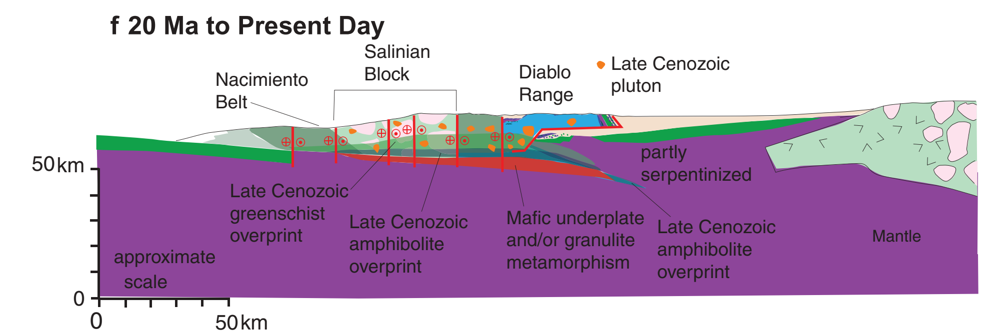


Wakabayashi, *Intl. Geol. Rev.*, 2015

e Ca. 70-20 Ma Tectonic wedging/frontal accretion

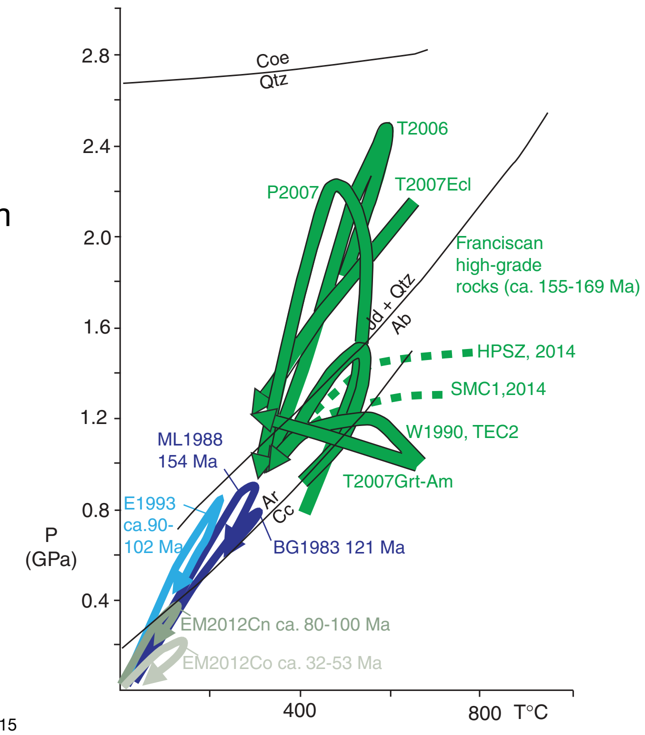


Wakabayashi, *Intl. Geol. Rev.*, 2015

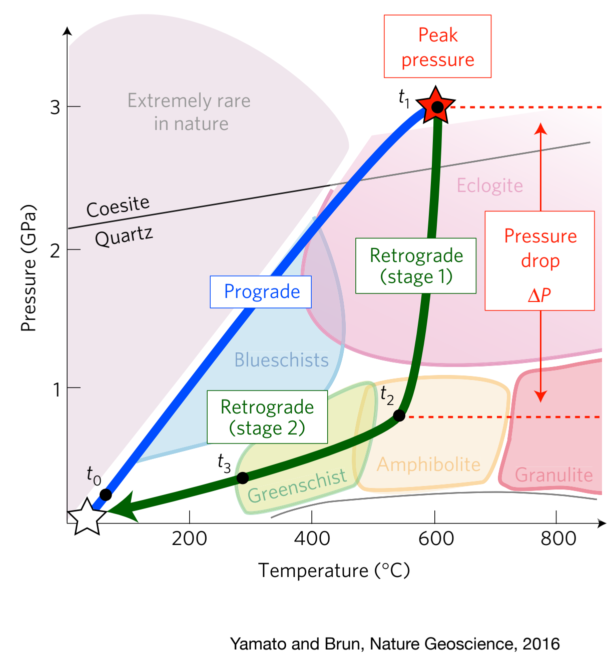


Wakabayashi, *Intl. Geol. Rev.*, 2015

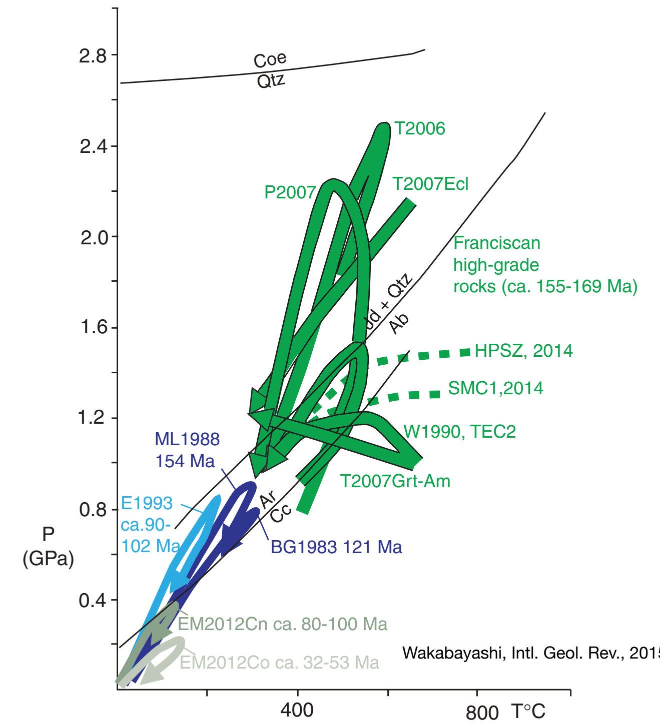
The blueschist problem



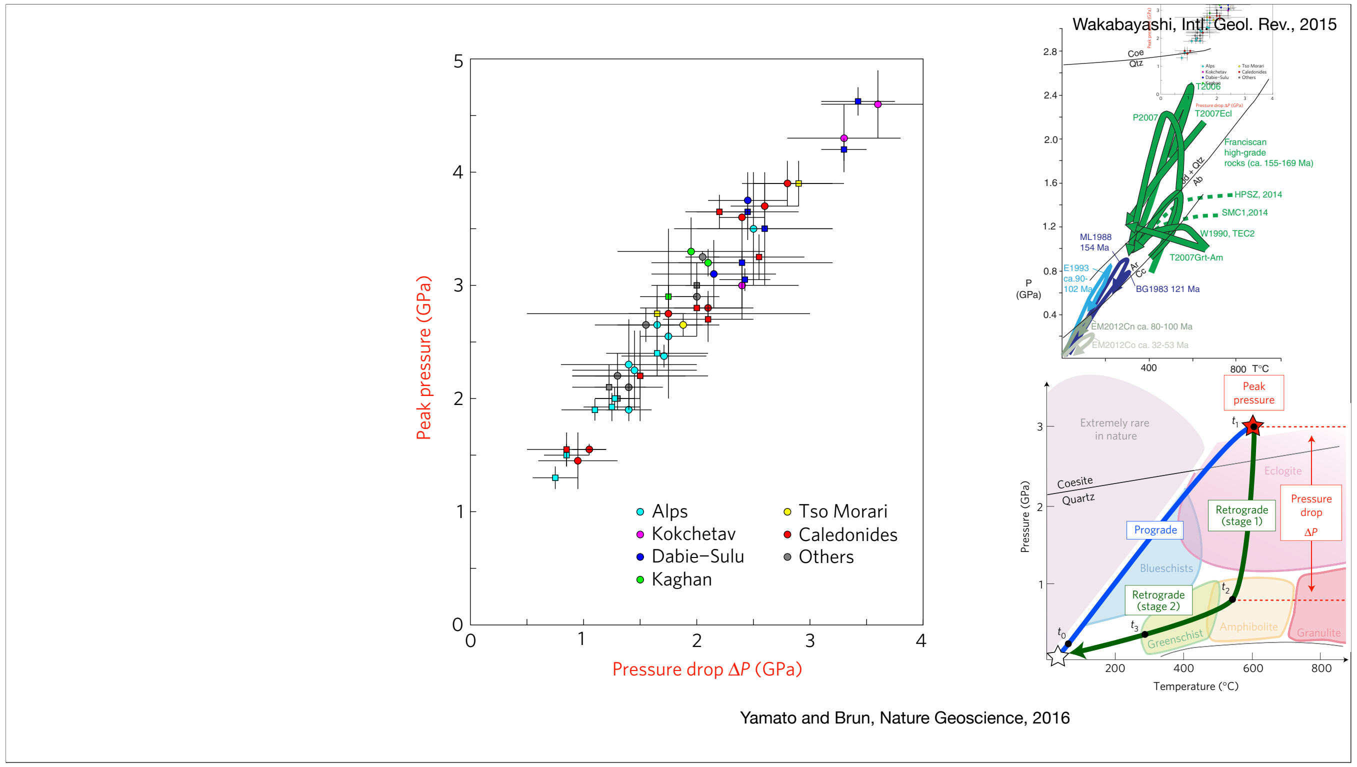
Wakabayashi, Intl. Geol. Rev., 2015



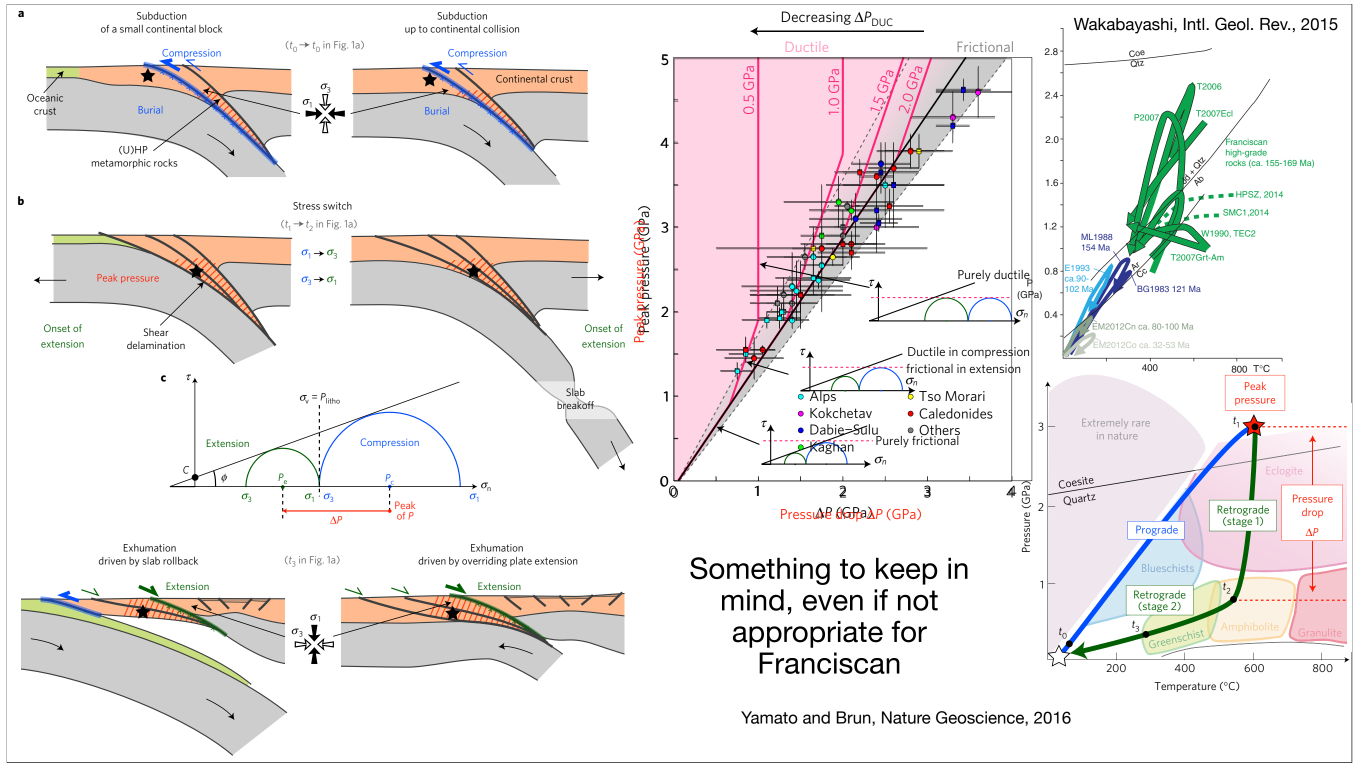
Peak pressure
Extremely rare in nature
Coesite
Quartz
Eclogite
Prograde
Retrograde (stage 1)
Pressure drop
ΔP
Blueschists
Retrograde (stage 2)
Greenschist
Amphibolite
Granulite
Pressure (GPa)
Temperature (°C)
Yamato and Brun, Nature Geoscience, 2016



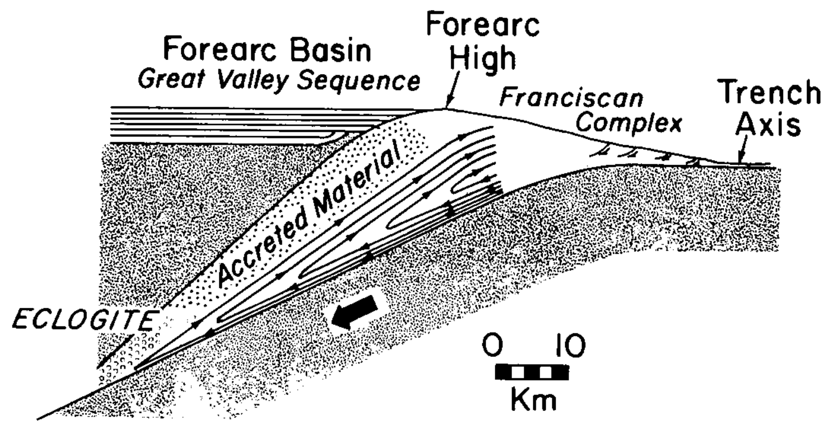
Coe
Qtz
T2006
P2007
T2007Ecl
Franciscan high-grade rocks (ca. 155-169 Ma)
HPSZ, 2014
SMC1,2014
W1990, TEC2
T2007Grt-Am
ML1988 154 Ma
E1993 ca.90-102 Ma
BG1983 121 Ma
EM2012Cn ca. 80-100 Ma
EM2012Co ca. 32-53 Ma
Wakabayashi, Intl. Geol. Rev., 2015
P (GPa)
T°C



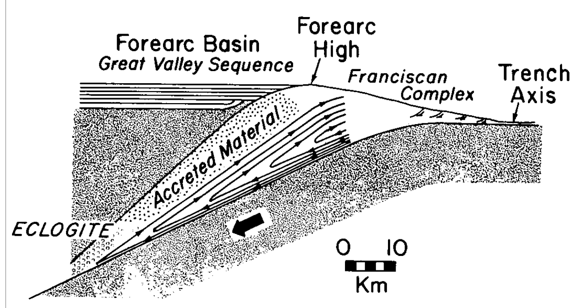
Note that none of these points are from Franciscan…



Note that none of these points are from Franciscan…and according to Wakabayashi, there is no extensional sense of shear in the Franciscan



Cloos, GSA Bull, 1982



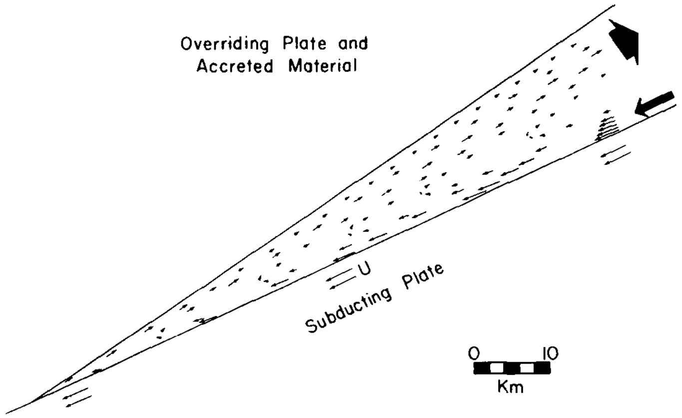


Figure 3. Velocity field calculated in the flow melange. Vectors are proportional to the subduction rate U. The wedge angle $\theta_0 = 10°$. Note the narrow zone going downward fast with large velocity gradients and the broad zone going upward more slowly.

Cloos, GSA Bull, 1982

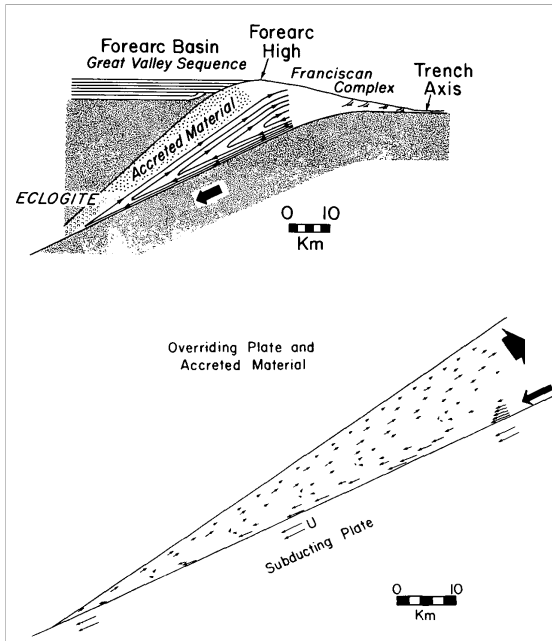


Figure 3. Velocity field calculated in the flow melange. Vectors are proportional to the subduction rate U. The wedge angle $\theta_0 = 10°$. Note the narrow zone going downward fast with large velocity gradients and the broad zone going upward more slowly.

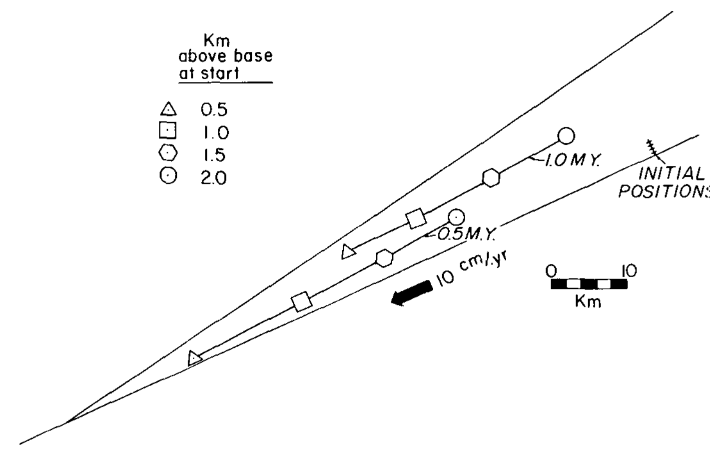
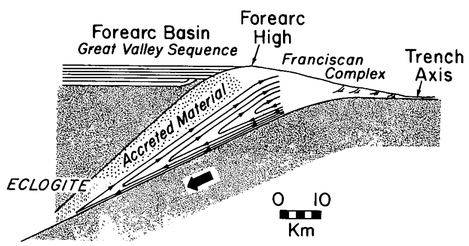


Figure 4. The dispersal of particles due to nonuniform laminar flow. Particles initially separated by 0.5 km become separated by 15 km after 500,000 yr at a 10 cm/yr subduction rate. During upward flow, the particles tend to come together but have a separation of 10 km upon reaching the original depth of burial.

Cloos, GSA Bull, 1982

Can also show that dense blueschist blocks can be transported up…
Note that this is forced by shear; some channel solutions rely more on density contrasts.



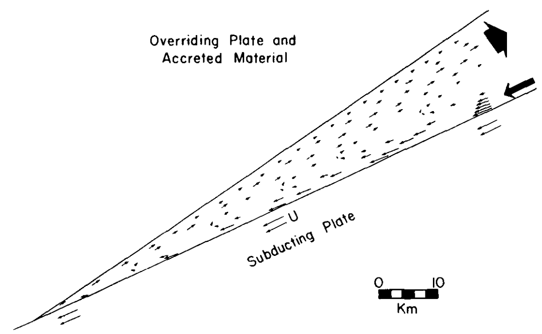


Figure 3. Velocity field calculated in the flow melange. Vectors are proportional to the subduction rate U. The wedge angle $\theta_0 = 10°$. Note the narrow zone going downward fast with large velocity gradients and the broad zone going upward more slowly.

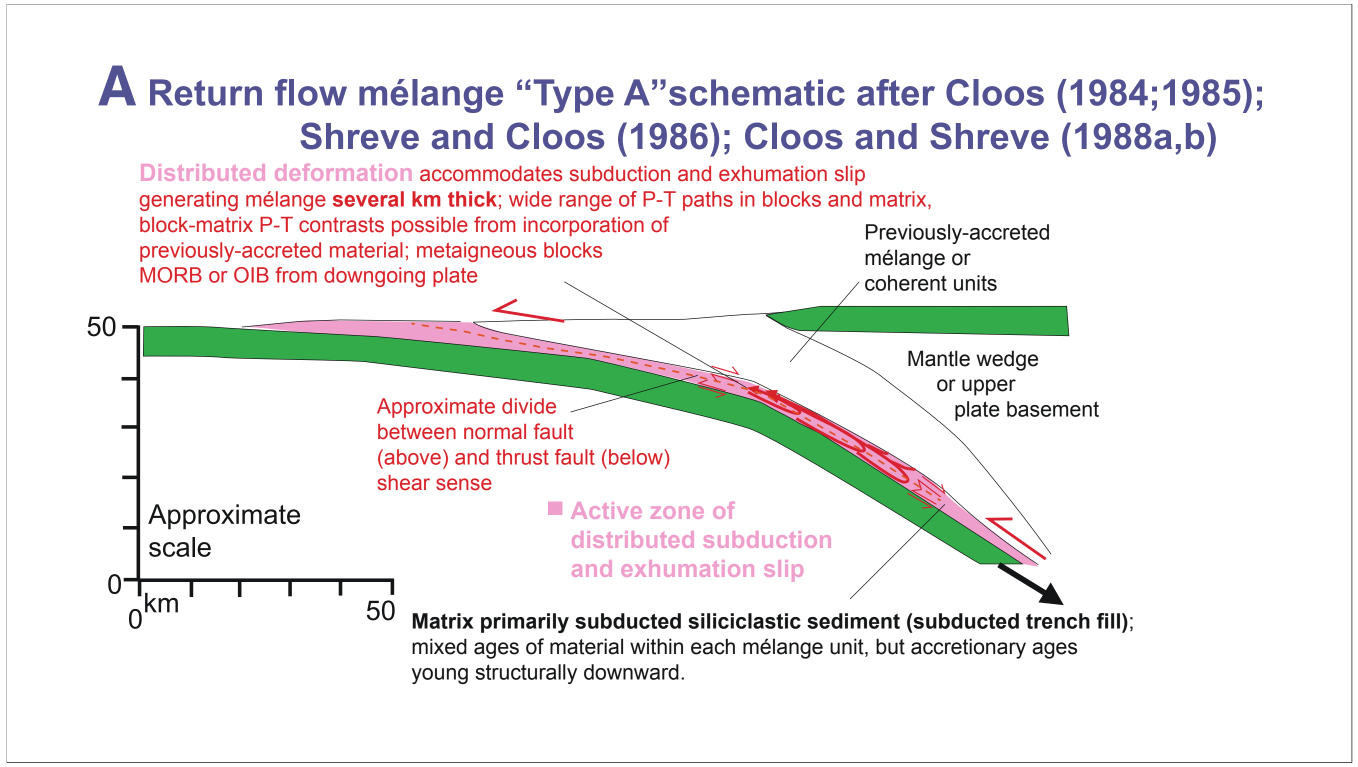
But some potential problems exist (Moulas et al., GJI 2021):

The narrow wedge will induce high dynamical normal stresses within the deep part of the deforming wedge. Thus pressure could be ~2x weight of material above (as Yamato and Brun suggested).

The narrow wedge also applies very high normal stresses to the margins of the wedge, tending to deform the margins and open the wedge up dramatically.

Cloos, GSA Bull, 1982

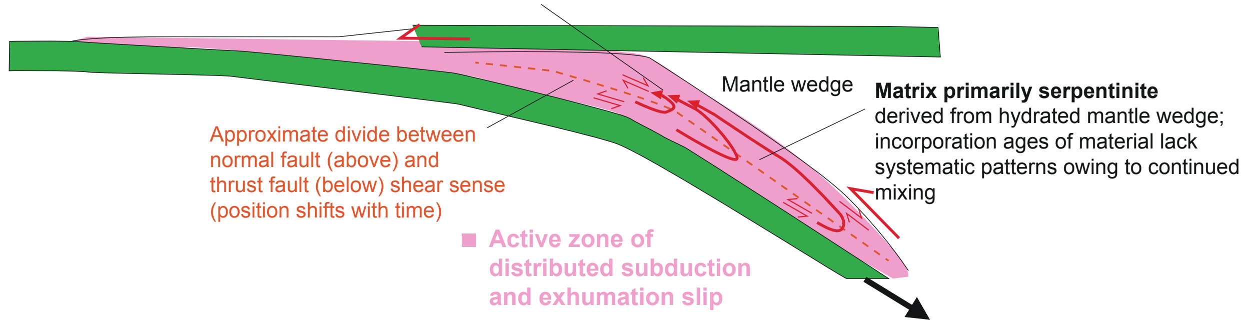
Can also show that dense blueschist blocks can be transported up…
Note that this is forced by shear; some channel solutions rely more on density contrasts.



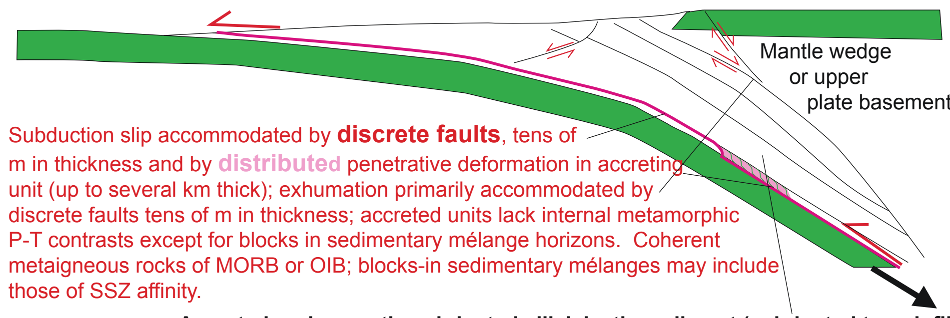
Even aside the blueschist problem, these rocks do get metamorphosed and get transferred to the upper plate.

B Return flow mélange "Type B" schematic after Gerya et al. (2002)

Distributed deformation accommodates subduction and exhumation slip generating mélange tens of km thick; wide range of P-T paths in blocks and matrix, matrix P-T paths concordant with adjacent blocks; metaigneous blocks MORB, OIB, or SSZ from downgoing or upper plate, respectively; no accretion.



C Coherent accretion (Wakabayashi, 2015a); exhumation along discrete faults (e.g., Platt, 1986).



Subduction slip accommodated by **discrete faults**, tens of m in thickness and by **distributed** penetrative deformation in accreting unit (up to several km thick); exhumation primarily accommodated by discrete faults tens of m in thickness; accreted units lack internal metamorphic P-T contrasts except for blocks in sedimentary mélange horizons. Coherent metaigneous rocks of MORB or OIB; blocks-in sedimentary mélanges may include those of SSZ affinity.

Accreted rocks mostly subducted siliciclastic sediment (subducted trench fill); accretionary ages young structurally downward.

■ **actively accreting**: discrete faults and penetrative deformation

——— non-accreting part of subduction fault, tens of m thick.

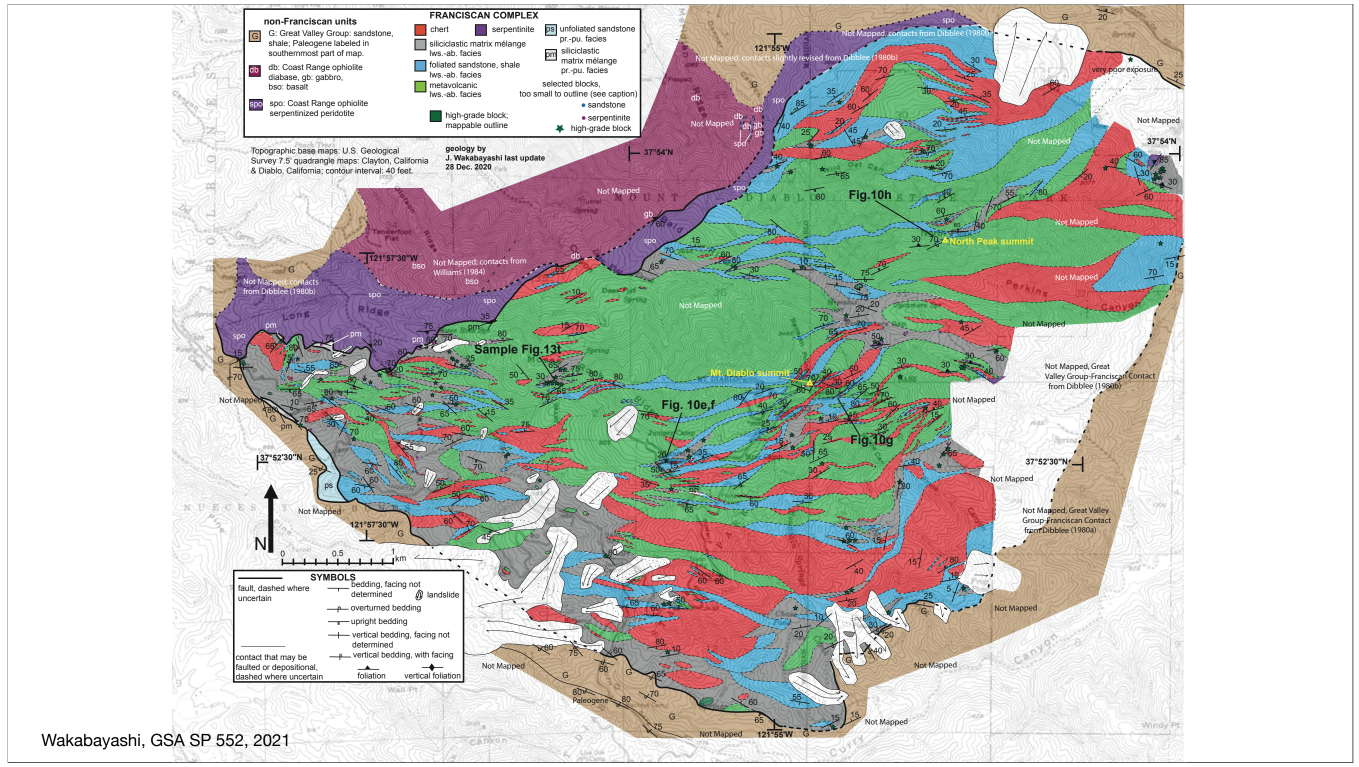


Figure 5. Geologic map shows the imbricate fault structure of Franciscan Complex rocks at Mt. Diablo. Most of these rocks are lawsonite- albite facies with high proportions of basalt and chert and comparatively low proportions of clastic sedimentary rocks and siliciclastic matrix mélange. Simplified from Wakabayashi (2021). The simplifications that diverge from the original geologic map include deletion of all mélange blocks (those too small to outline) except for high-grade blocks (and these are not distinguished by type as they on the original map) and serpentinite as well as a significant reduction in the amount of orientation data and an increase in serpentinite block and high-grade block symbol size.

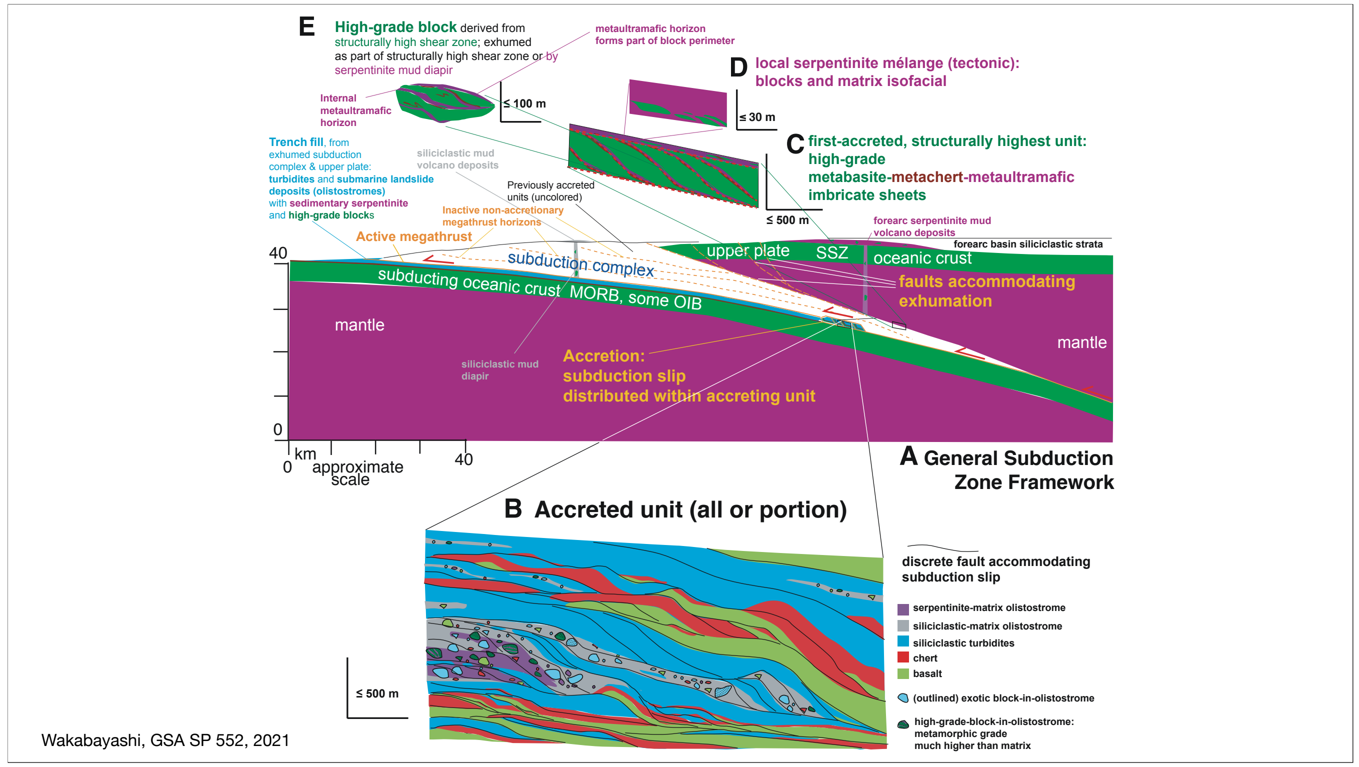
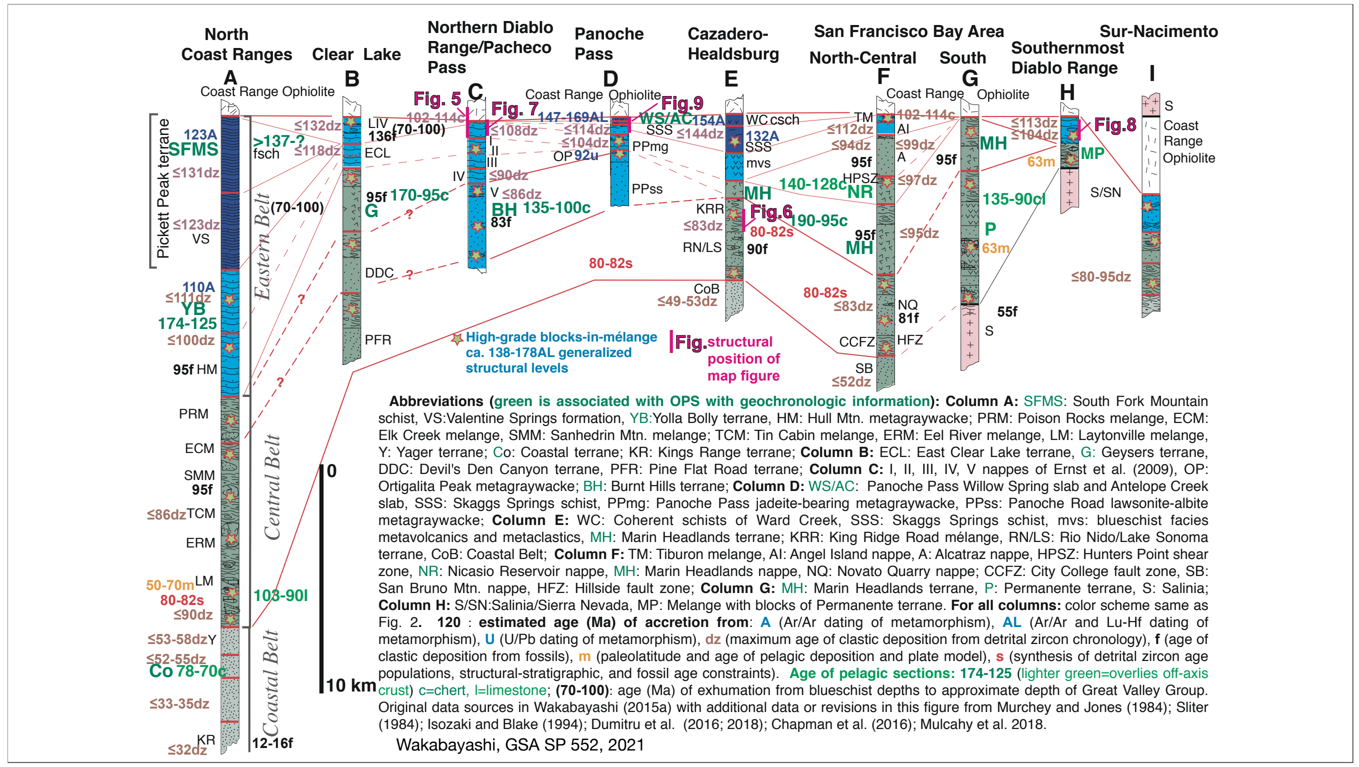
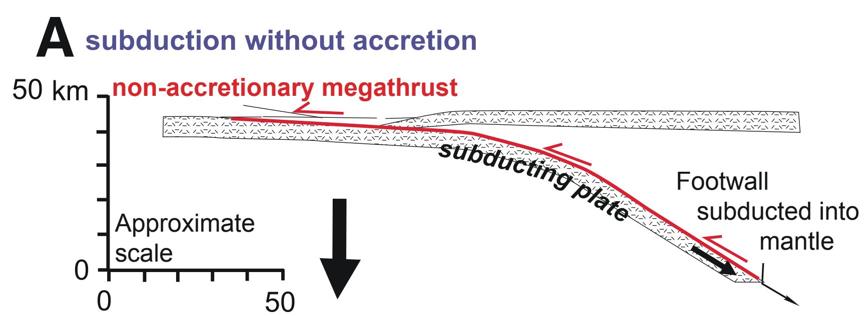


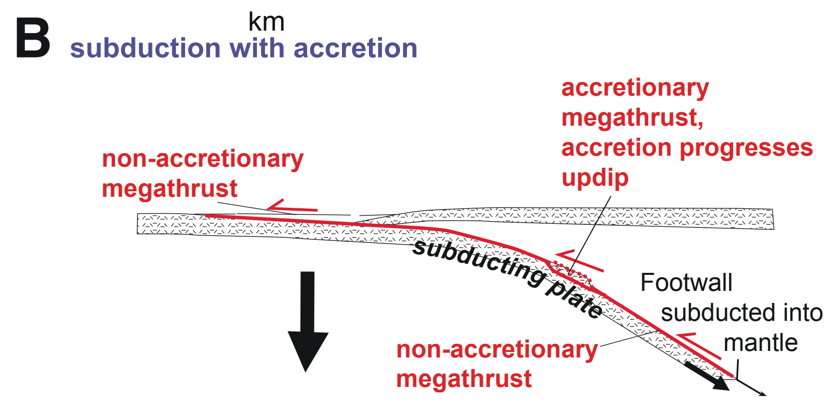
Figure 14. Schematic diagram shows the nature of accommodation of subduction and exhumation slip in a subduction complex during accre- tion. In addition to showing the accommodation of subduction slip during accretion, this diagram also shows how block-in-matrix (mélange units) are generated by sedimentary processes in trench fill and upper plate environments prior to subduction-accretion and tectonic processes during subduction-accretion. Diagram B depicts an accreting unit and shows the imbricate faulting of ocean plate stratigraphy. This faulting disrupts all parts of the ocean plate stratigraphy stack including overprinting of the olistostromal (sedimentary mélange) horizons. This fault- ing creates blocks (tectonic mélange) but not exotic ones, although exotic blocks can be inherited where such faulting overprints sedimentary mélange horizons. This process is scale-independent from the kilometer scale to the outcrop scale shown in Figures 10 and 11. The general schematic geologic relationships shown resemble the geologic map pattern of Figure 5 (Mt. Diablo).



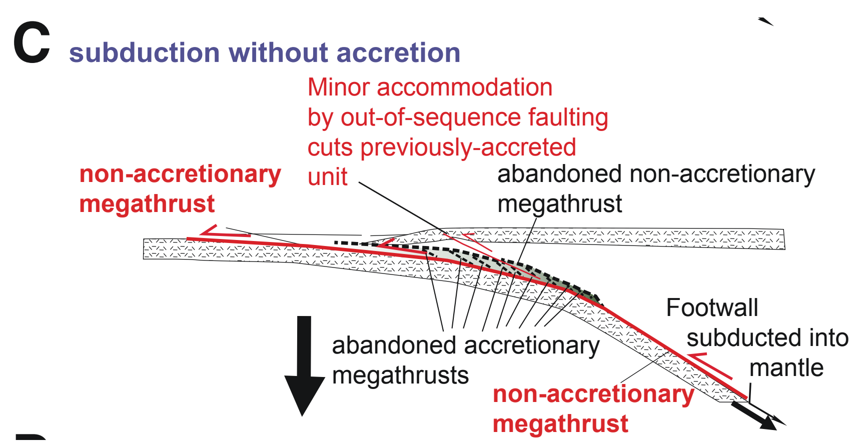
Main thing is red lines are interpreted to bound major accretion events. Fundamentally the argument here is that the melanges created by some models do not reflect the more coherent packages of rocks actually seen.



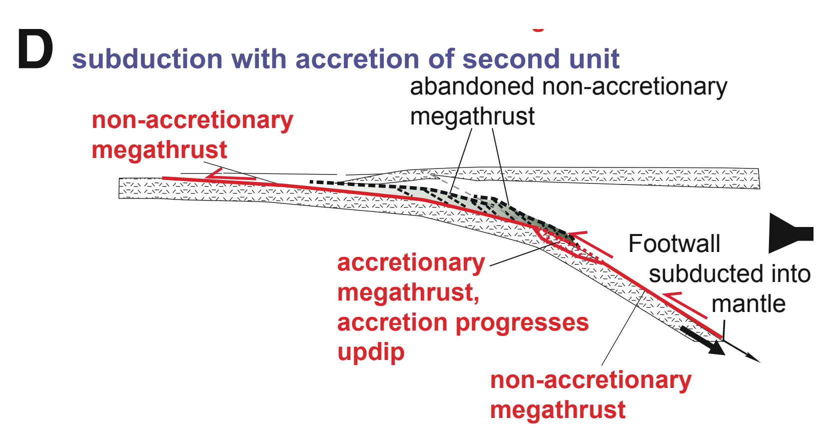
Wakabayashi, GSA SP 552, 2021



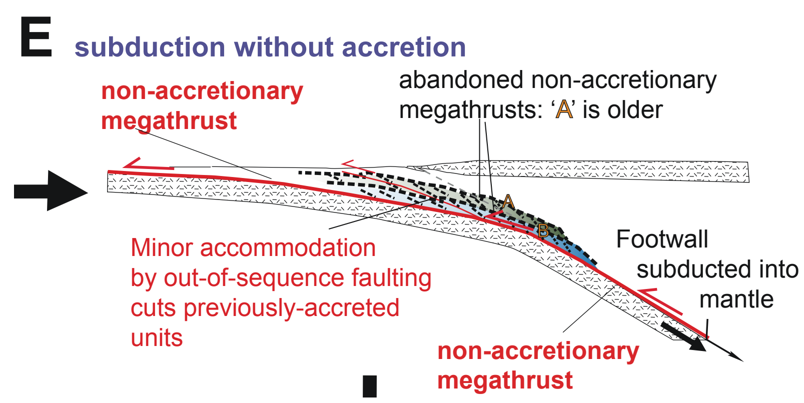
Wakabayashi, GSA SP 552, 2021



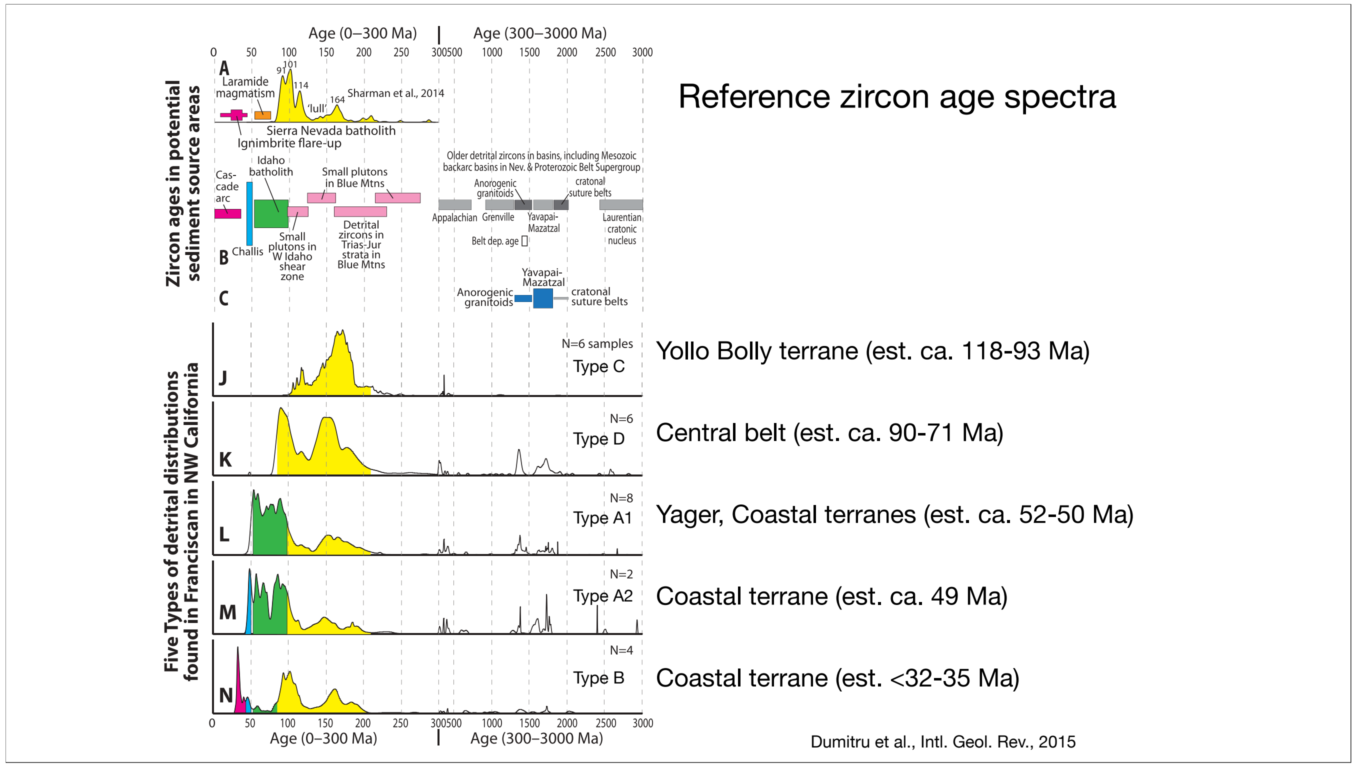
Wakabayashi, GSA SP 552, 2021



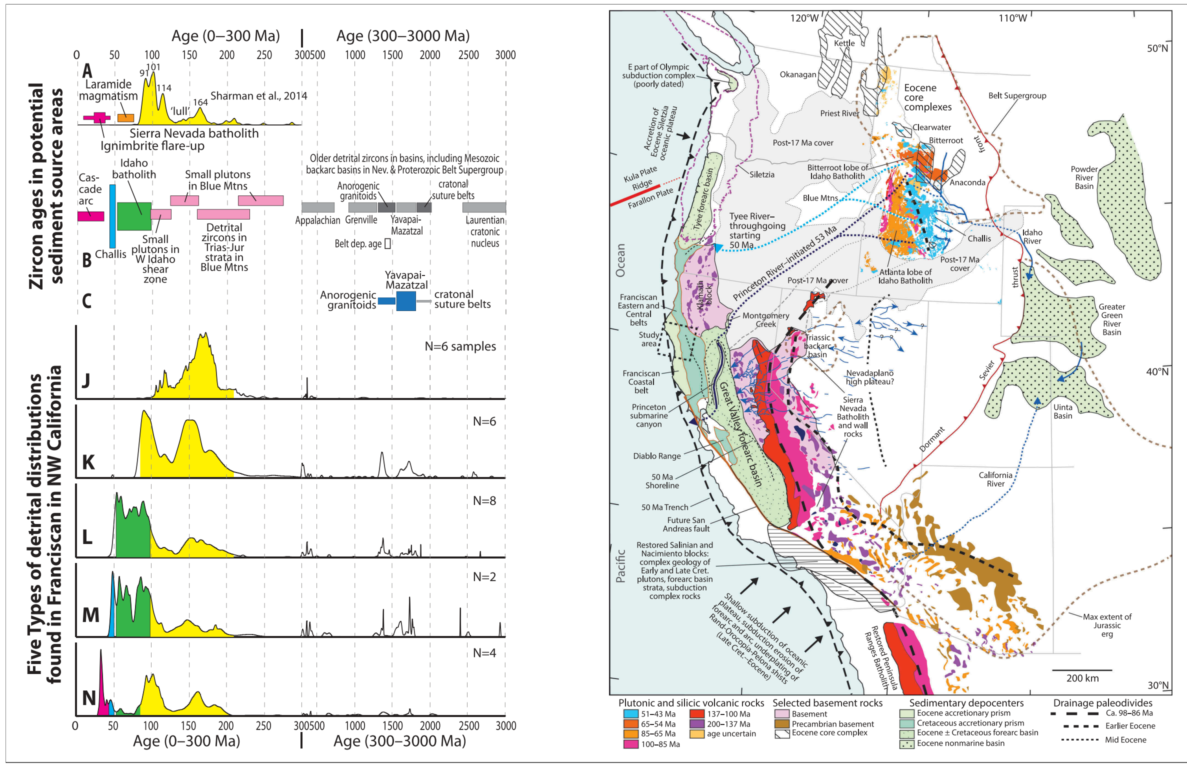
Wakabayashi, GSA SP 552, 2021



Wakabayashi, GSA SP 552, 2021



The changing Sierran contribution is echoed in the forearc sediments. Note that Grenville zircons pretty rare.



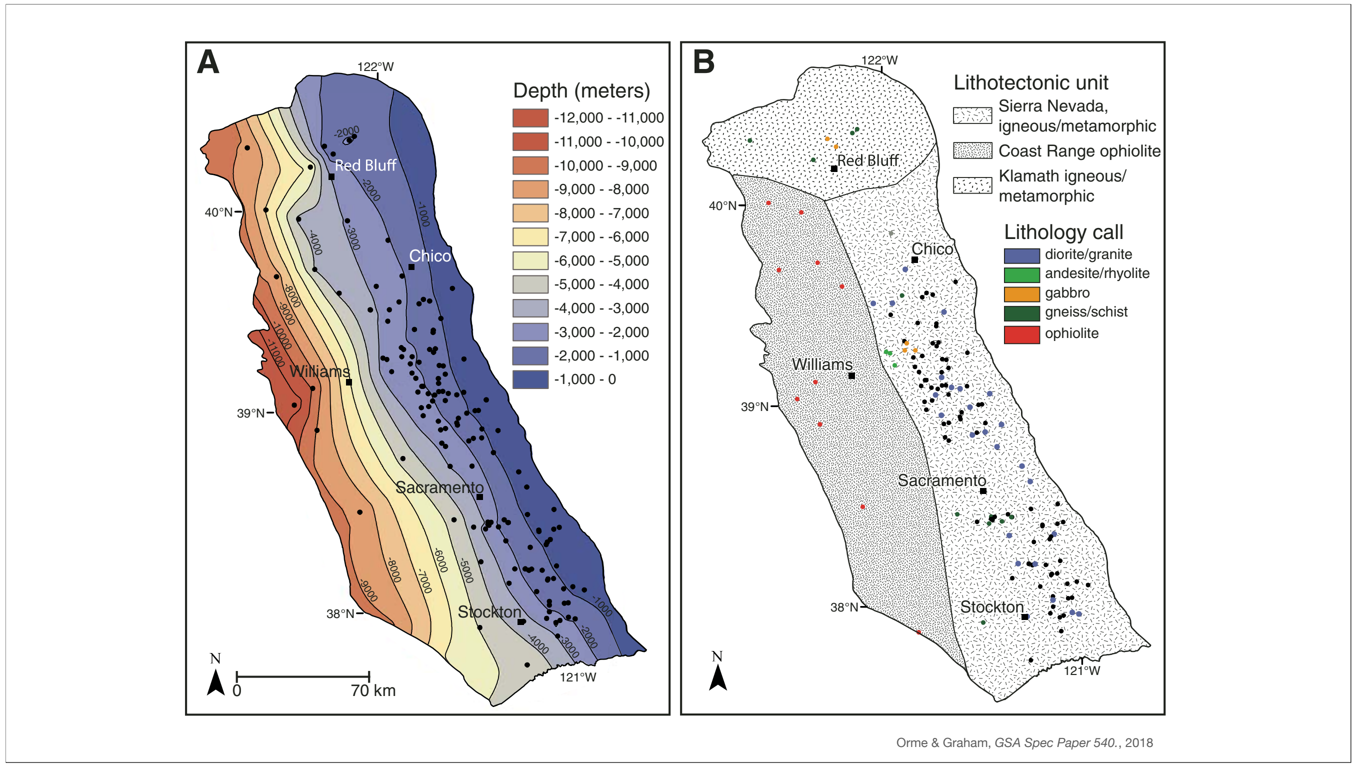
Dumitru et al.,
Intl. Geol. Rev.,
2015

Implications for other areas

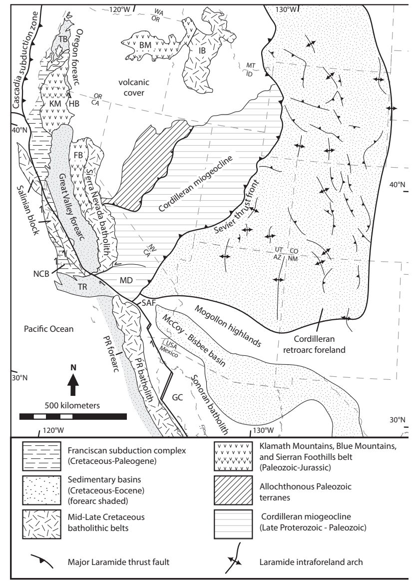
While there are pauses in accretion, subduction was continuous

According to Wakabayashi, there is no syn-Franciscan dextral shear

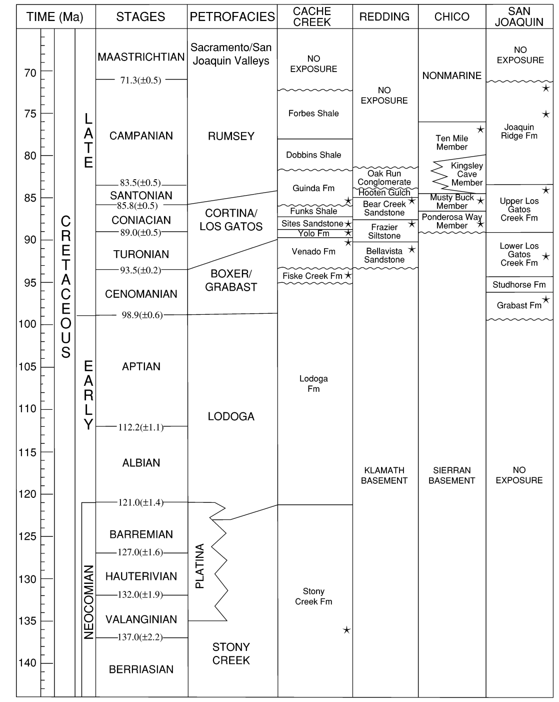
Zircons to date are not requiring an exotic source (e.g., Insular ST); indeed suggest little input from backarc.



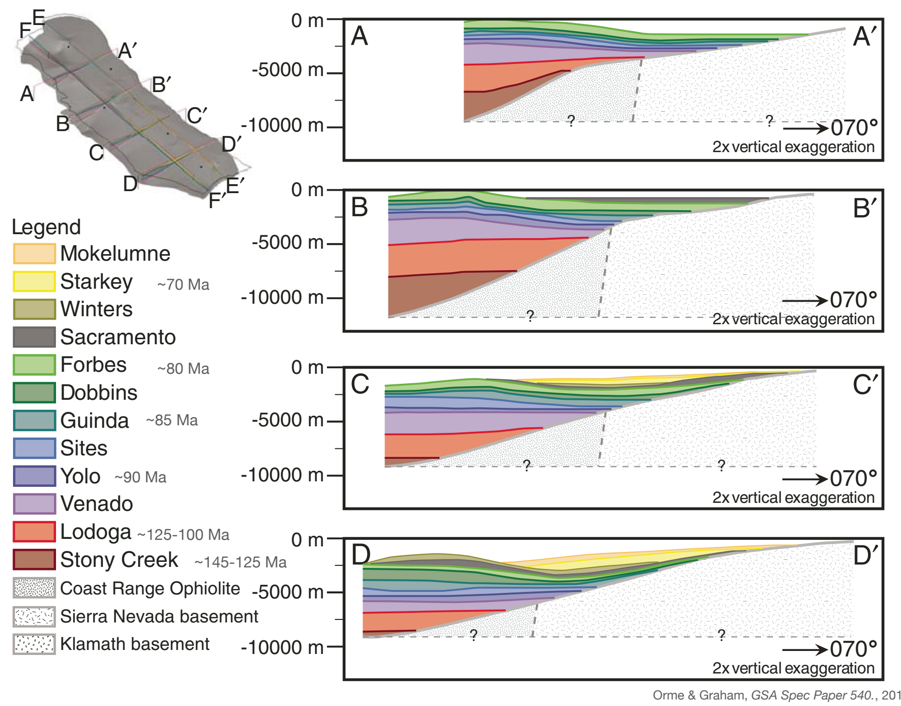
Overview of what the northern part of the basin is currently like. Note that the basement from cores is largely Sierra arc (which a lot of papers get wrong).



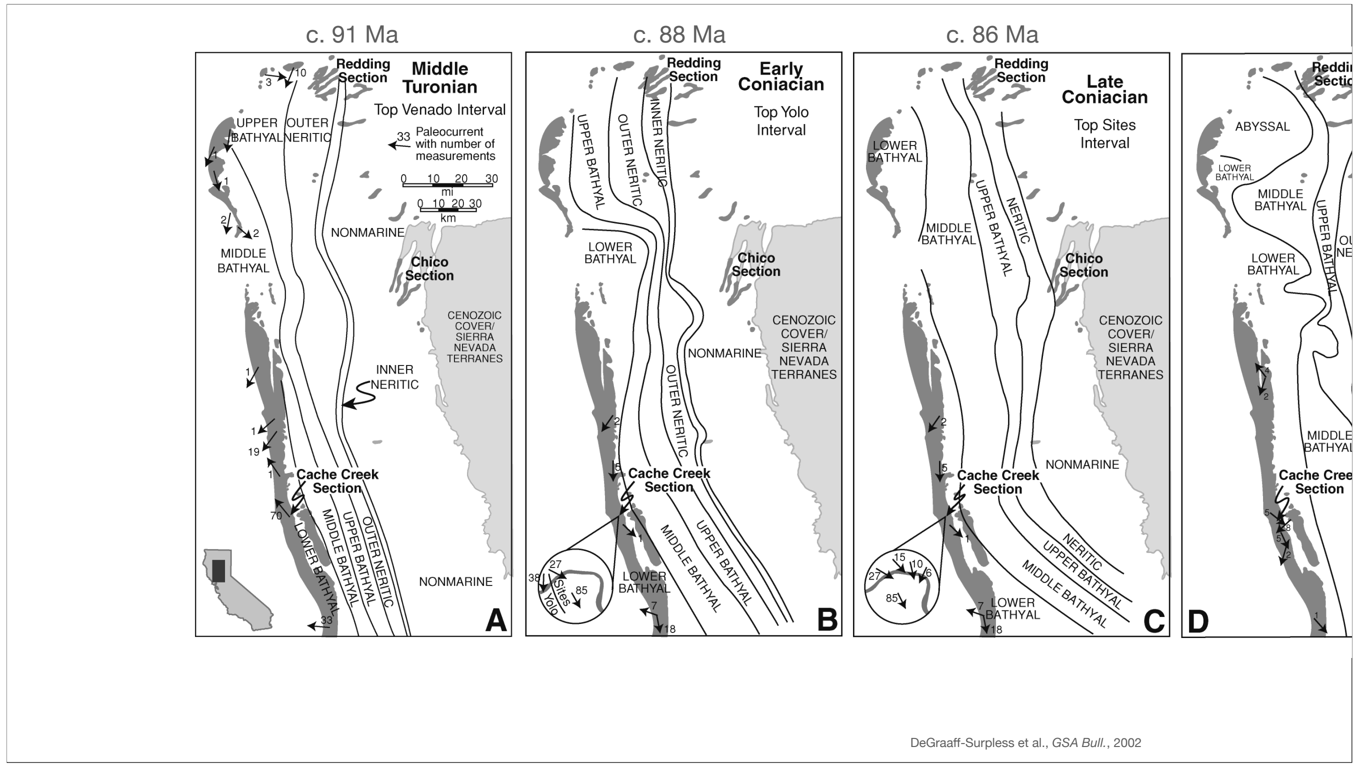
Sharman et al., *GSA Bull.*, 2015



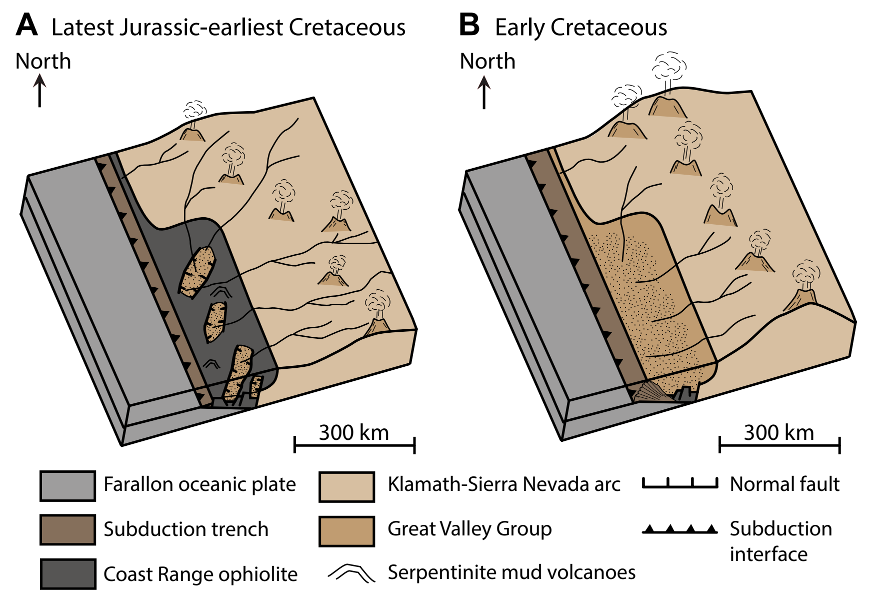
DeGraaff-Surpless et al., *GSA Bull.*, 2002



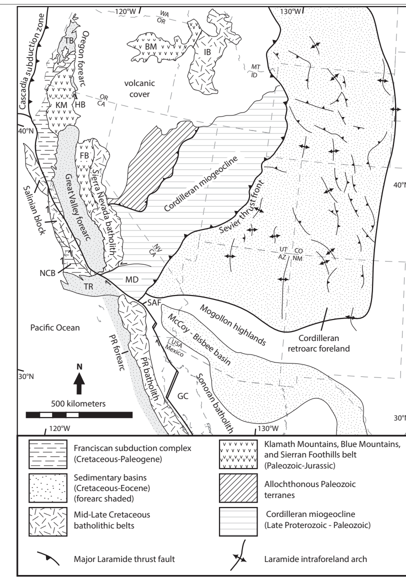
Sediments onlap to the Sierra to the east

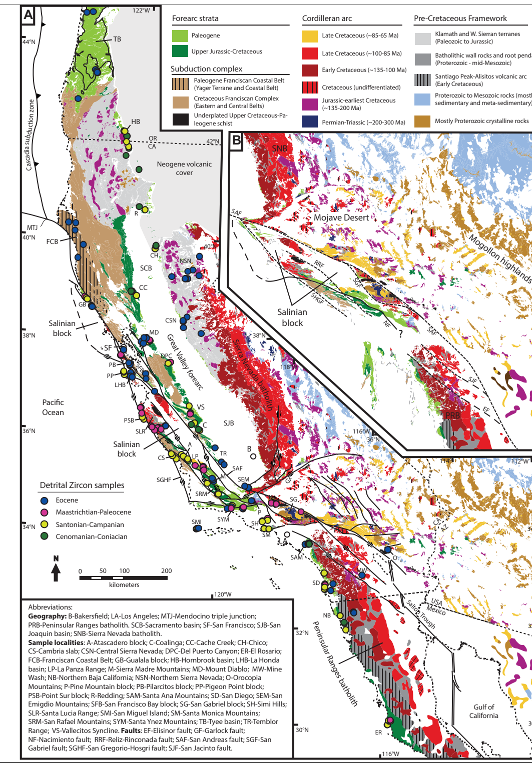


In addition to the onlap, facies deepen rapidly going offshore—and deepen through time as sediments onlap to Sierra

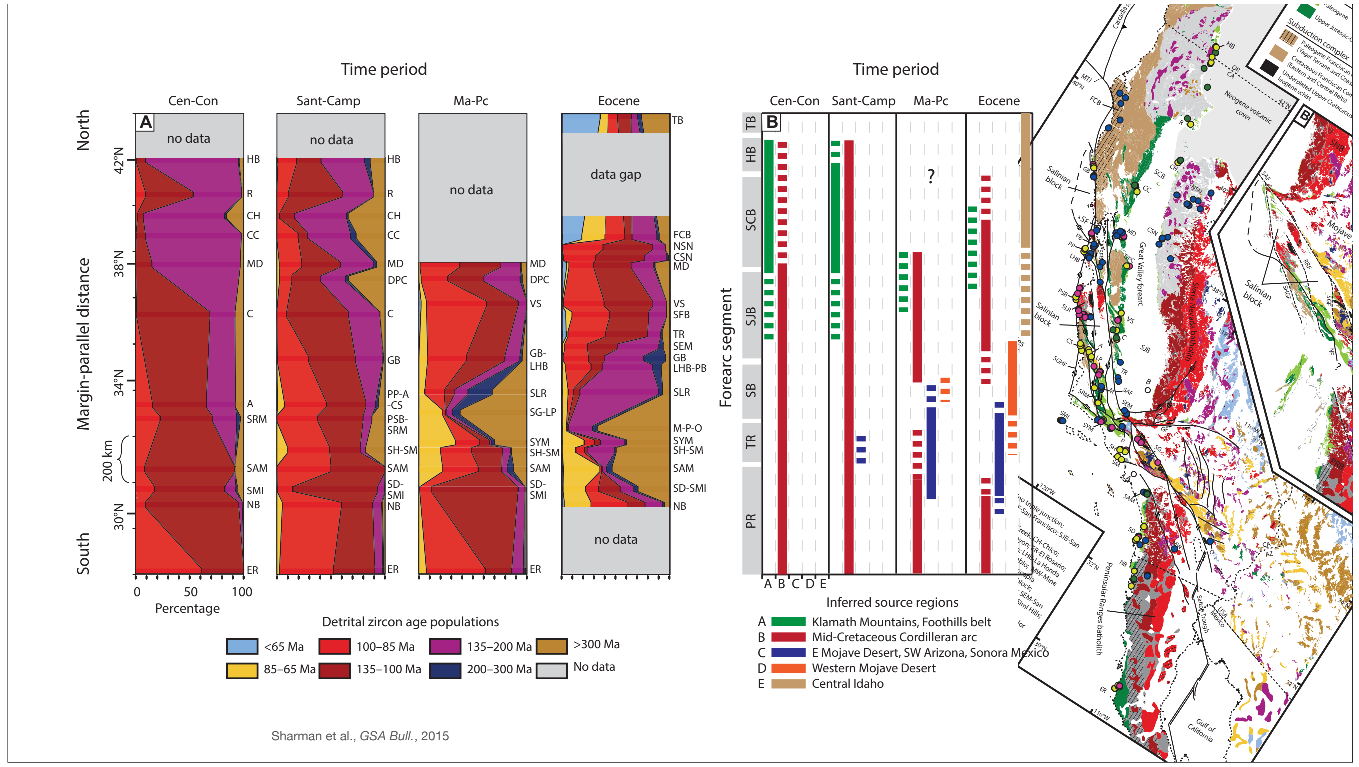


Orme & Surpless, *Geology*, 2019

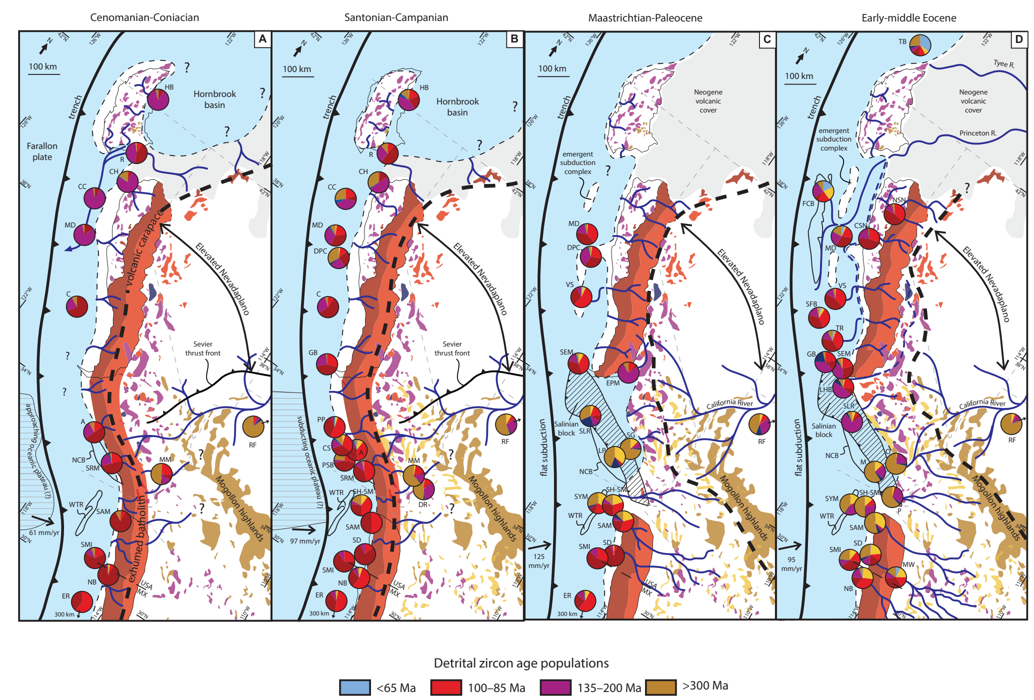




Sharman et al., *GSA Bull.*, 2015

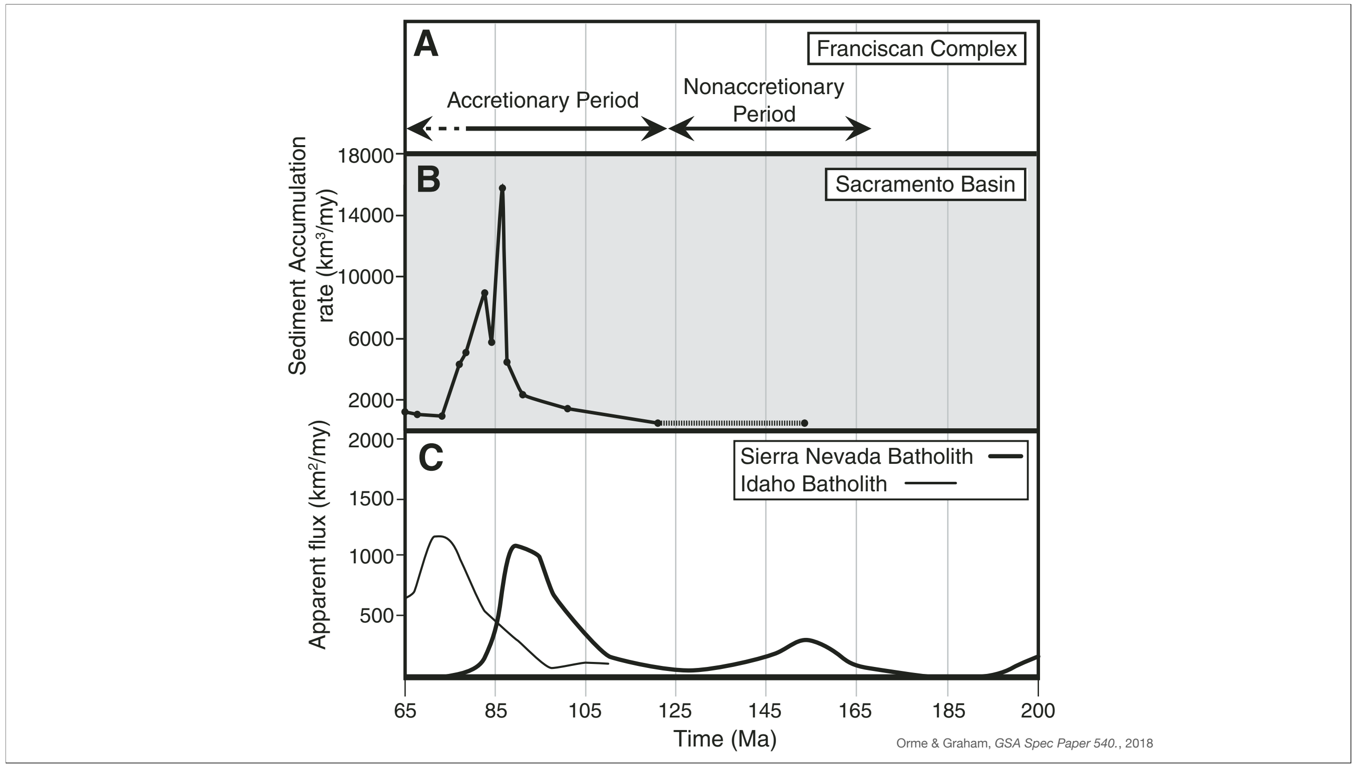


Compilation of a lot of detrital zircons



Sharman et al., *GSA Bull.*, 2015

…leads to ability to infer some paleogeography



Most sedimentation in the Sacramento Valley from Sierra eroding—generally overlaps with time when Franciscan was accumulating…