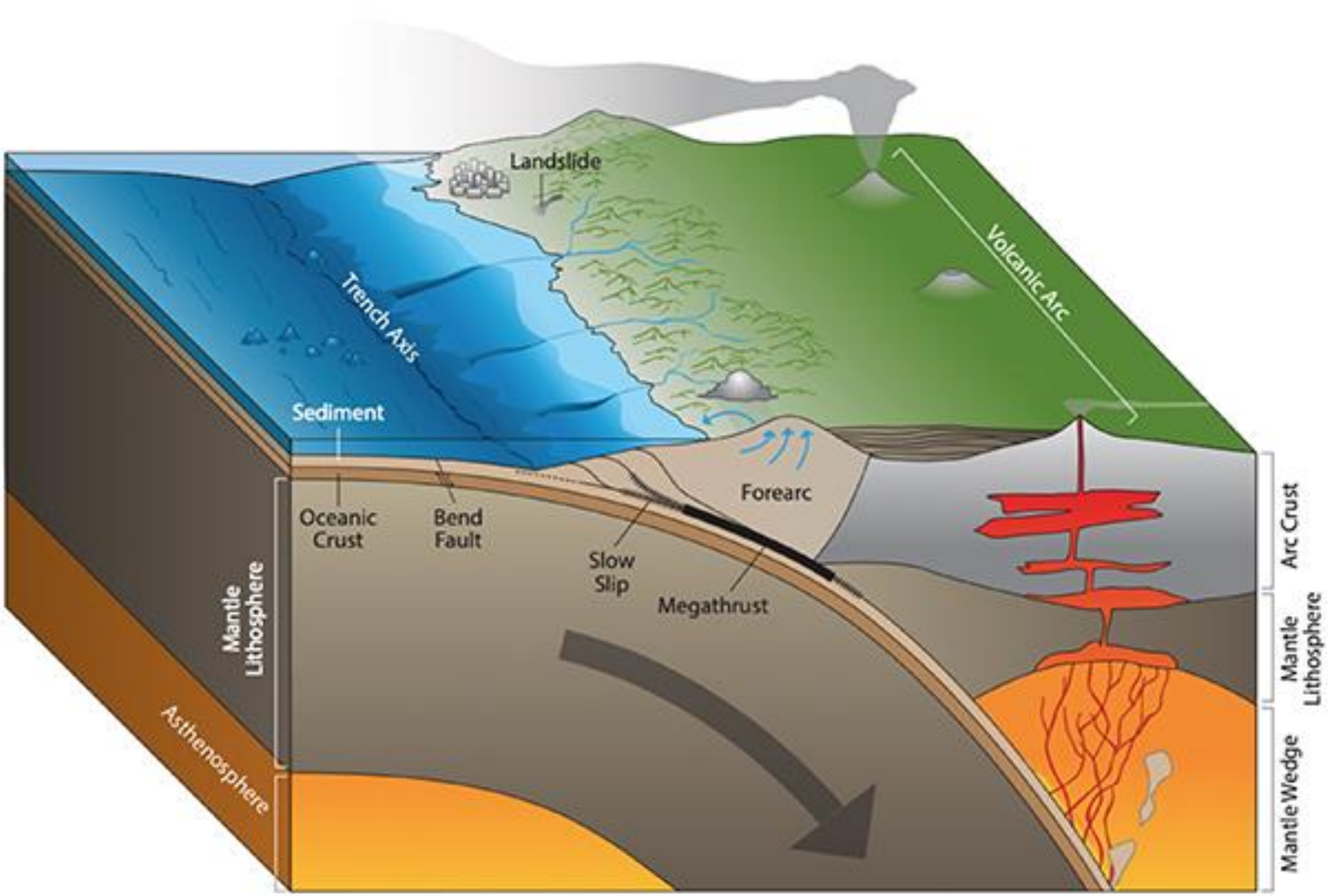
Geophysical Observations

What can we use to constrain the processes?



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- ***Direct geological observations***
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  - Margin shape
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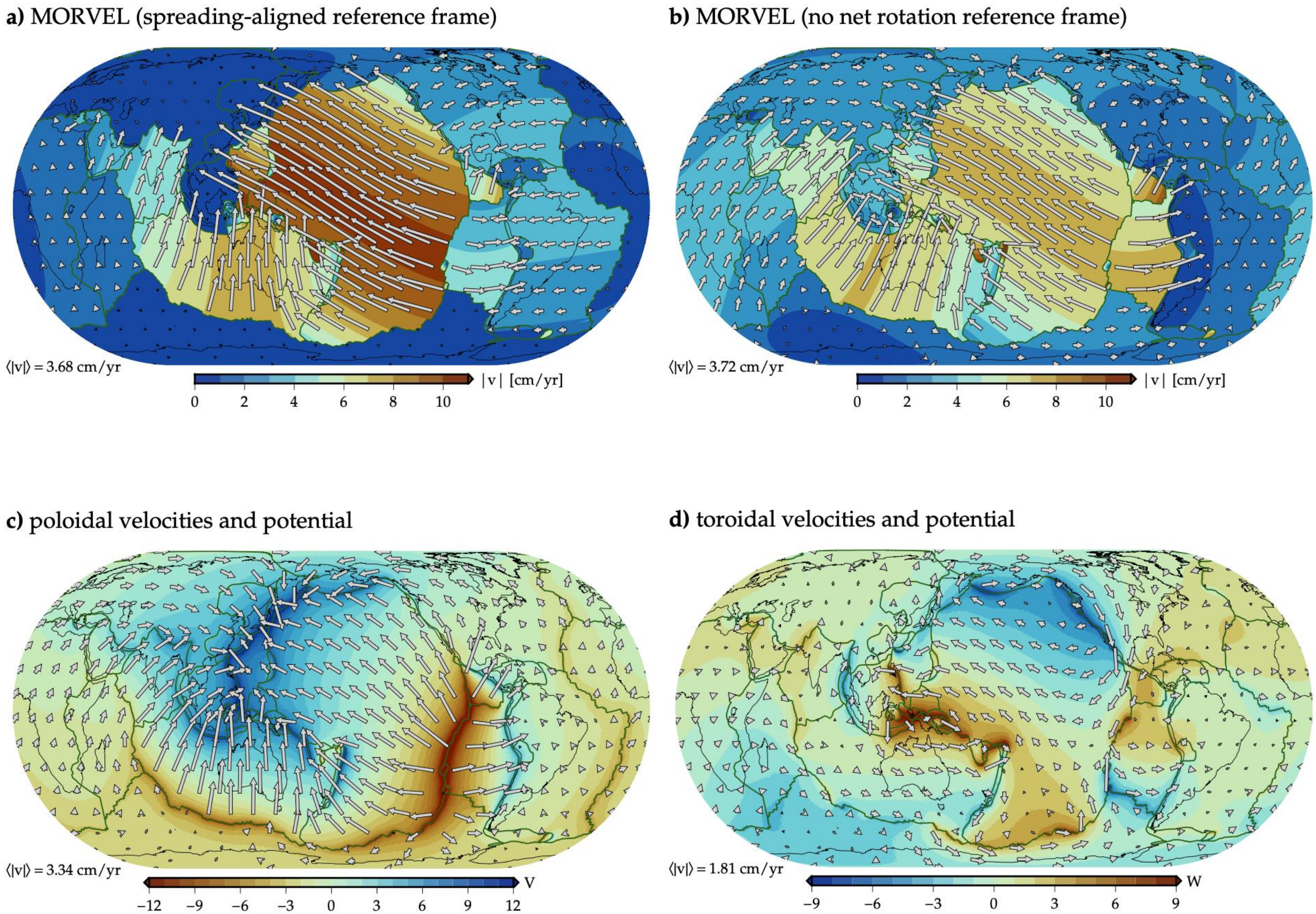
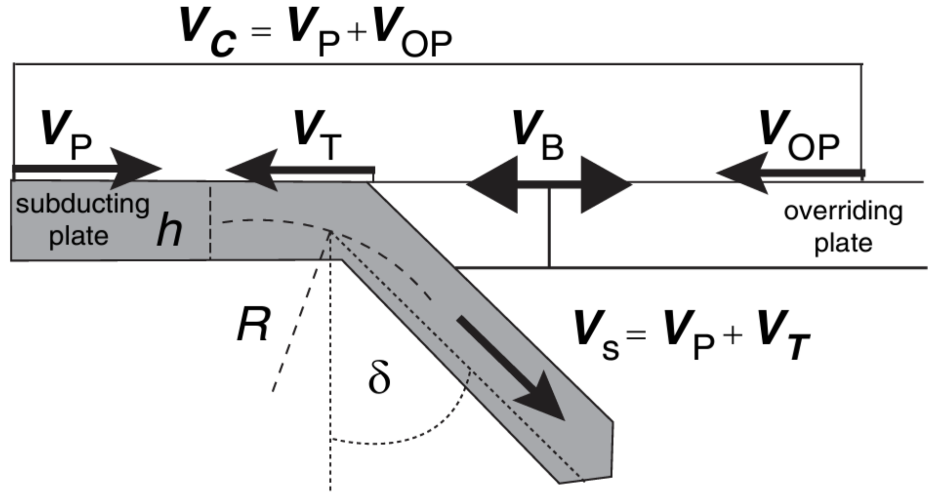
Plate velocities

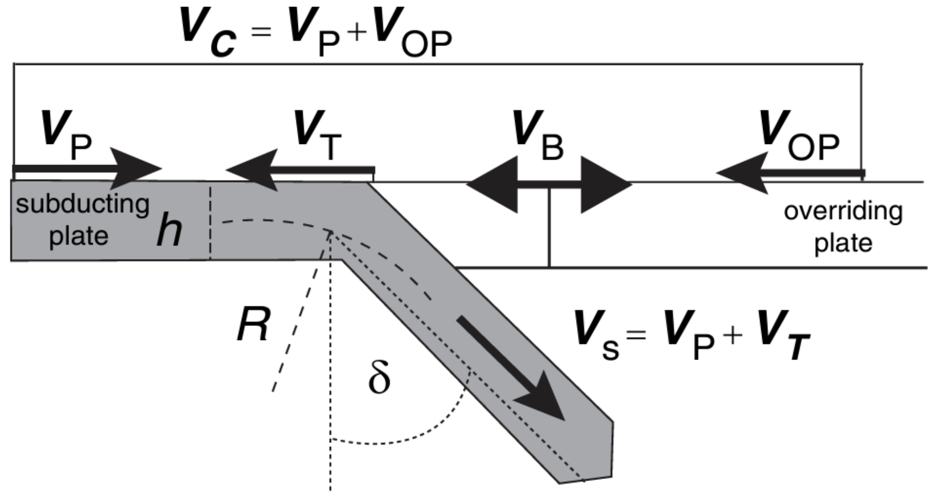


MORVEL56 (*Argus et al.*, 2011)

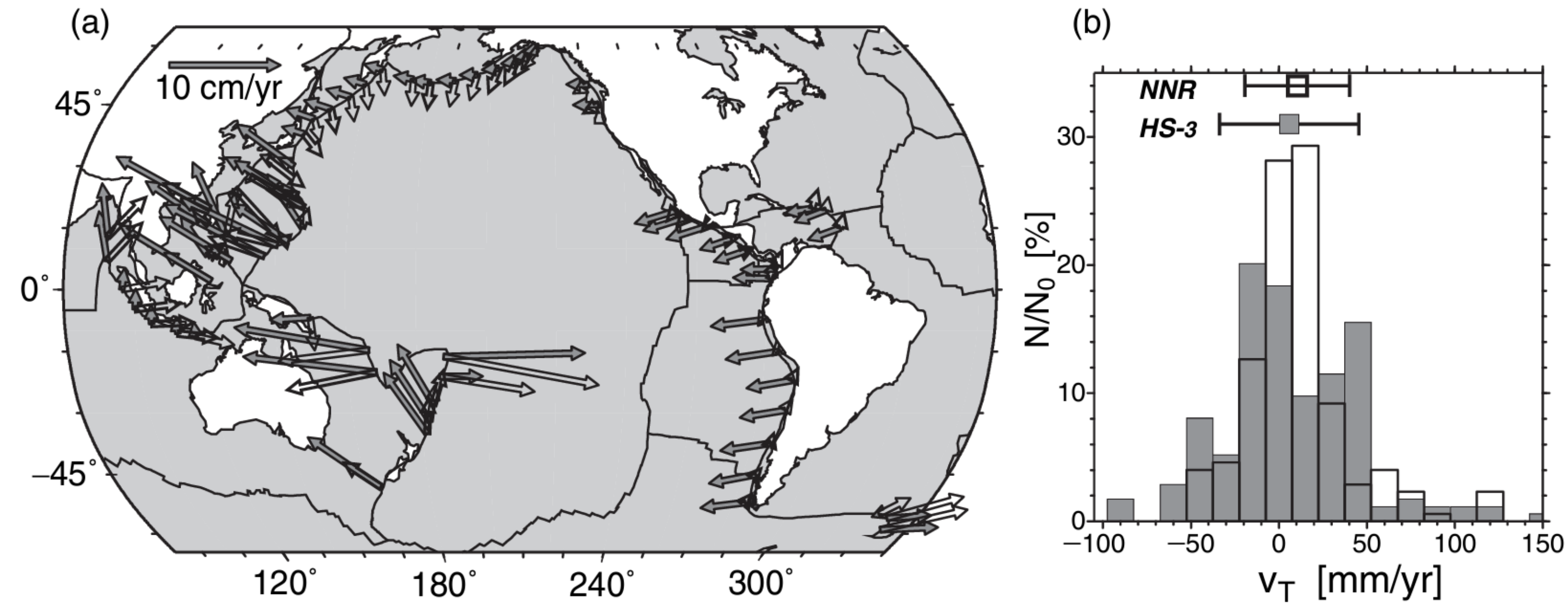
Becker & Faccenna, 2009

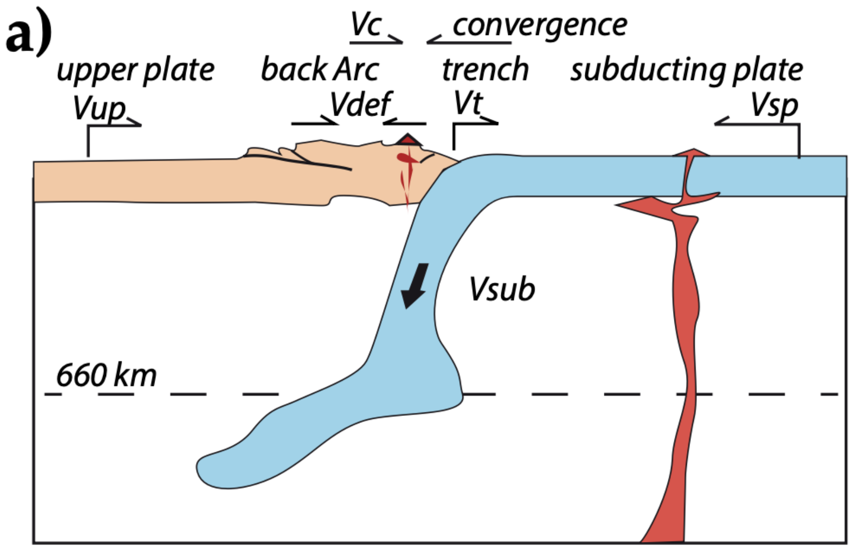


Becker & Faccenna, 2009

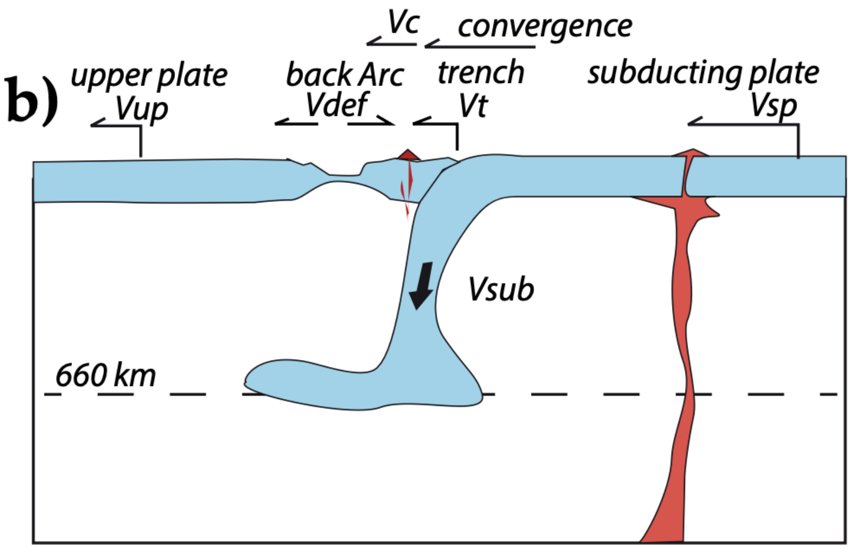


V_T is reference frame dependent! *(dark = hs-3)*

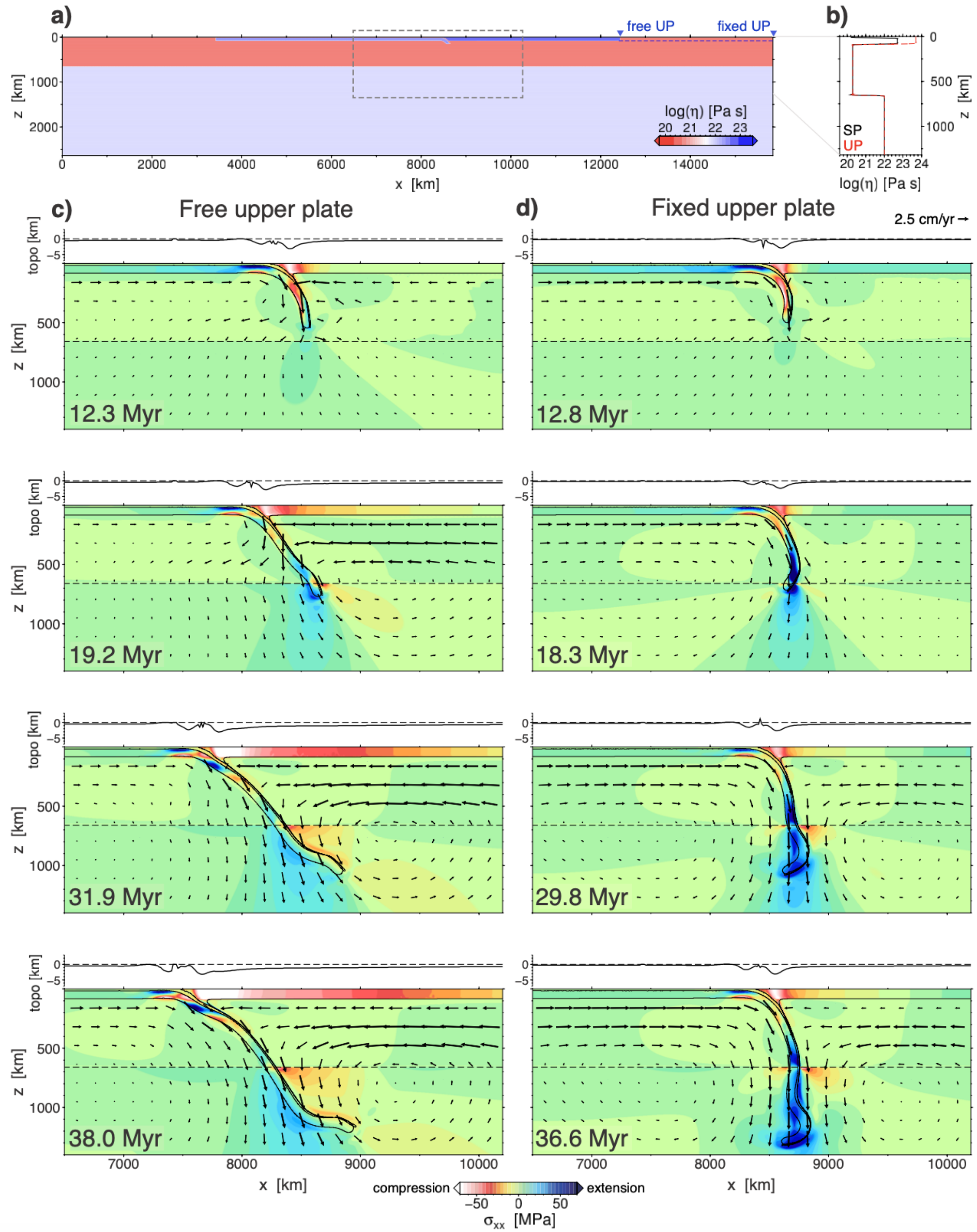




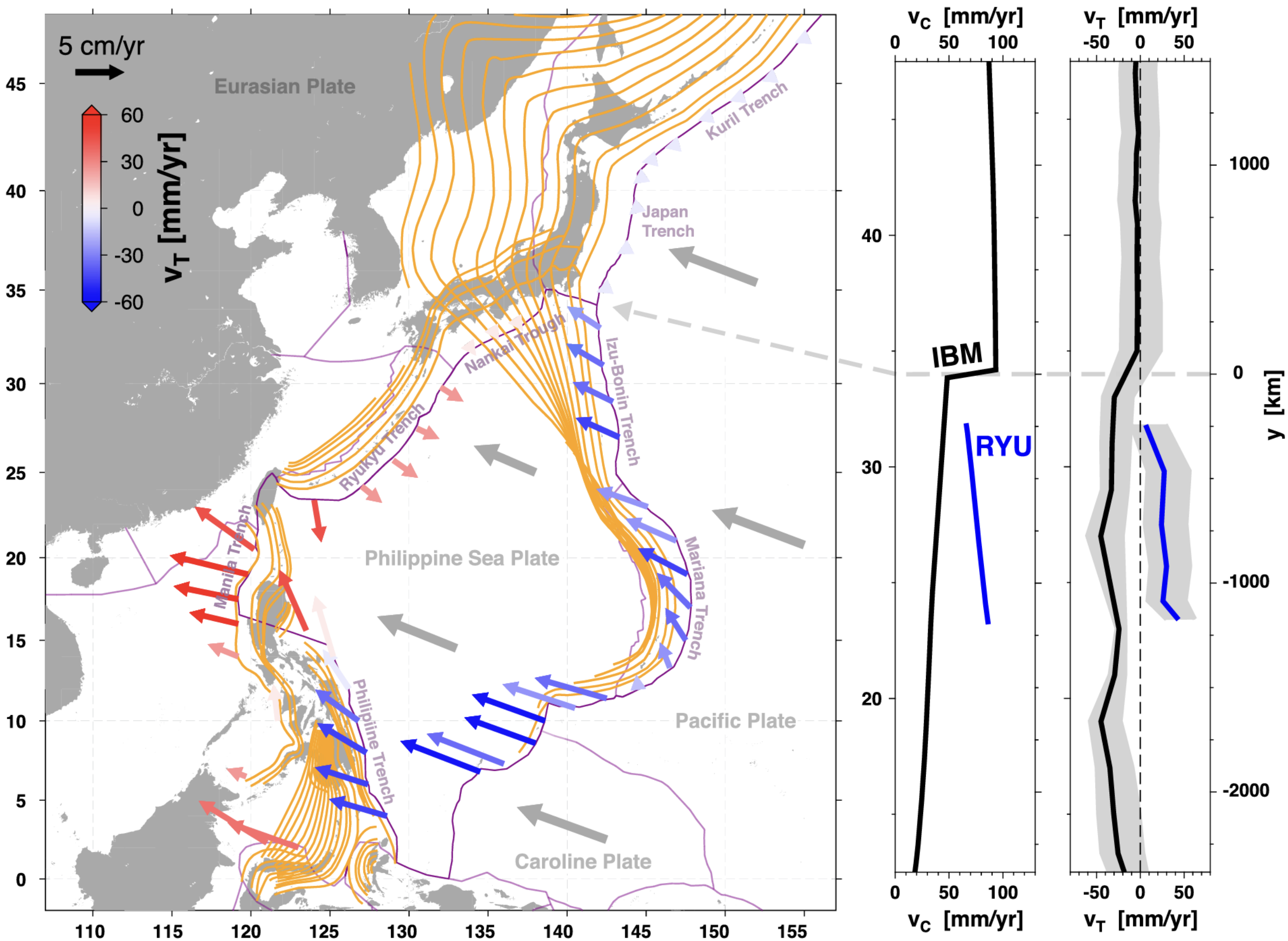
Andean-type



Marianas-type

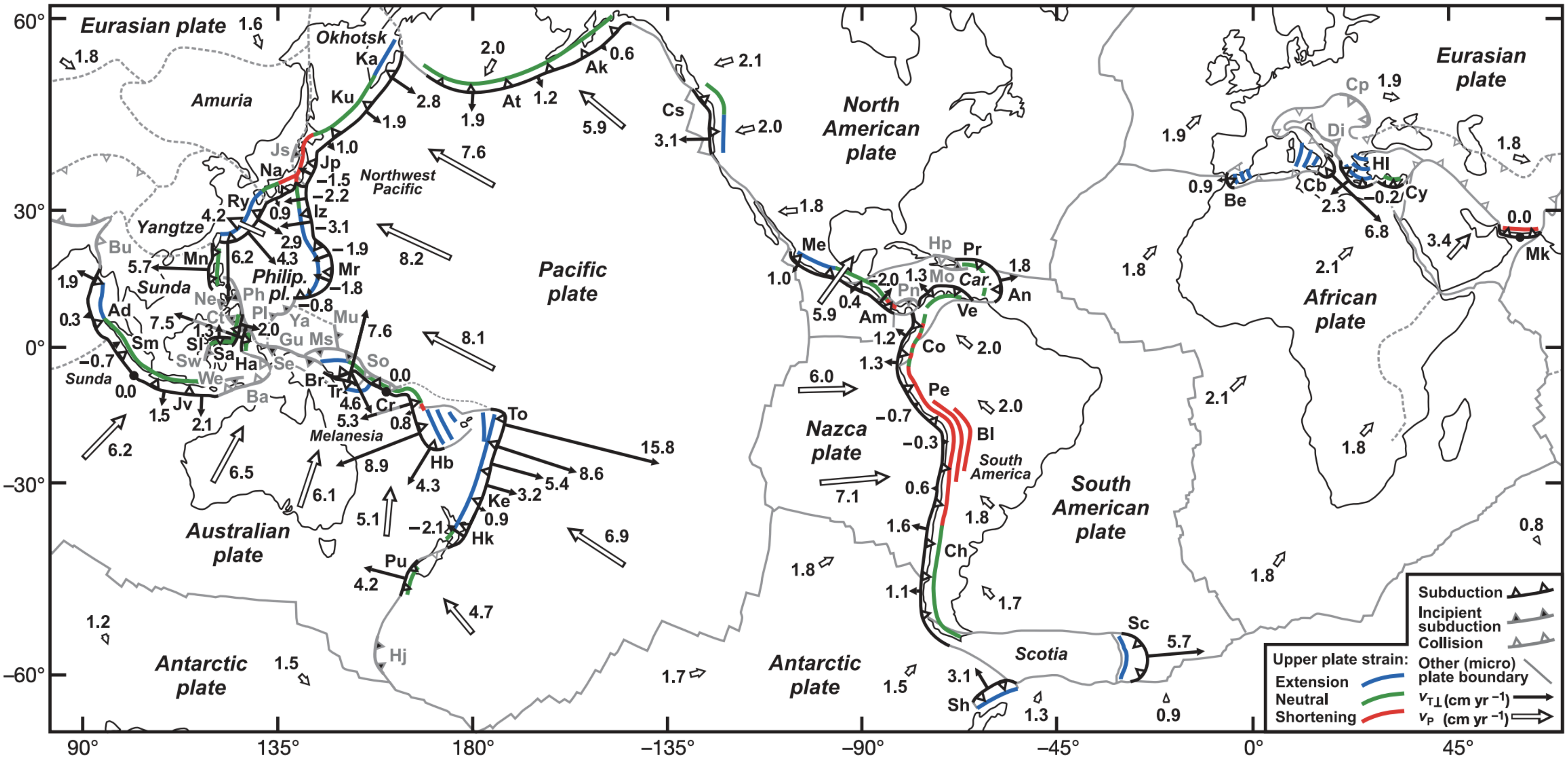


Faccenna et al., 2017



Holt et al., 2018

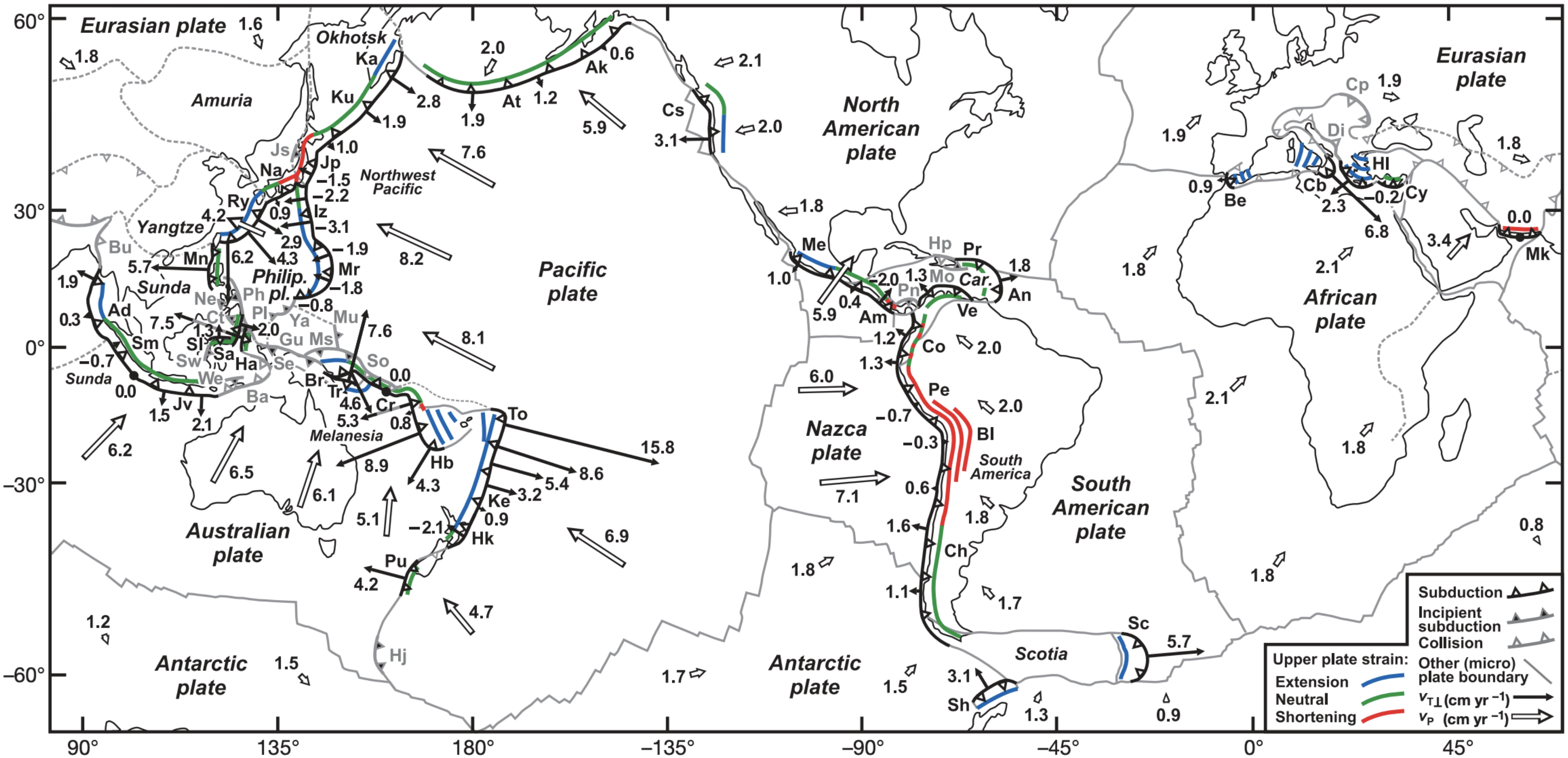
Margin shape



Schellart et al., 2007

Concave vs. convex:

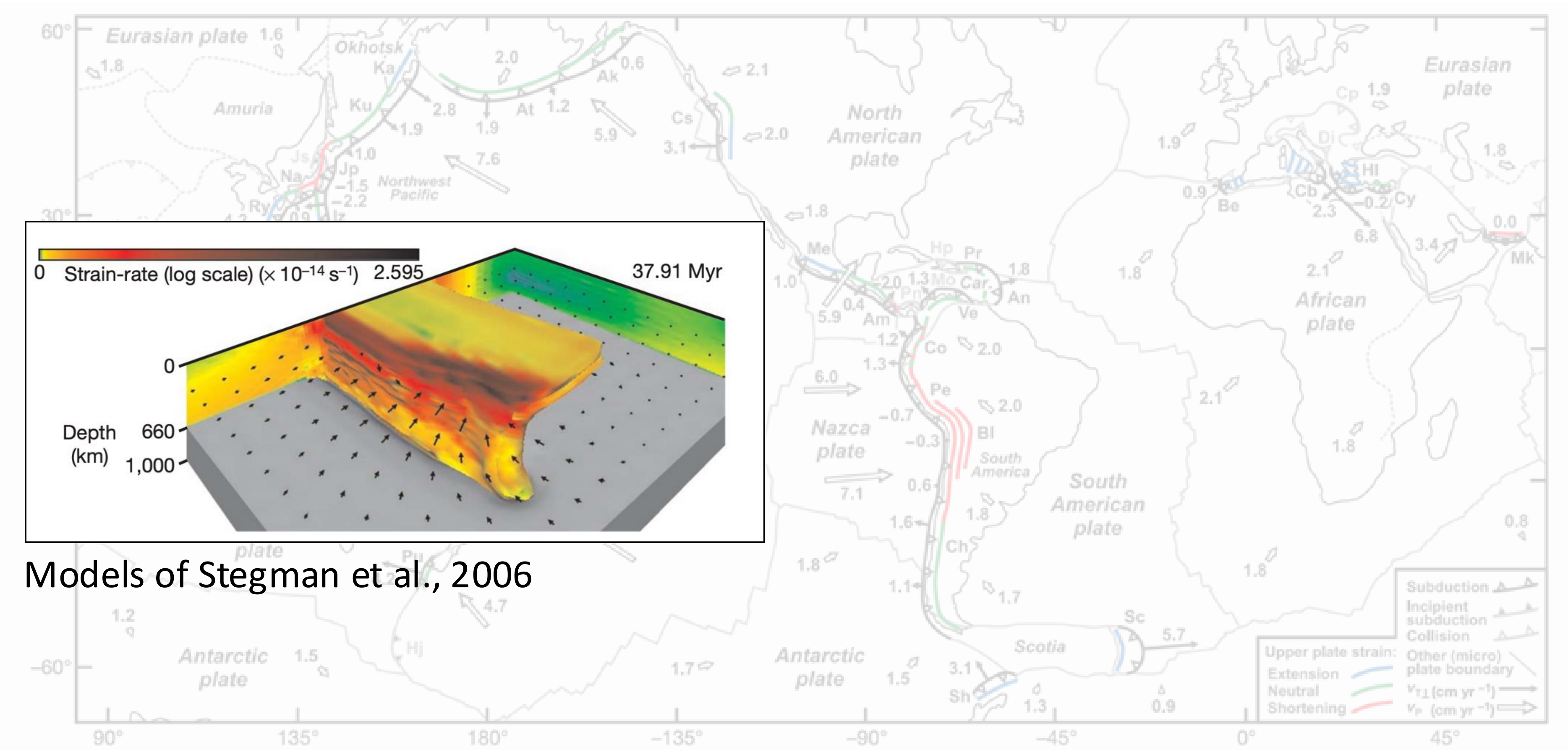
Margin shape



Schellart et al., 2007

Concave vs. convex: ***Controlled by slab width?***

Margin shape



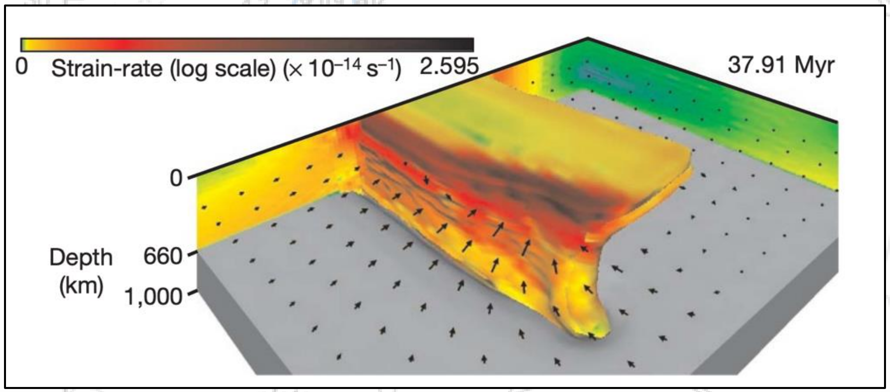
Models of Stegman et al., 2006

Schellart et al., 2017

Concave vs. convex: *Controlled by slab width?*

Margin shape

Schellart et al., 2007



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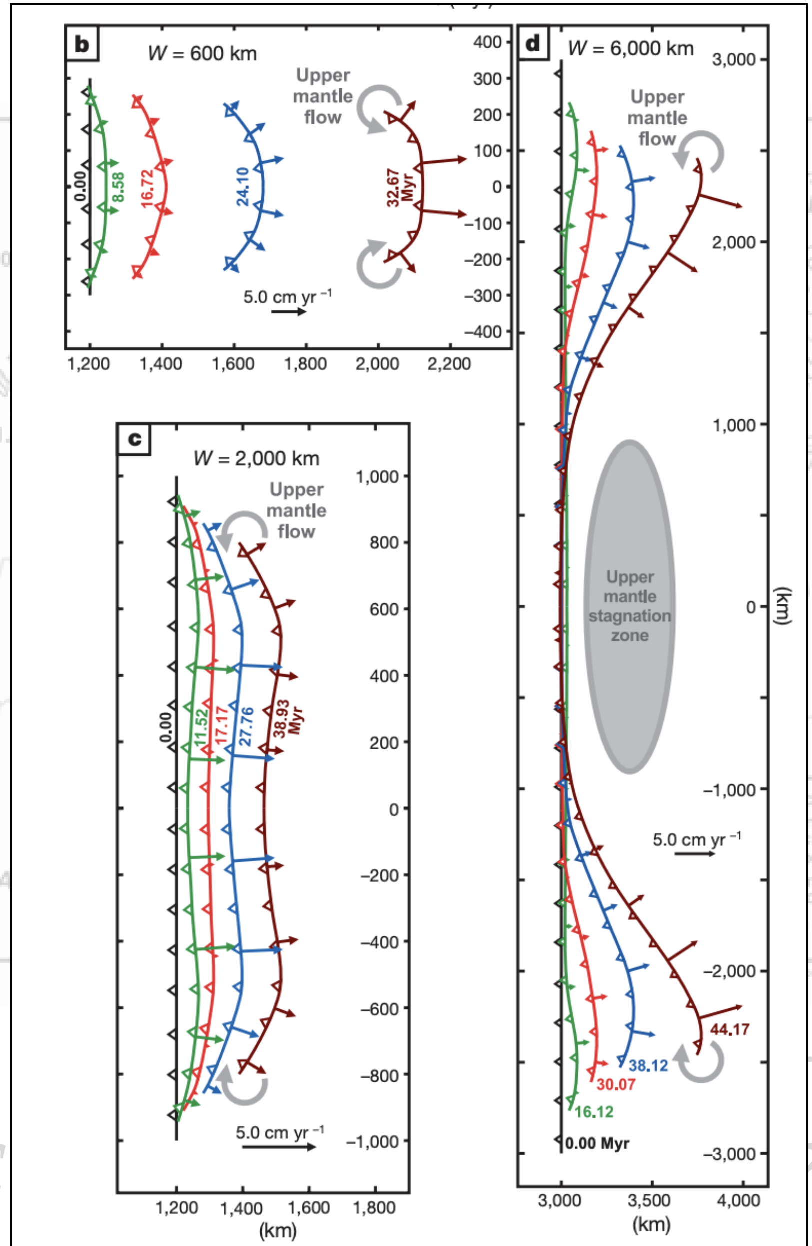
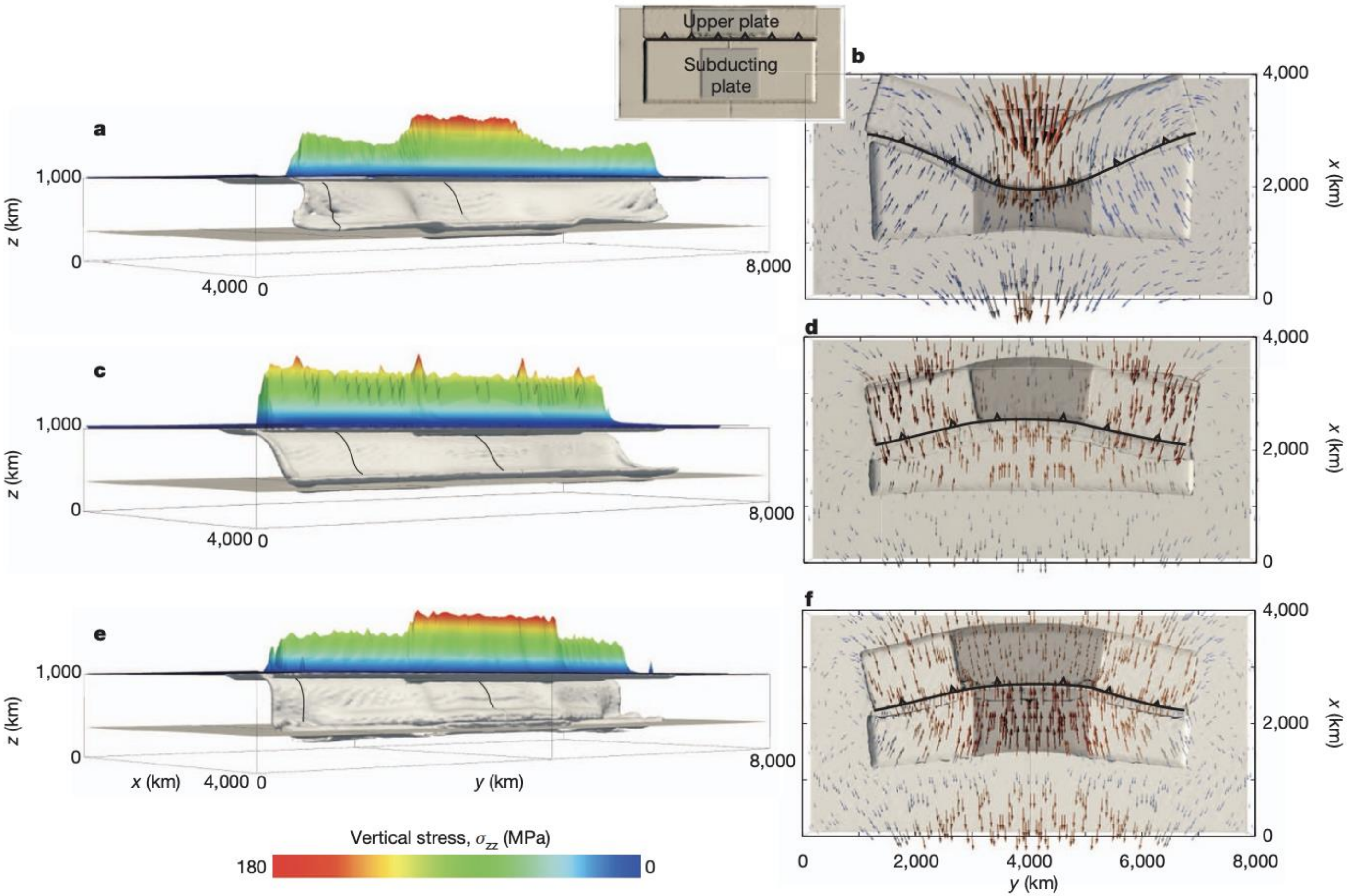


Concave vs. convex: C

, 2017

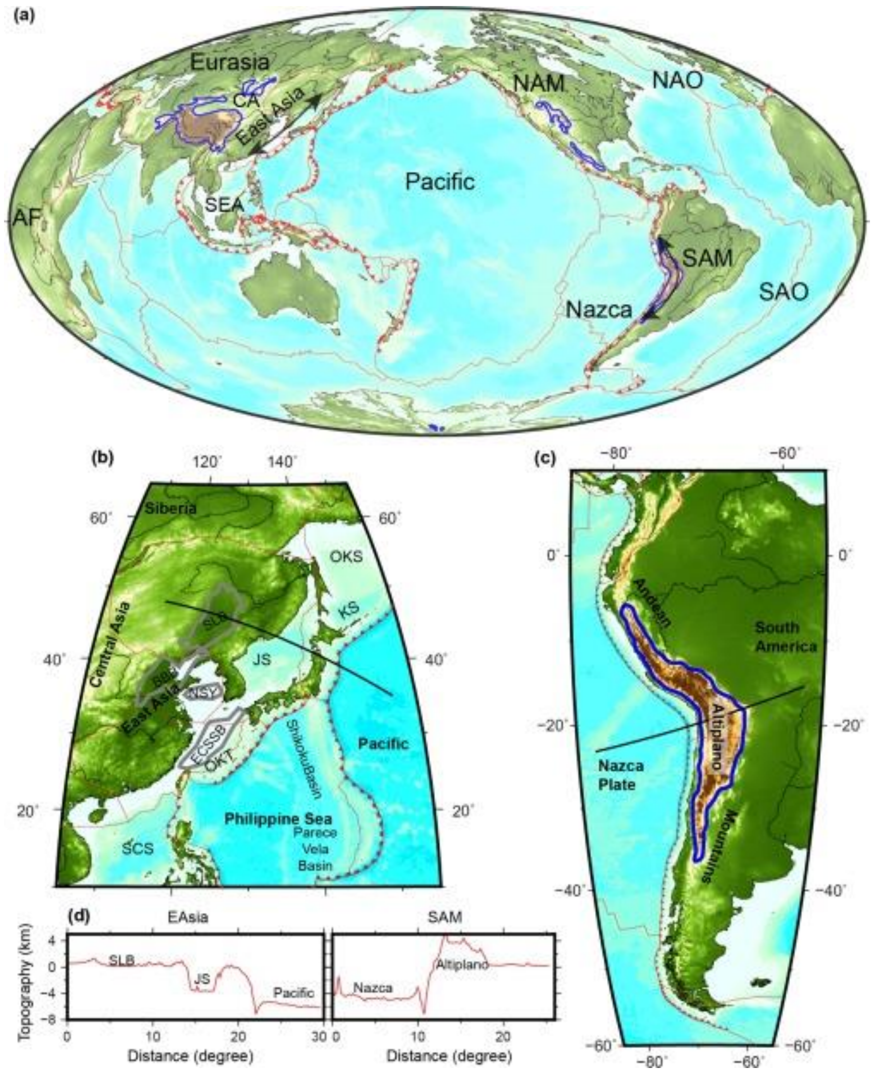
Margin shape

Plenty of other ideas: e.g., structure in upper/lower plates



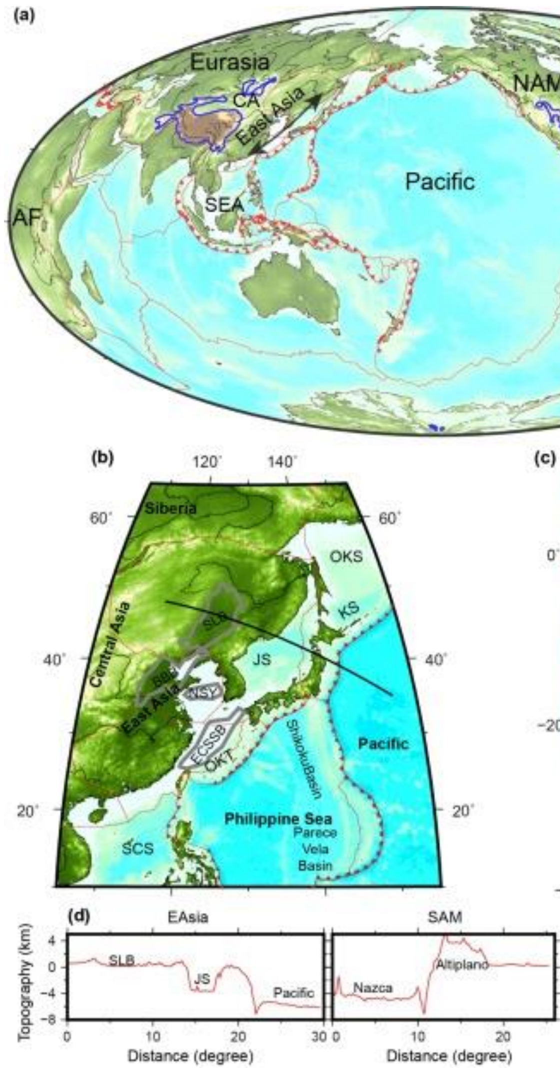
Capitanio et al., 2011

Structures



Yang et al., 2019

Structures



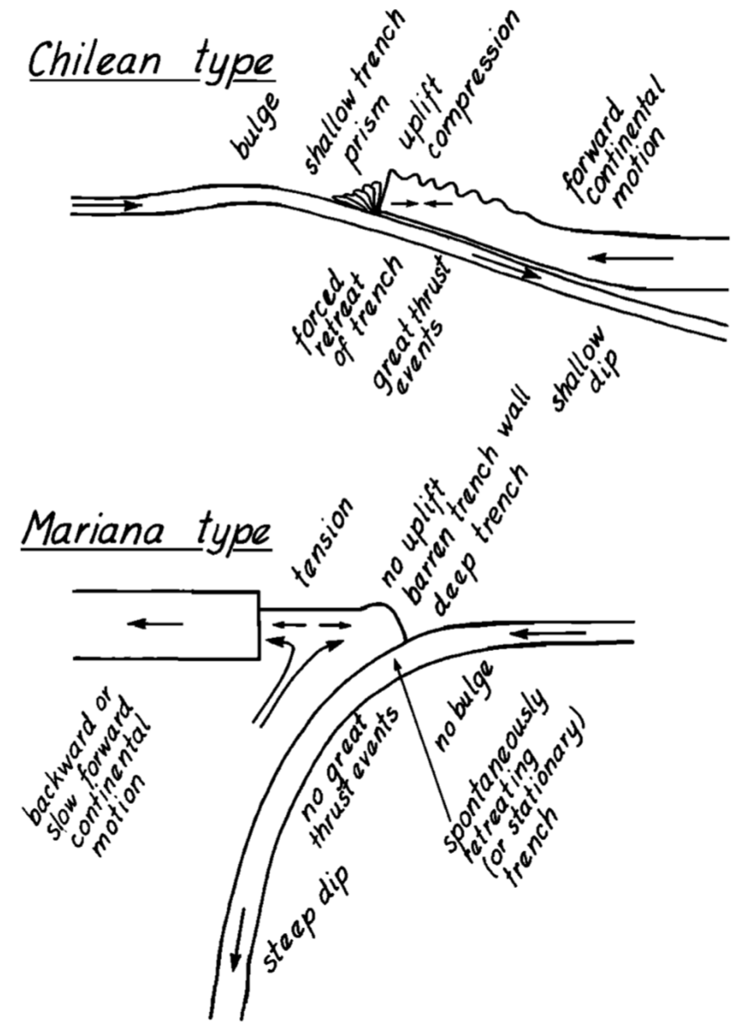
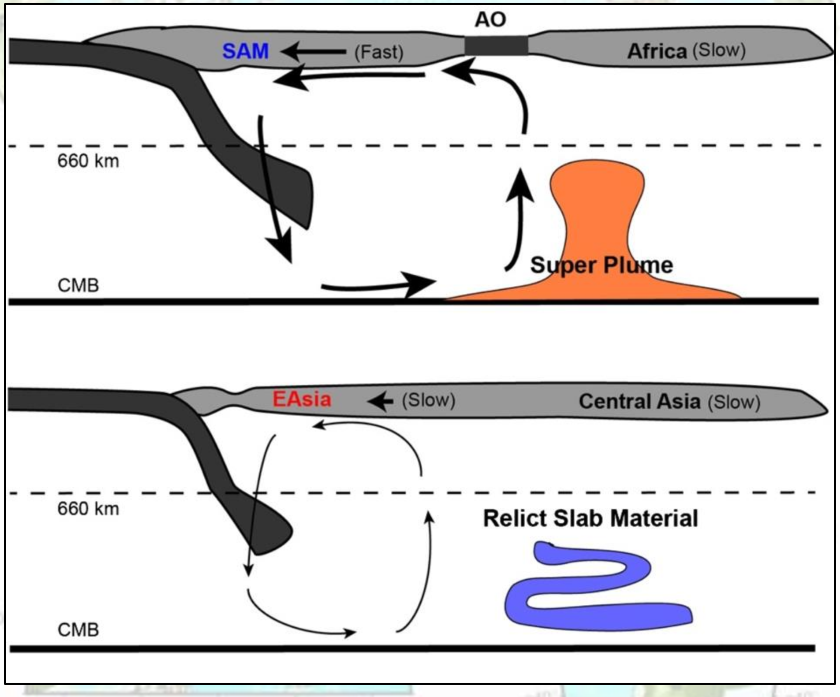


Fig. 7. Two kinds of subduction boundaries.

Yang et al., 2019

Uyeda & Kanamoori, 1979

Structures



Yang et al., 2019

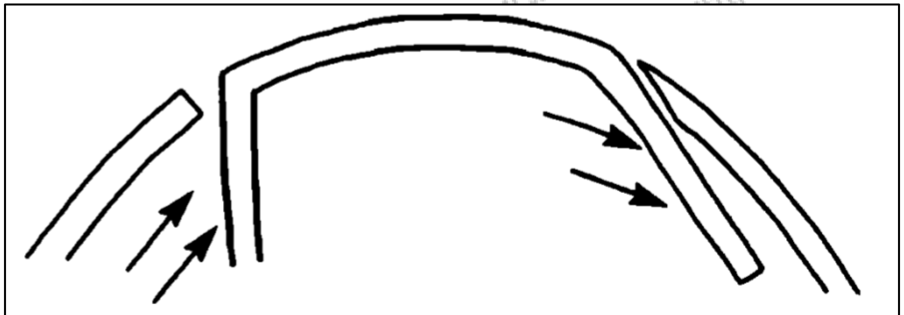
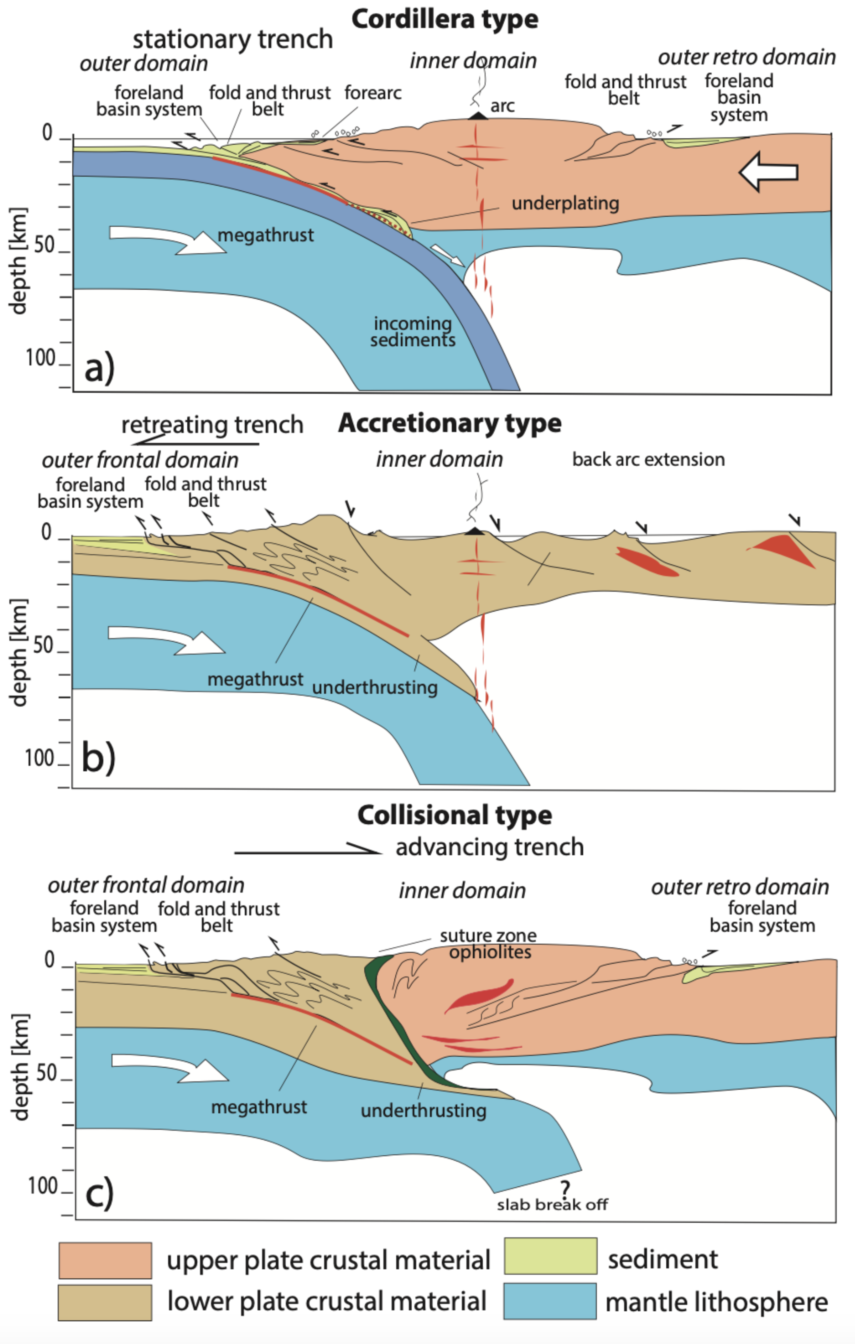


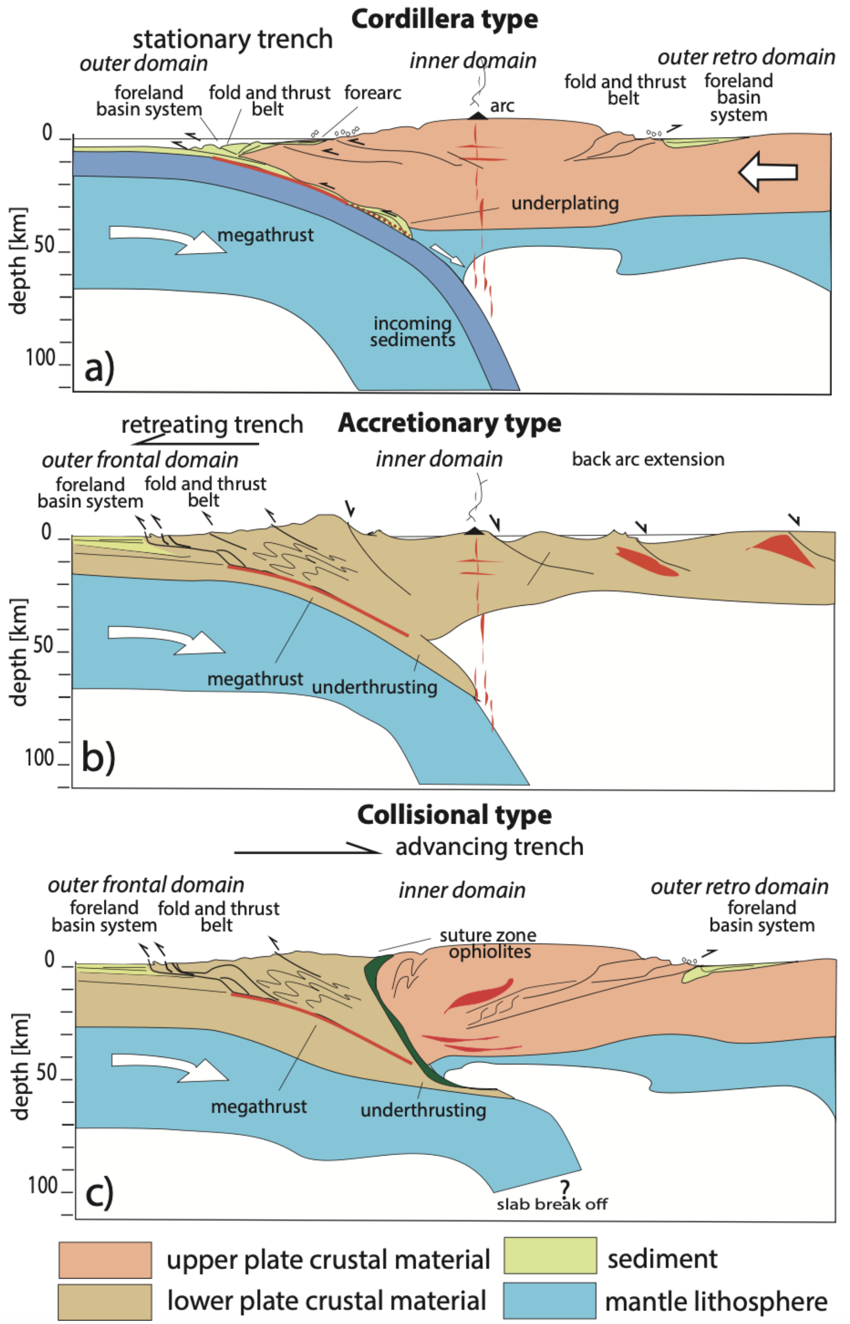
Fig. 11. An interpretation for the east-west asymmetry.

Uyeda & Kanamoori, 1979

Becker & Faccenna: Tectonic Geodynamics



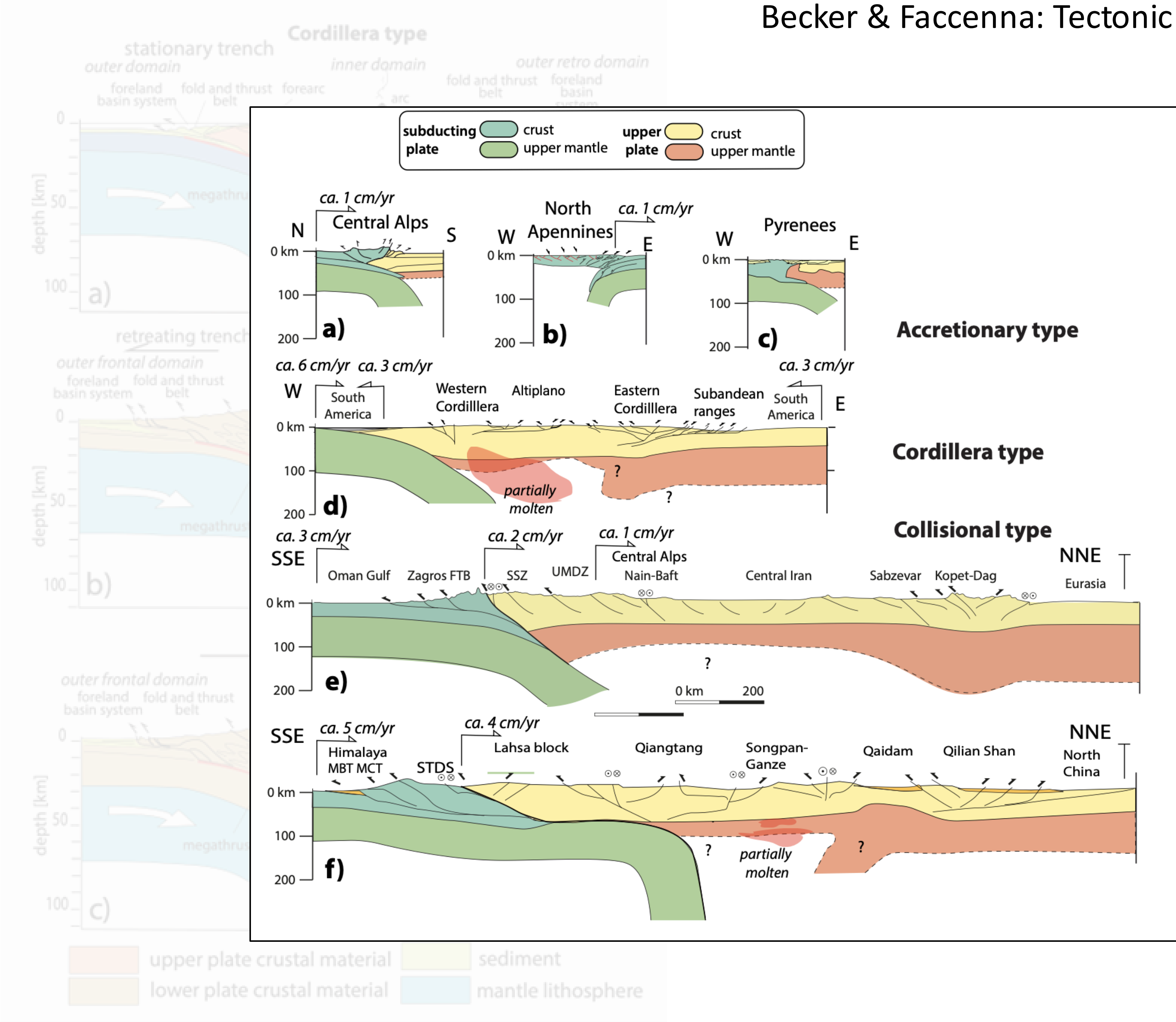
Becker & Faccenna: Tectonic Geodynamics



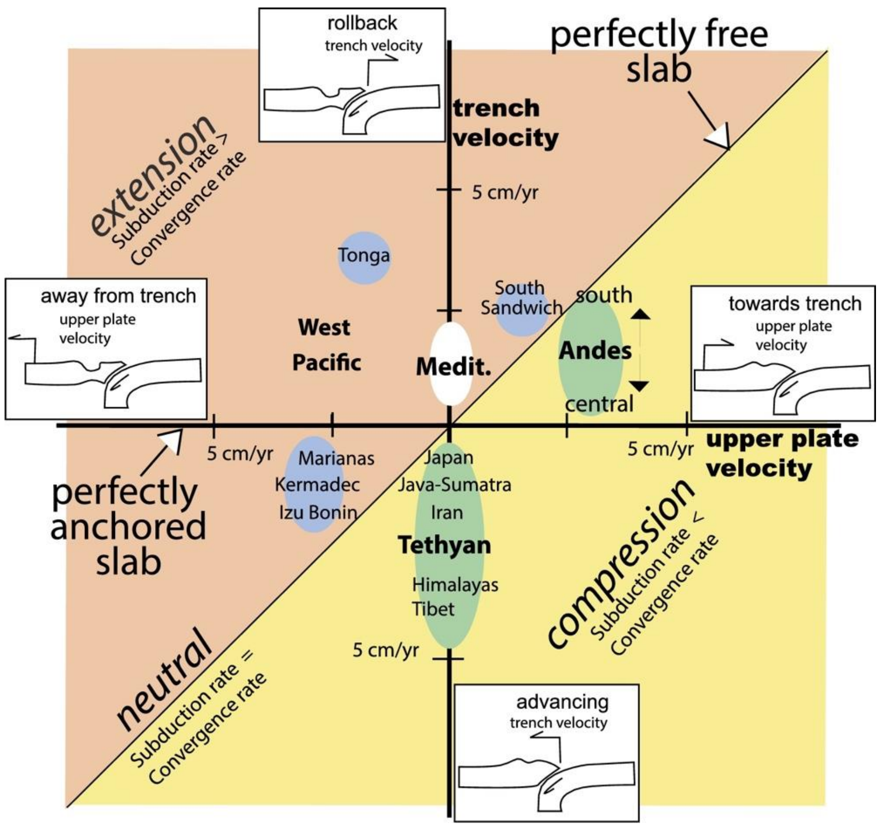
Cordillera type orogeny, e.g., the western side of the Americas, where oceanic subducts beneath continental lithosphere. The material making up the orogenic belt derives mainly from the upper plate.

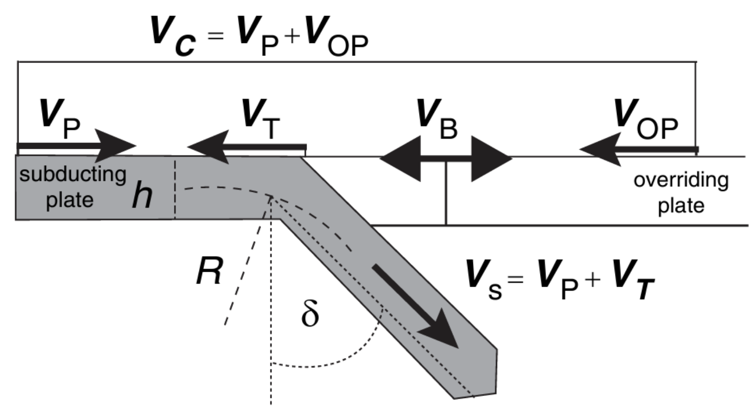
Accretionary type orogeny, or *subduction orogeny*, is well expressed in the Mediterranean, also in Taiwan; mainly transitional or continental lithosphere subducts beneath continental lithosphere. The material constituting the orogenic belt derives mainly from the downgoing plate

Collisional type orogeny, as found in the Himalaya-Tibet, where subduction of oceanic lithosphere has ceased. This orogeny is made of both upper (Tibet) and lower plate (Himalaya) crustal material.


subducting plate
crust
upper mantle
upper plate
crust
upper mantle
ca. 1 cm/yr
N
Central Alps
S
0 km
100
200
a)
North Apennines
ca. 1 cm/yr
W
E
b)
Pyrenees
W
E
c)
Accretionary type
ca. 6 cm/yr
ca. 3 cm/yr
W
South America
Western Cordilllera
Altiplano
Eastern Cordilllera
Subandean ranges
ca. 3 cm/yr
South America
E
?
partially molten
d)
Cordillera type
Collisional type
ca. 3 cm/yr
ca. 2 cm/yr
ca. 1 cm/yr
SSE
Oman Gulf
Zagros FTB
SSZ
UMDZ
Central Alps
Nain-Baft
Central Iran
Sabzevar
Kopet-Dag
NNE
Eurasia
e)
0 km
200
SSE
ca. 5 cm/yr
Himalaya
MBT MCT
ca. 4 cm/yr
STDS
Lahsa block
Qiangtang
Songpan-Ganze
Qaidam
Qilian Shan
NNE
North China
partially molten
f)

Kinematics





Faccenna et al., 2021

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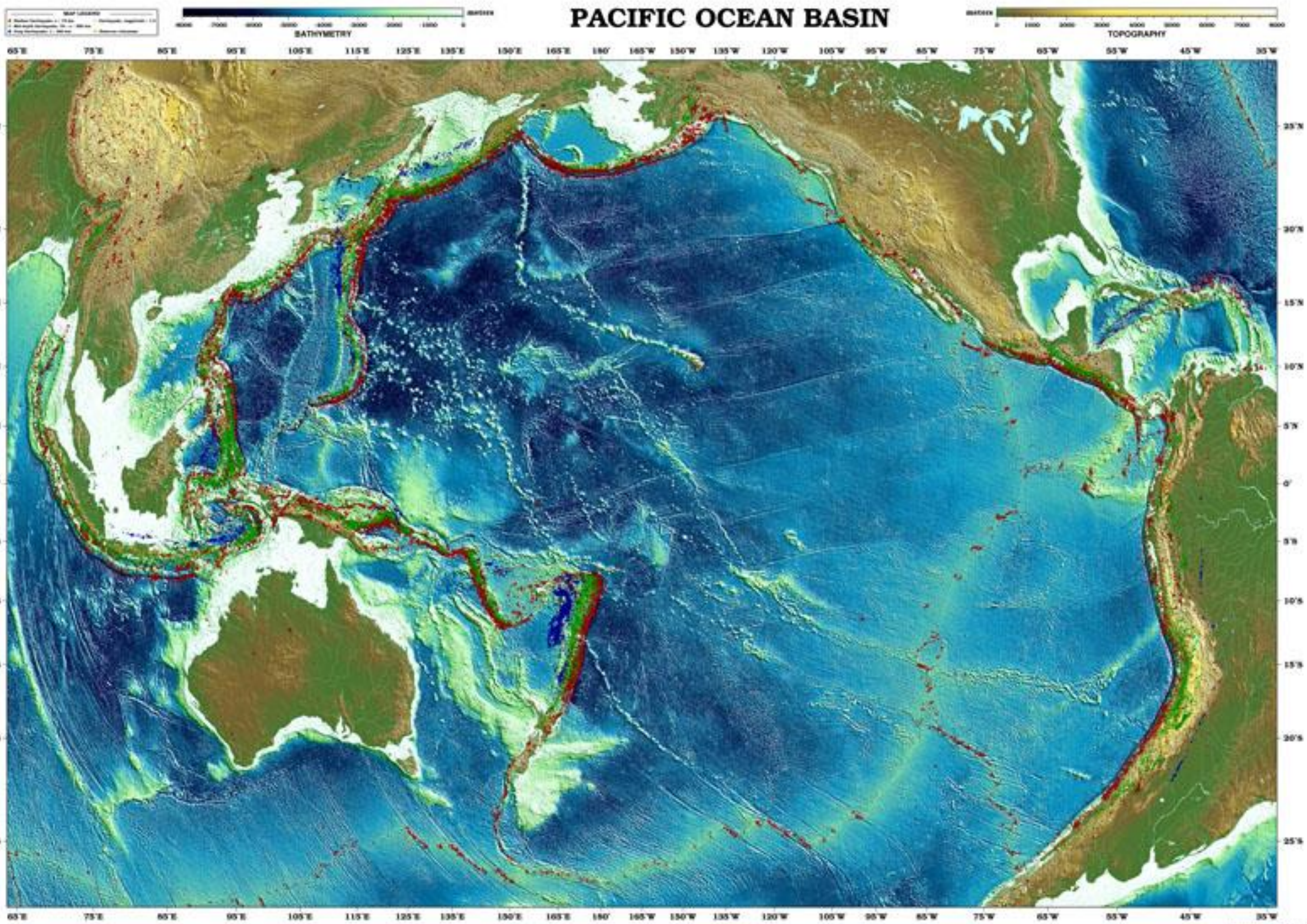
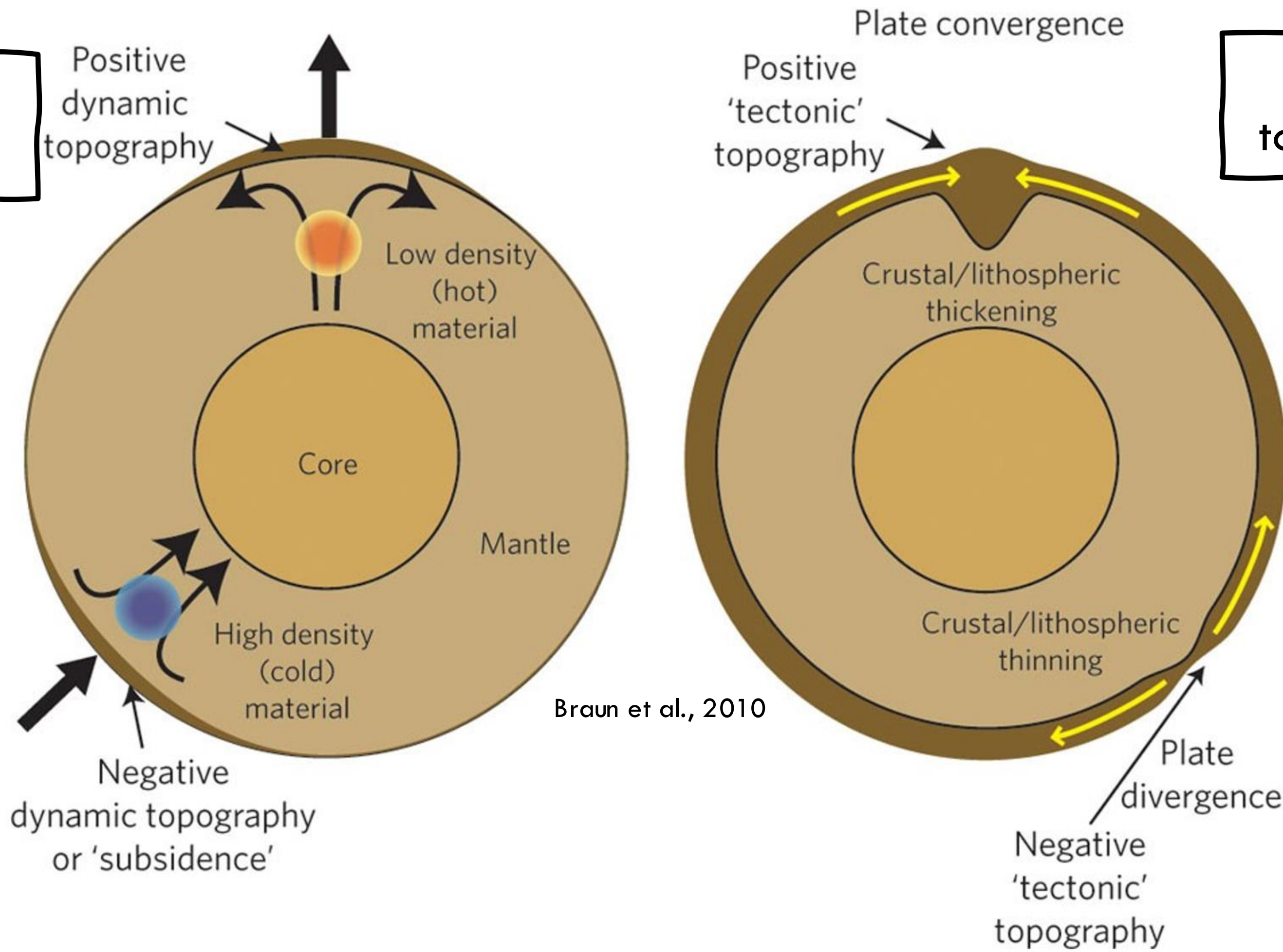
Topography and how it changes



Dynamic topography / Residual topography

“dynamic” topography

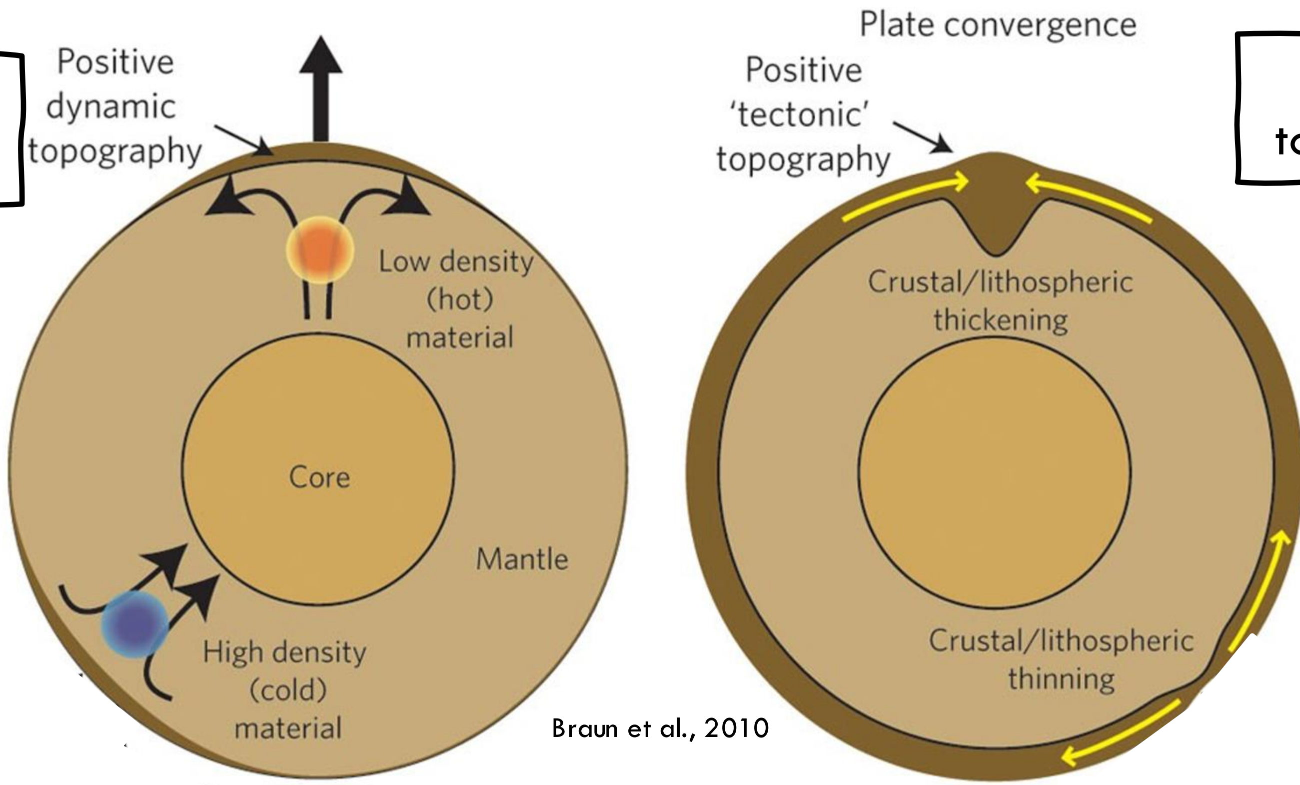


Braun et al., 2010

“tectonic” topography

Dynamic topography / Residual topography

“dynamic” topography



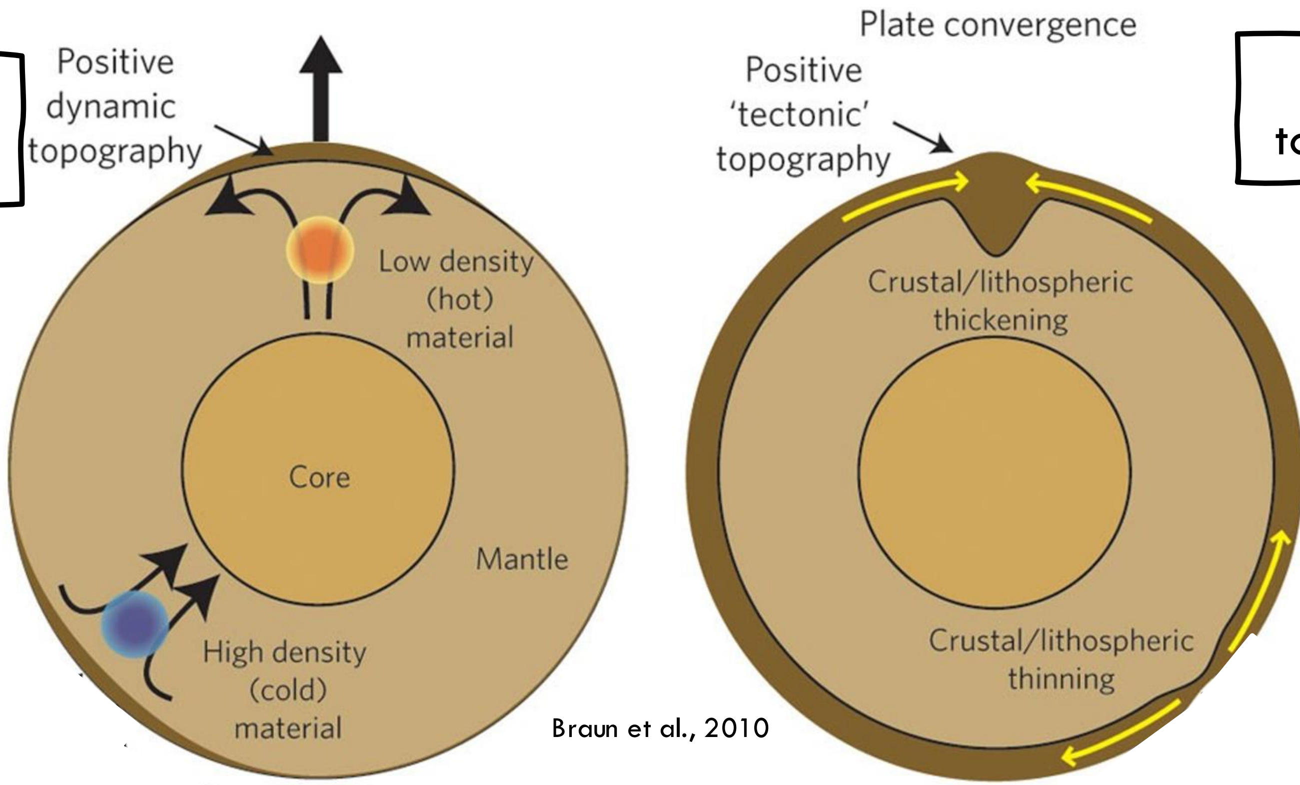
Braun et al., 2010

“tectonic” topography

Total topography ≈ dynamic + tectonic topography

Dynamic topography / Residual topography

"dynamic" topography



Braun et al., 2010

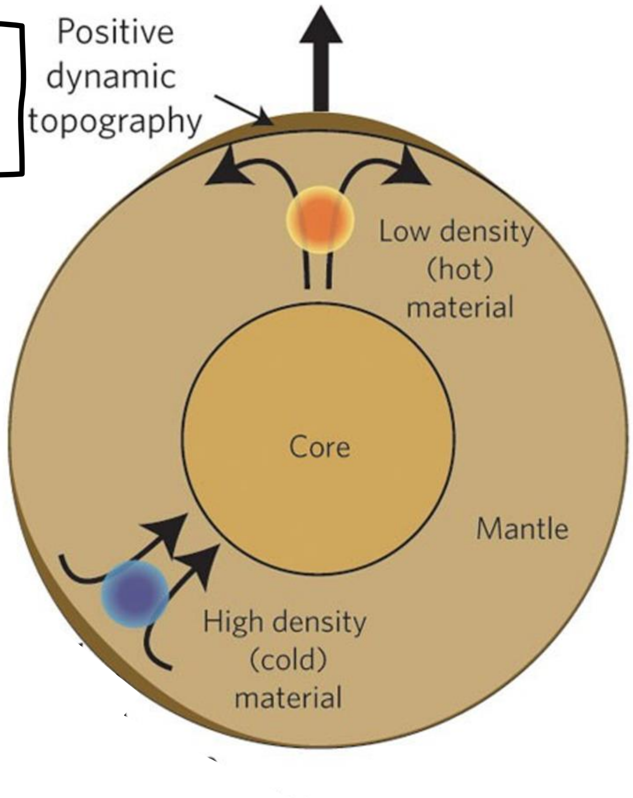
"tectonic" topography

Total topography ≈ dynamic + tectonic topography

Dynamic topography ≈ total - tectonic topography

Dynamic topography / Residual topography

“dynamic” topography



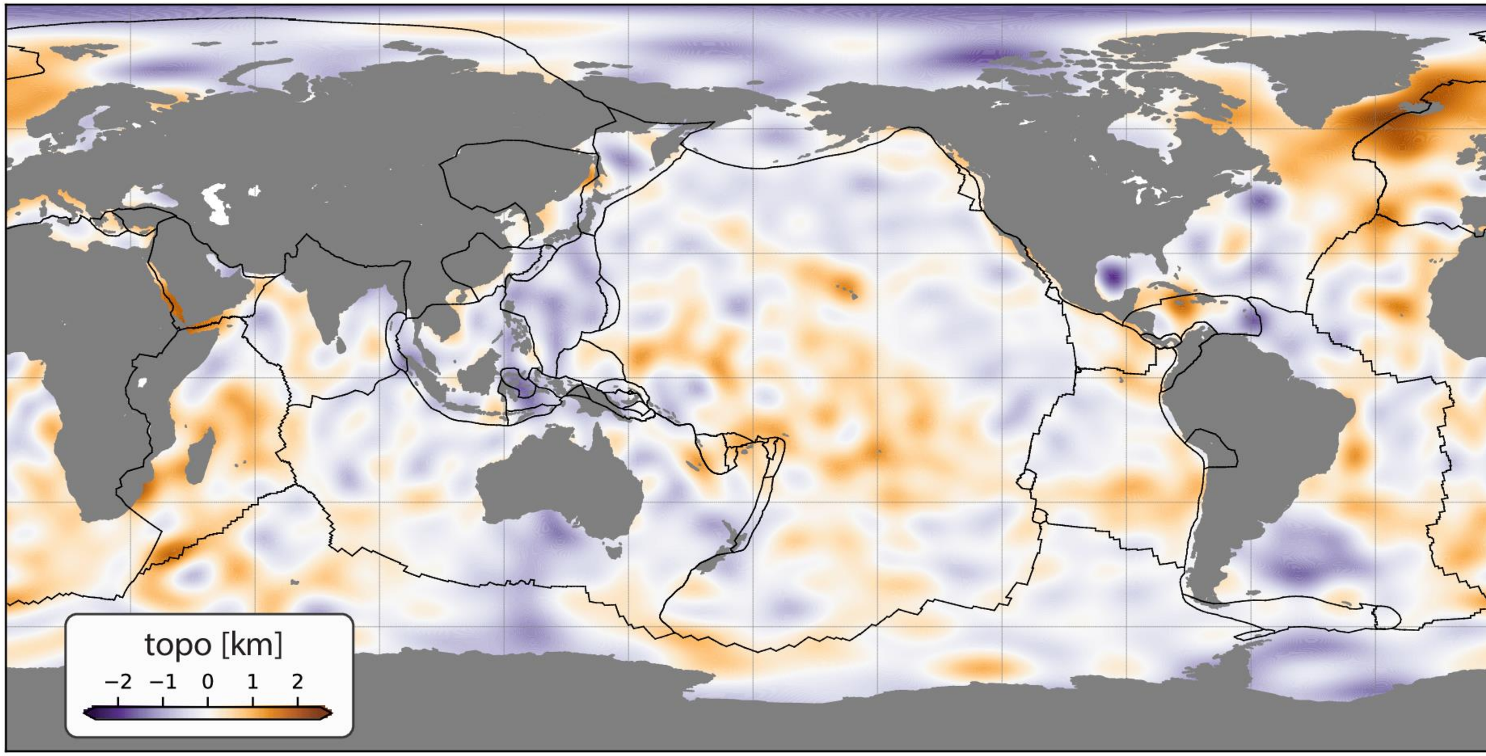
- Dynamic topography is a window into the conditions of the flowing mantle.
- Mainly produced by rising hot anomalies (e.g., plumes) and sinking cold ones (e.g., slabs).
- “Residual” topography attempts to estimate dynamic topography (DT) observationally.

Total topography ≈ dynamic + tectonic topography

Dynamic topography ≈ total - tectonic topography

A recent residual topography map…

Holdt et al., 2022



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Holdt et al., 2022

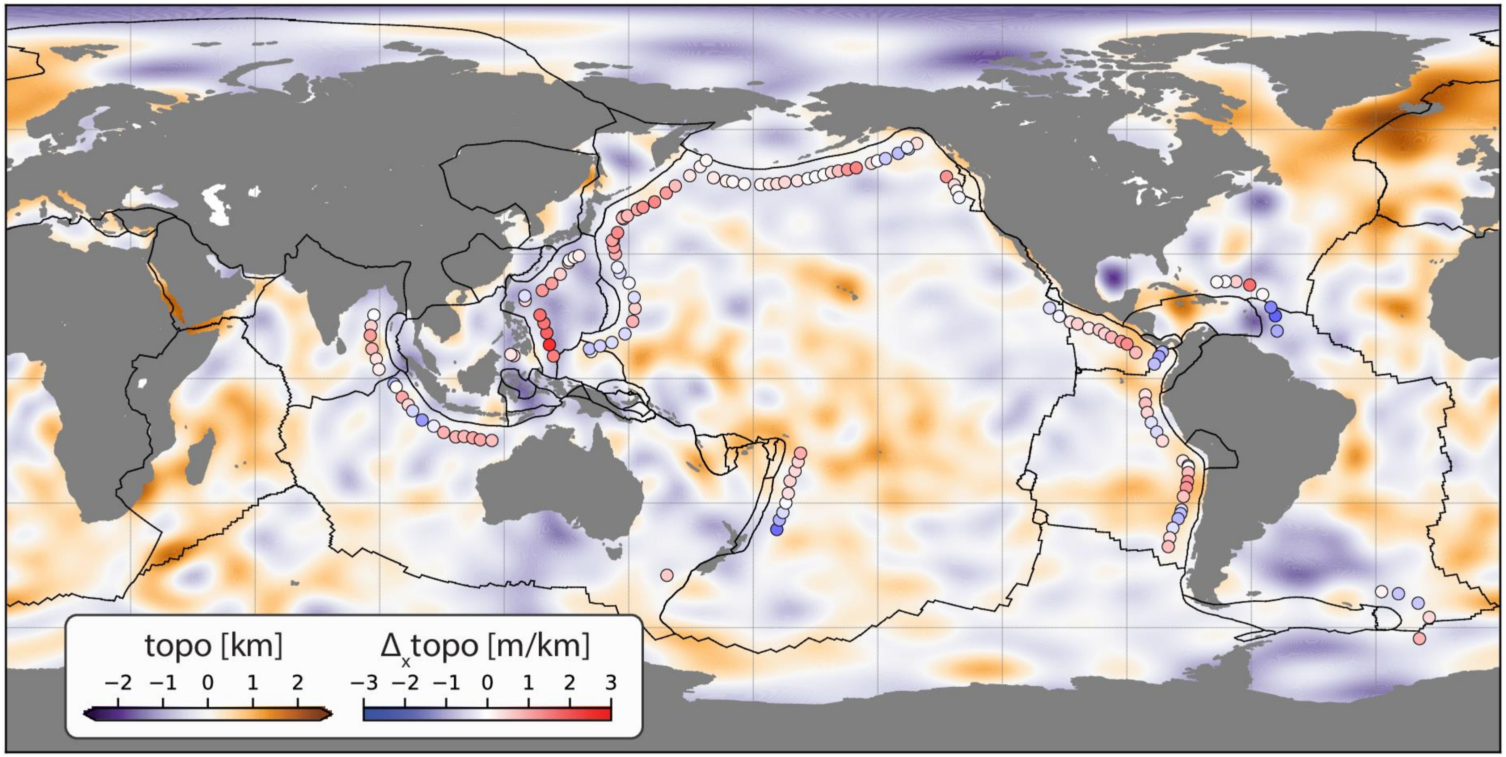
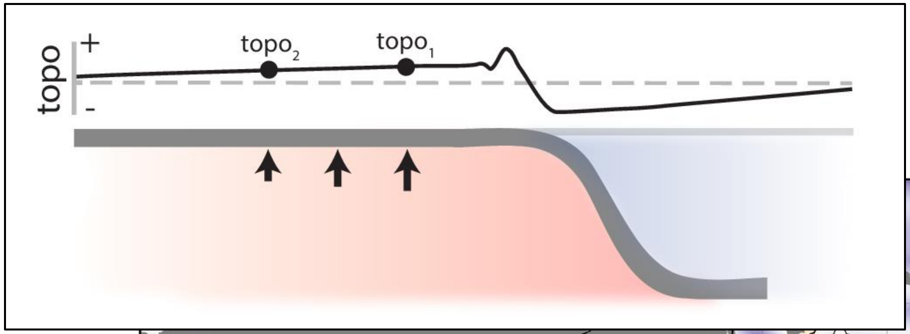


Plate tilting down towards trench; Plate tilting upwards towards trench

A recent residual topography map…



Holt, 2022

Holdt et al., 2022

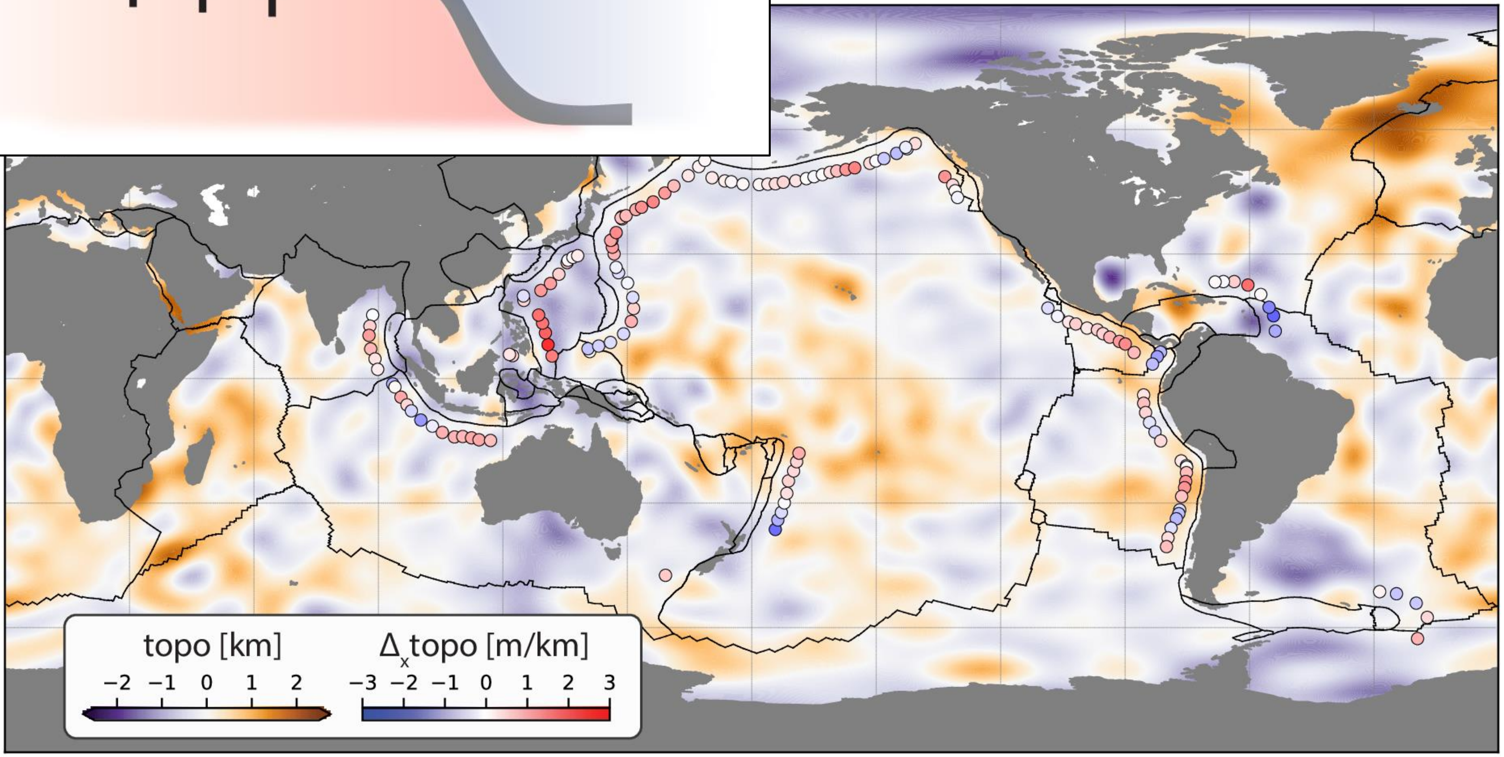
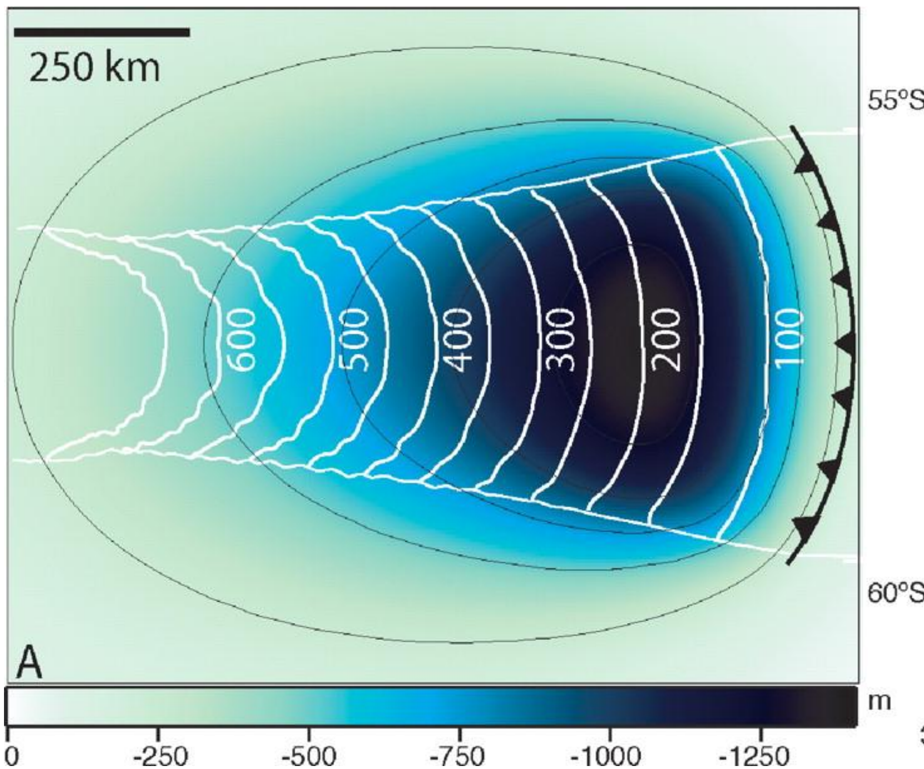


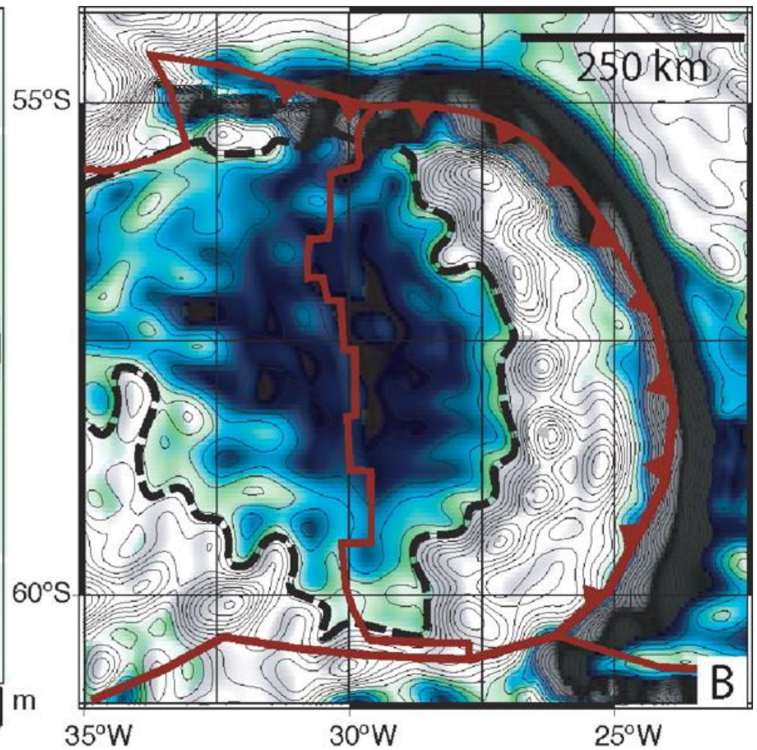
Plate tilting down towards trench; Plate tilting upwards towards trench

Regionally

Very simple model



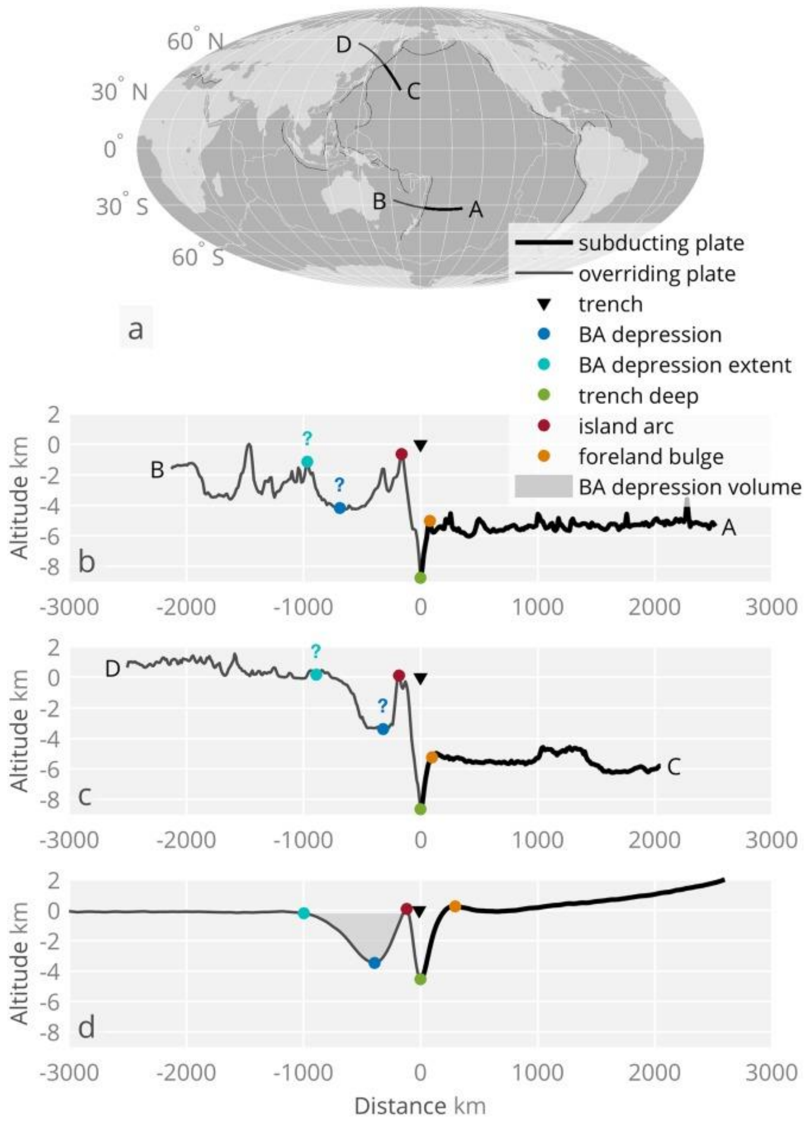
Scotia Residual Topography



Husson et al., 2006

Regionally

Crameri et al., 2017

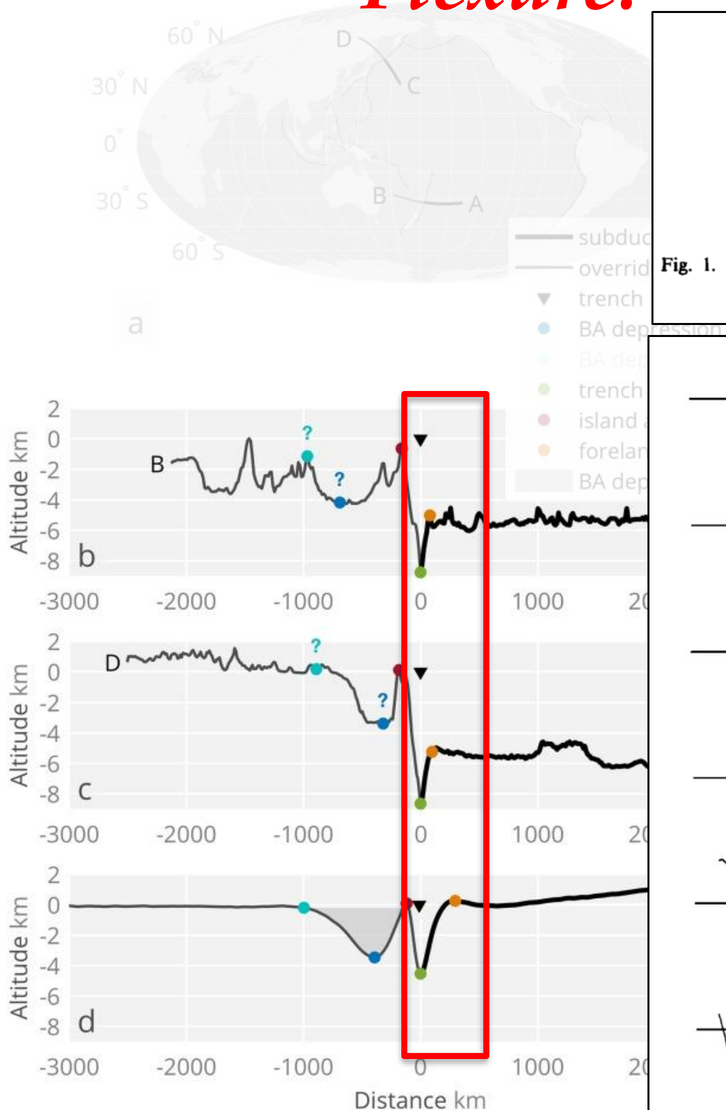


Regionally

Crameri et al., 2017

Flexure:

Caldwell & Turcotte, 1979



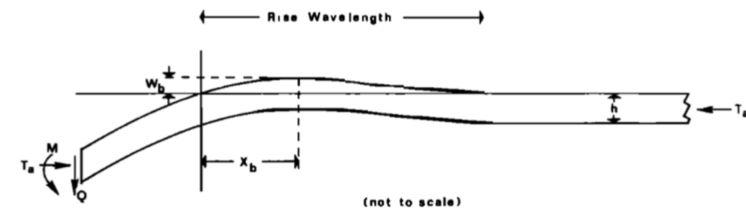
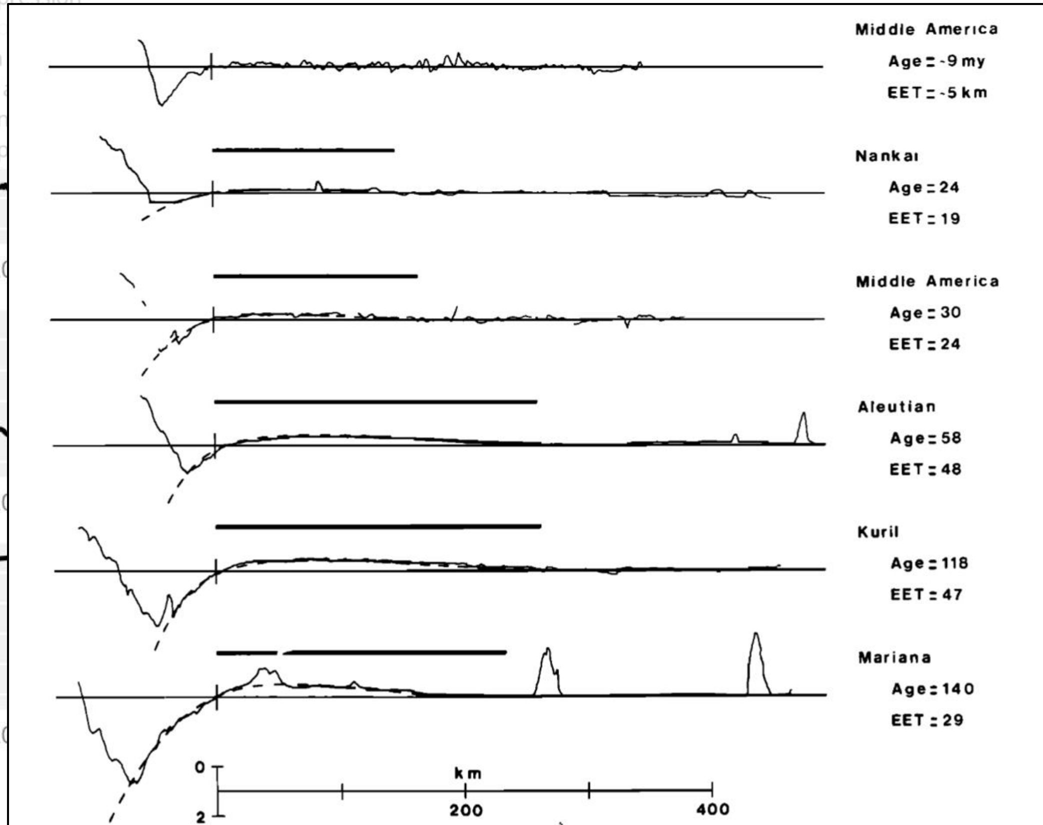


Fig. 1. (*a*) Illustration of the topography associated with an ocean trench. (*b*) The equivalent elastic bending problem. The generalized end loading includes a vertical force Q, a bending moment M, and a horizontal force T_a.

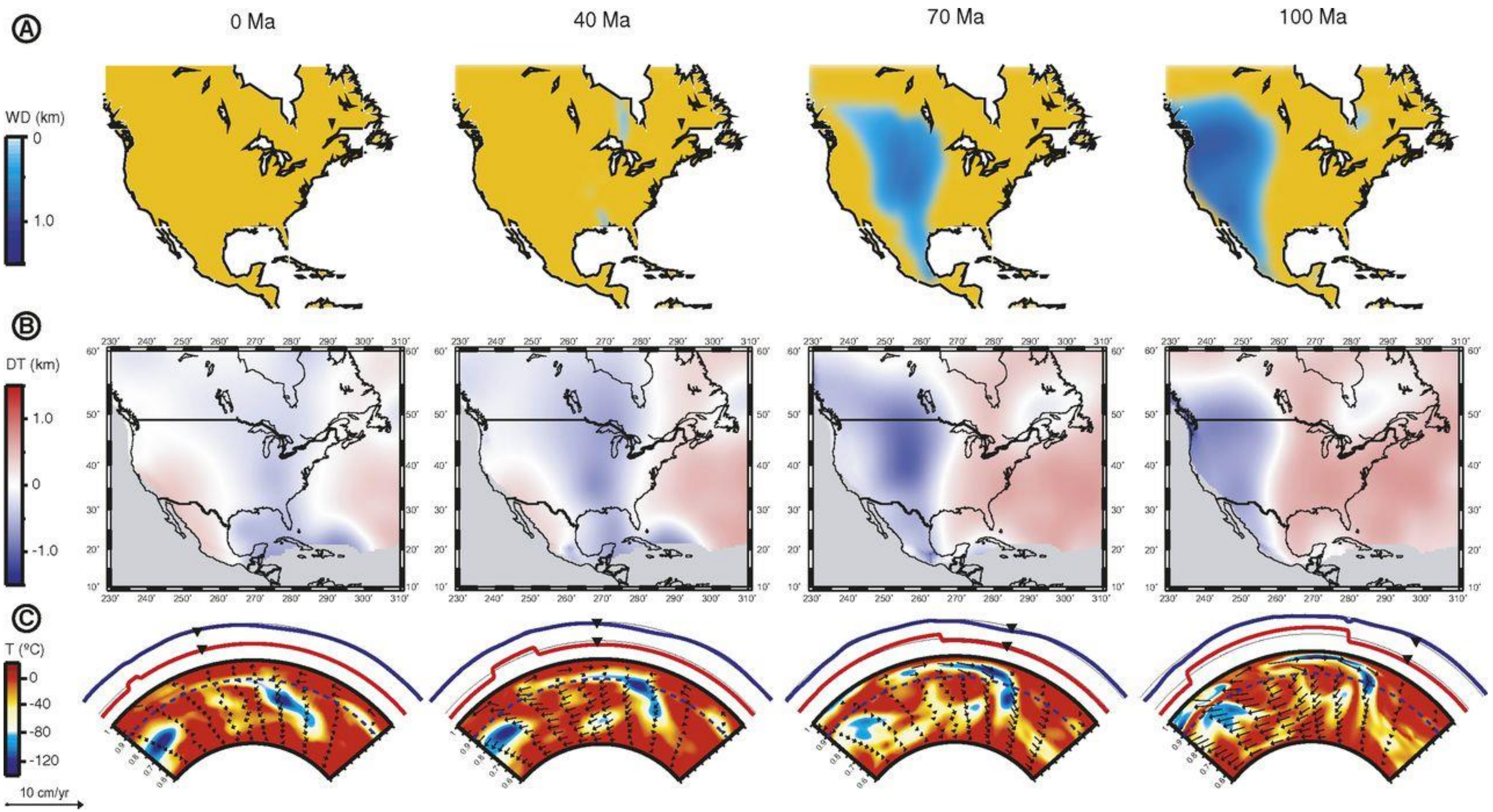


Uplift / subsidence

Uplift / subsidence

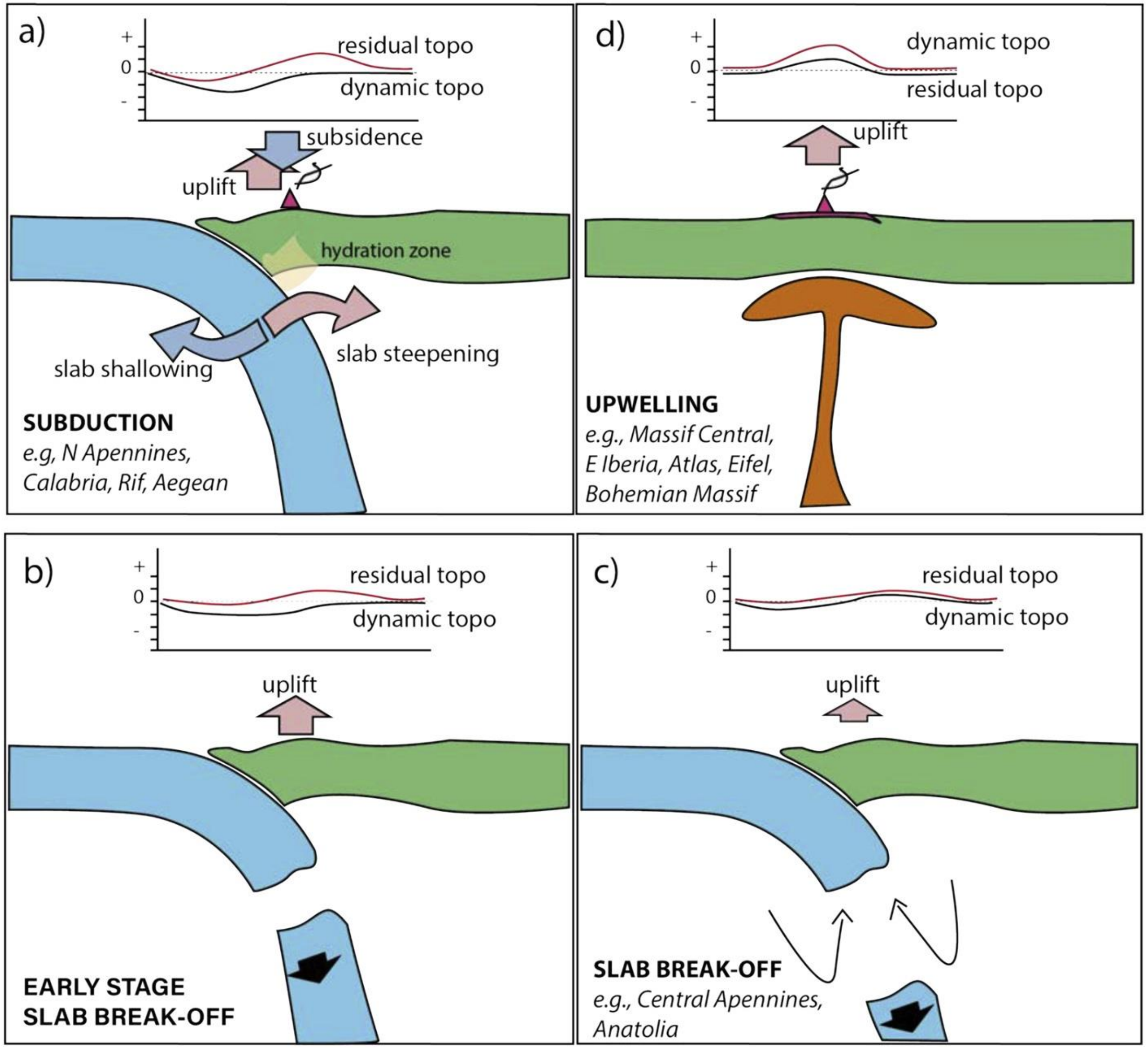
Spasojevic et al., 2009: The Cretaceous flooding of the The Western Interior Seaway of North America.

~10 Myr-timescales



Uplift / subsidence

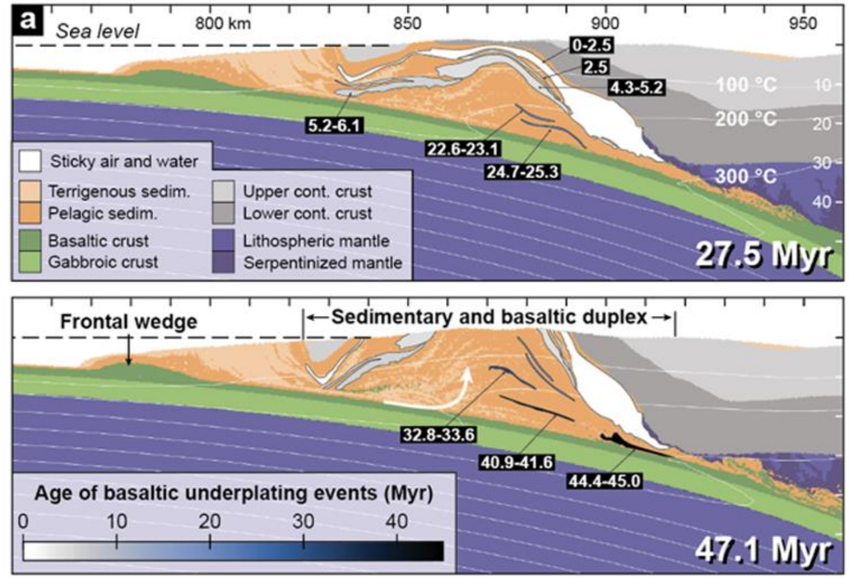
Faccenna and Becker, 2020

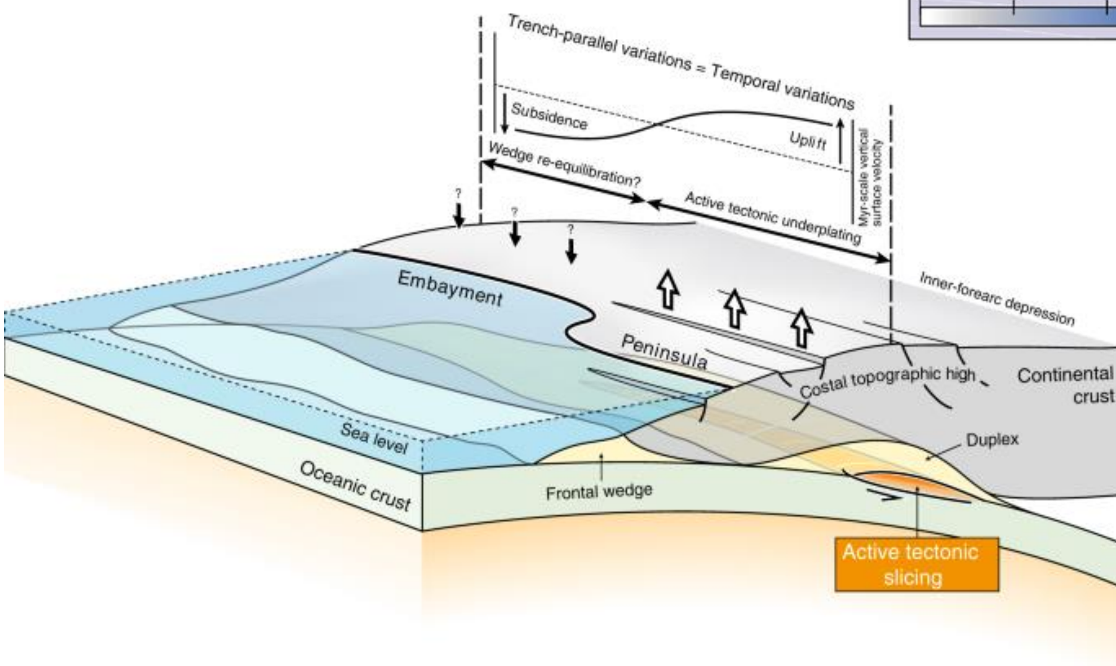


Uplift / subsidence

Menant et al. 2020: *"Transient stripping of subducting slabs controls periodic forearc uplift"*

few Myr-timescales

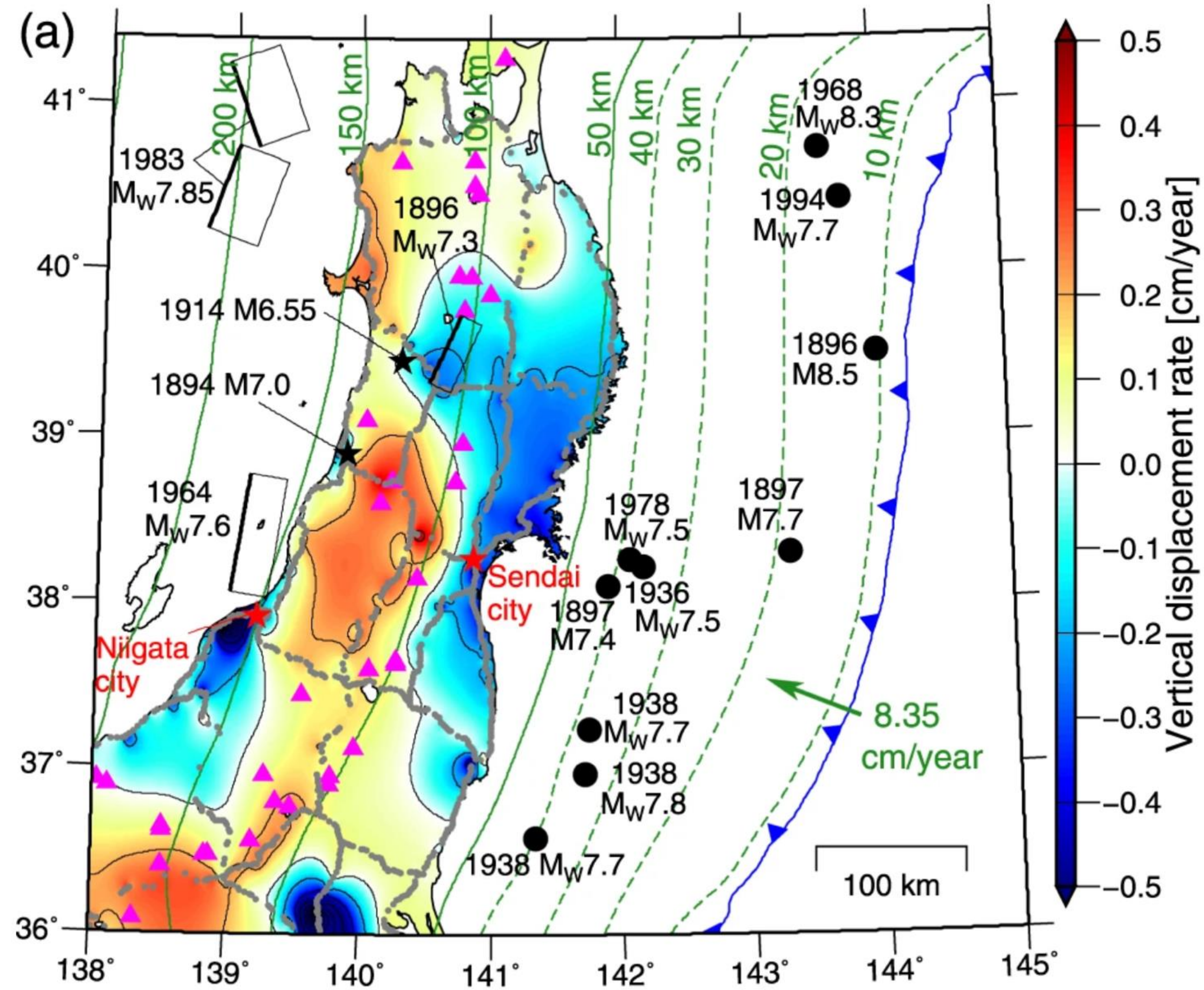




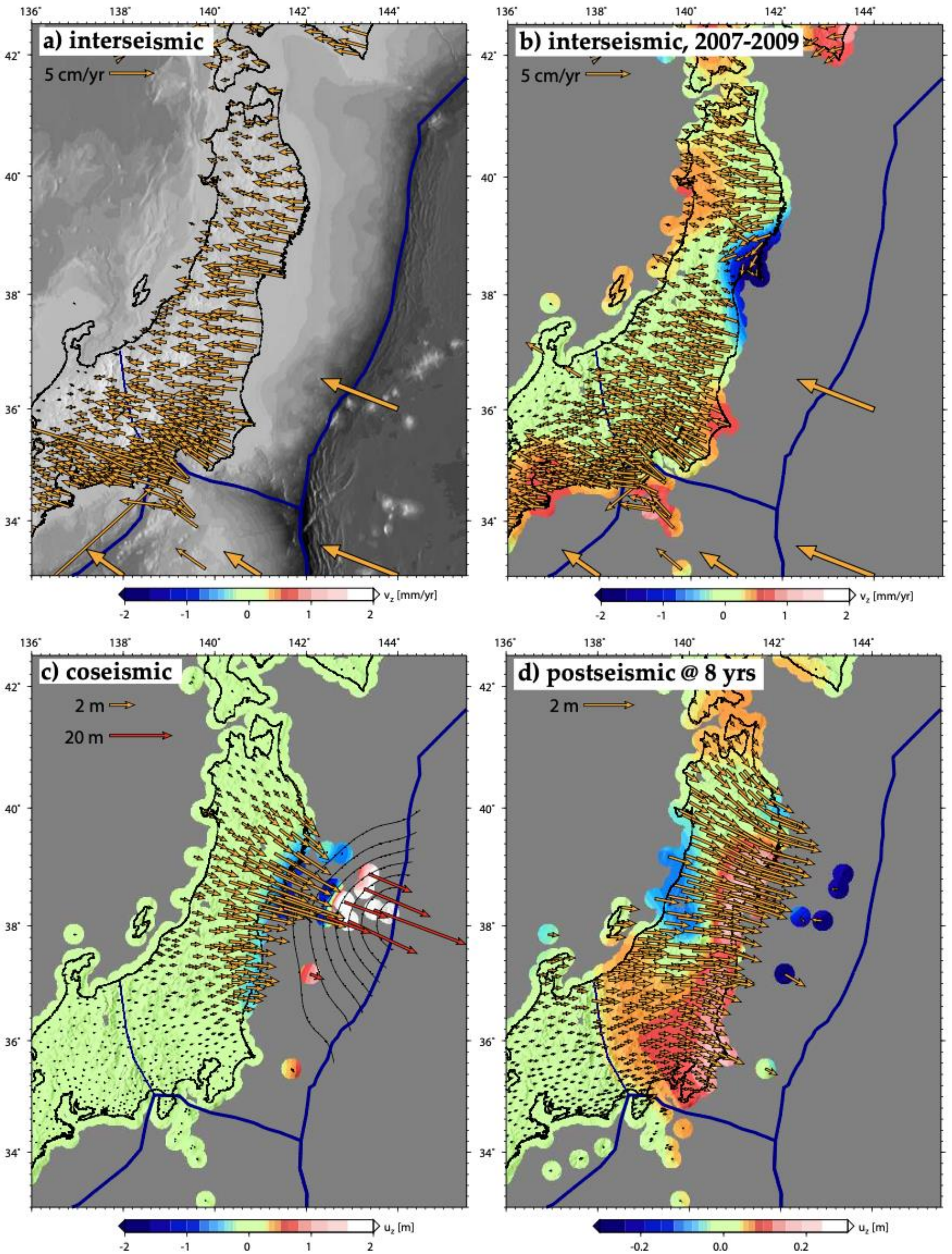
Uplift / subsidence

Sasajima et al, 2009: Inter-seismic subsidence between great Japan earthquakes.

day to year timescales



Surface velocities



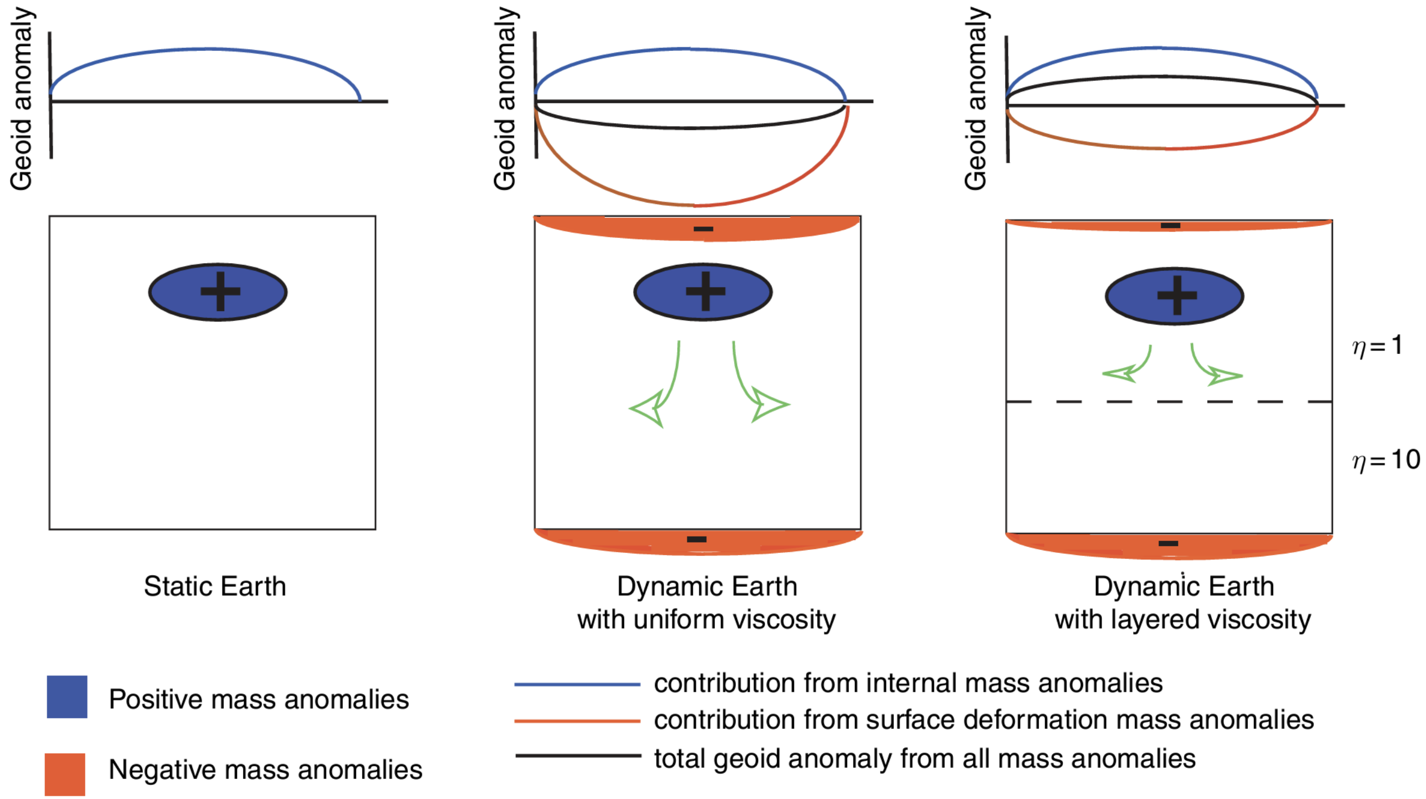
GPS

Becker & Faccenna: Tectonic Geodynamics

Re-start point

Geoid & Gravity

King, 2016

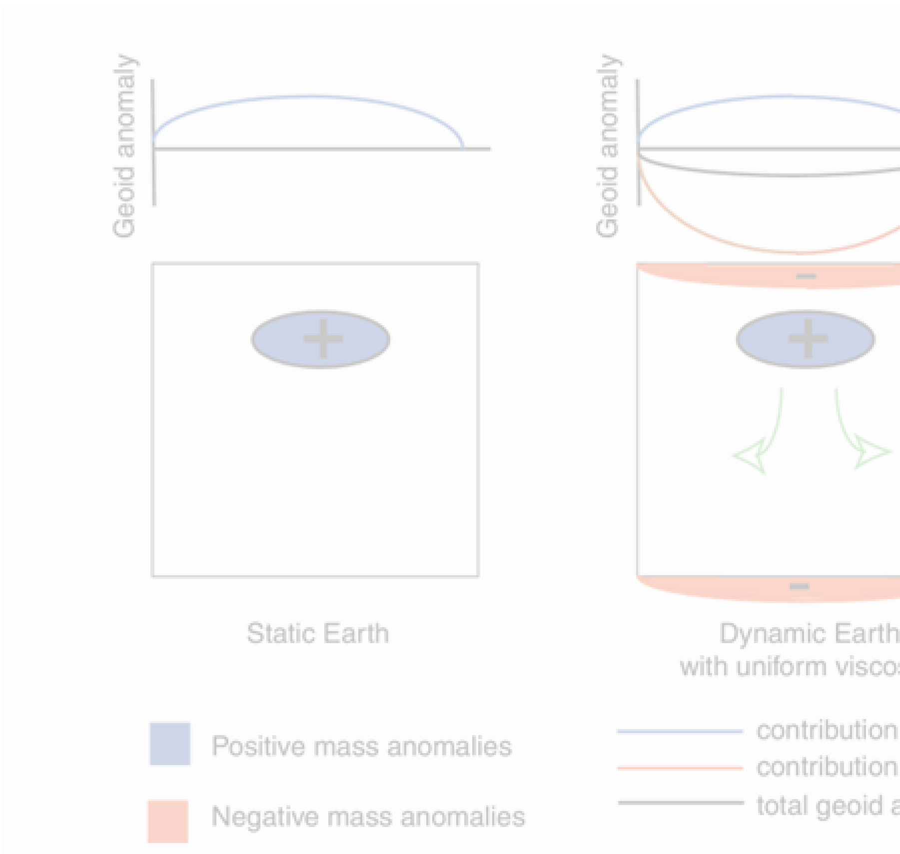


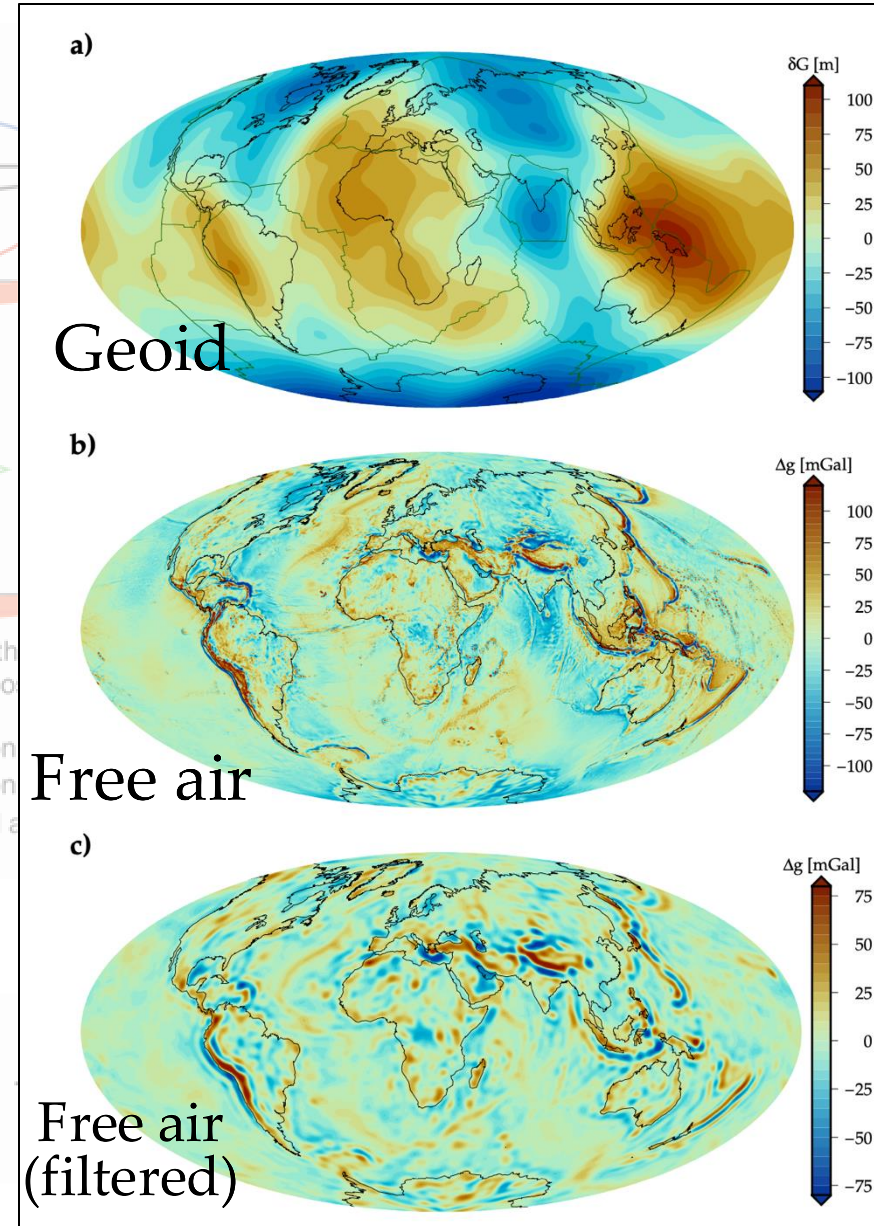
$$g = |\boldsymbol{g}| = \frac{GM}{r^2} = \frac{F}{m}$$

$$\boldsymbol{F} = G\frac{mM}{r^2}\boldsymbol{e}_r \qquad U = G\int_M \frac{\mathrm{d}M}{r} + \frac{1}{2}\omega_E^2 r_0^2 \cos^2\lambda,$$

$$g_r = -\frac{\partial U}{\partial r}$$

Geoid & Gravity



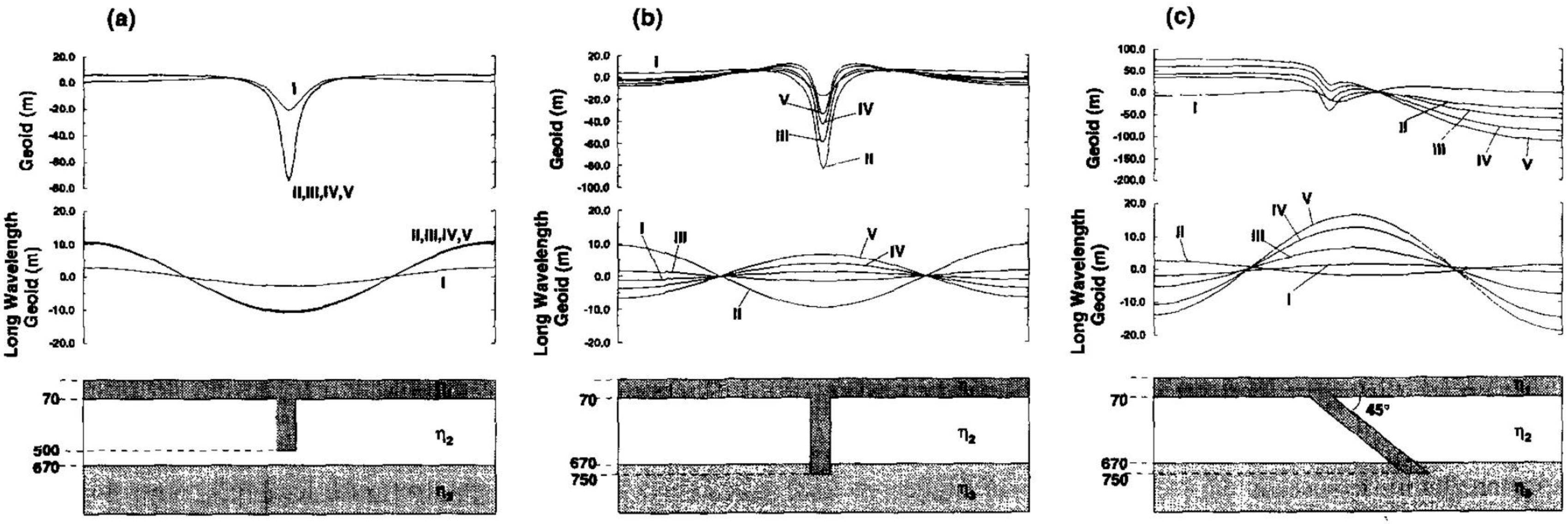


$$\boldsymbol{F} = G\frac{mM}{r^2}\boldsymbol{e}_r$$

$$U = G\int_M \frac{\mathrm{d}M}{r}$$

Geoid & Gravity

Model	η_1	η_2	η_3	slab viscosity
I	10	0.05	1	ambient
II	10	0.05	1	10
III	10	0.05	3	10
IV	10	0.05	10	10
V	10	0.05	50	10



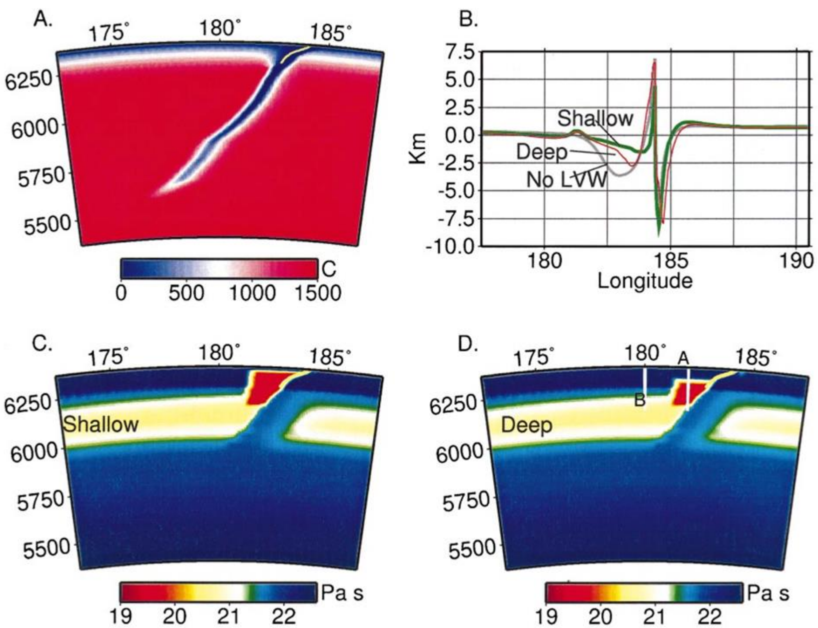
Geoid and weak slabs: Moresi and Gurnis, 1996 (cf. Billen et al., 2003; Mao & Zhong, 2021)

A low viscosity wedge in subduction zones

Magali I. Billen *, Michael Gurnis

Seismological Laboratory, California Institute of Technology, Pasadena, CA 91125, USA

Received 22 May 2001; received in revised form 14 August 2001; accepted 20 August 2001



Billen and Gurnis, 2001

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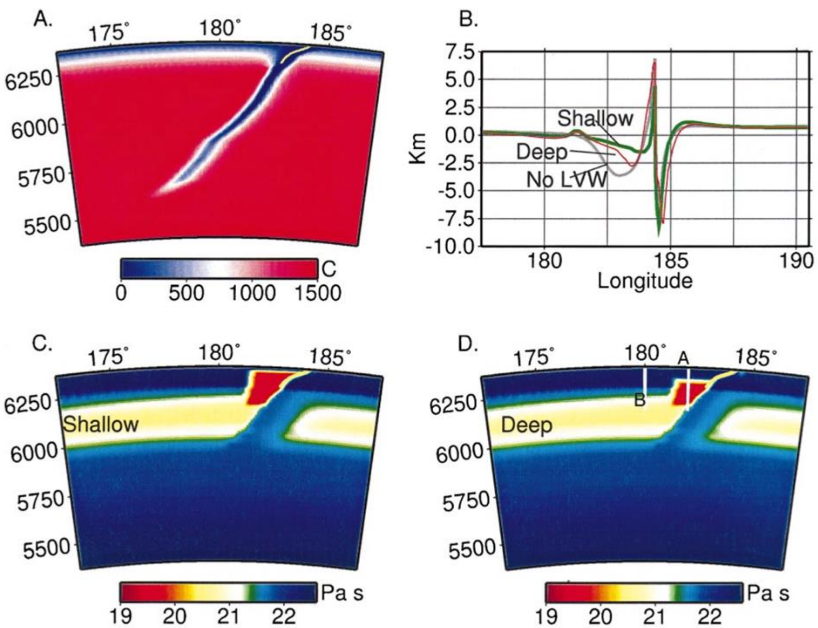

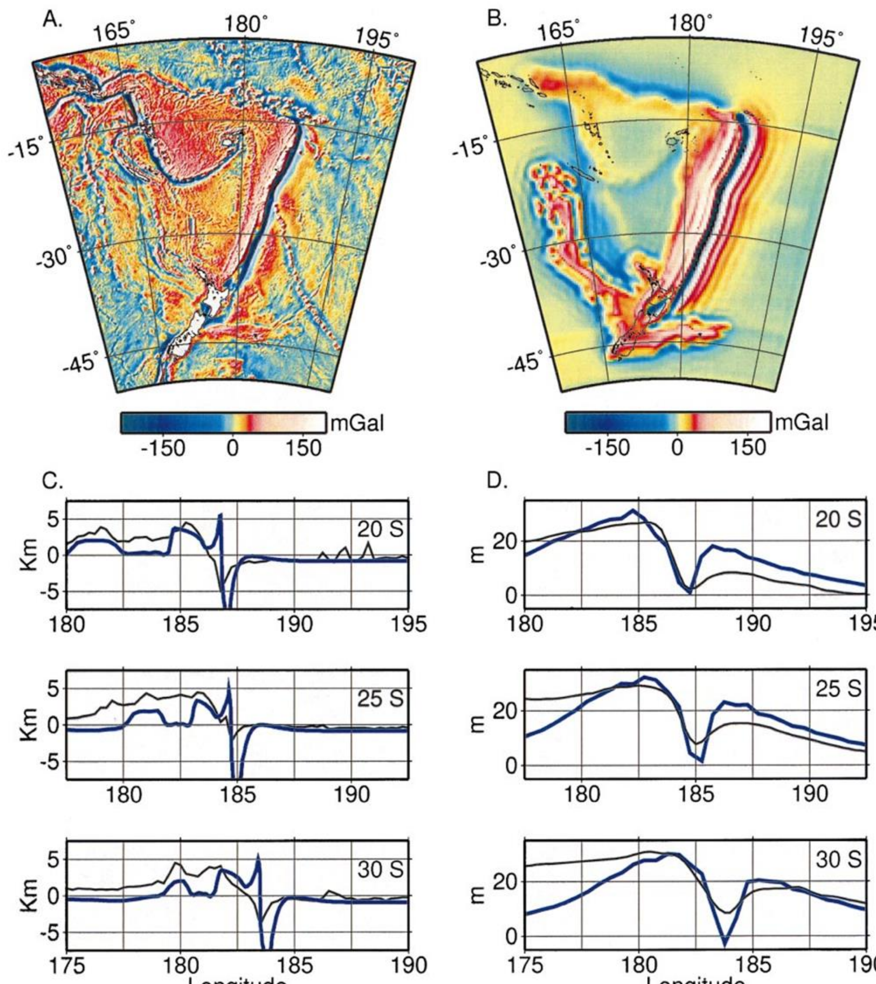

Billen and Gurnis, 2001

Topog.

Geoid.

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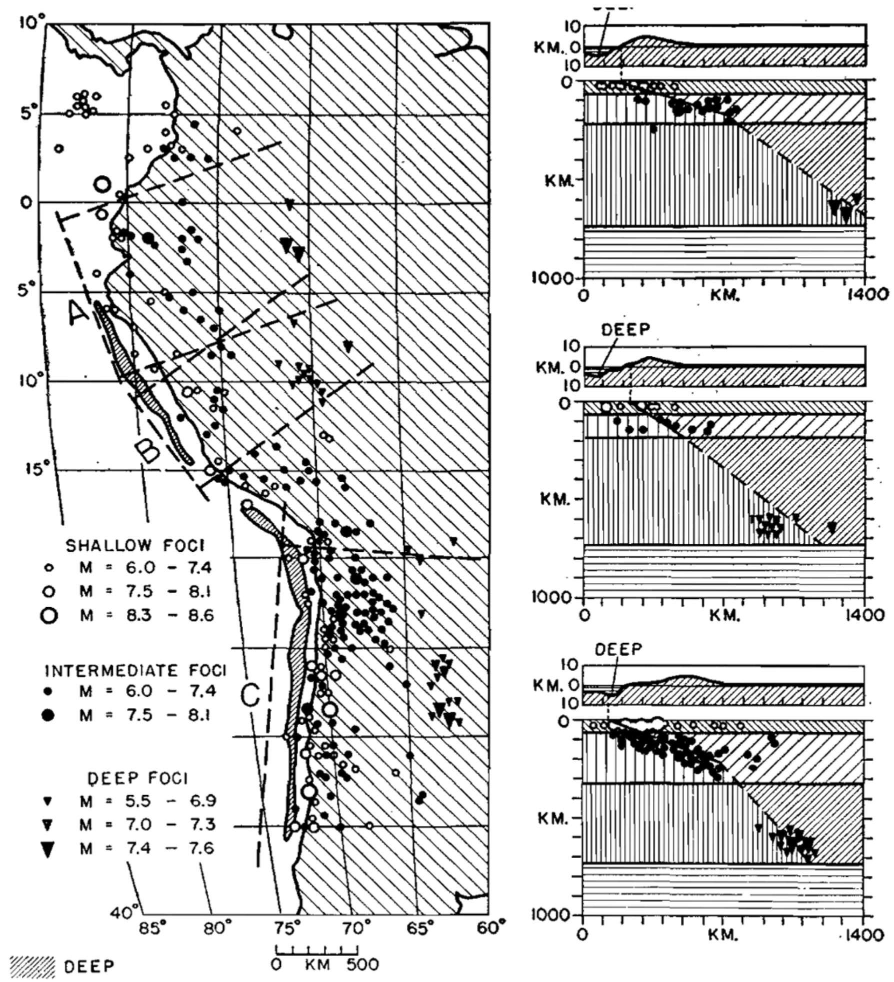
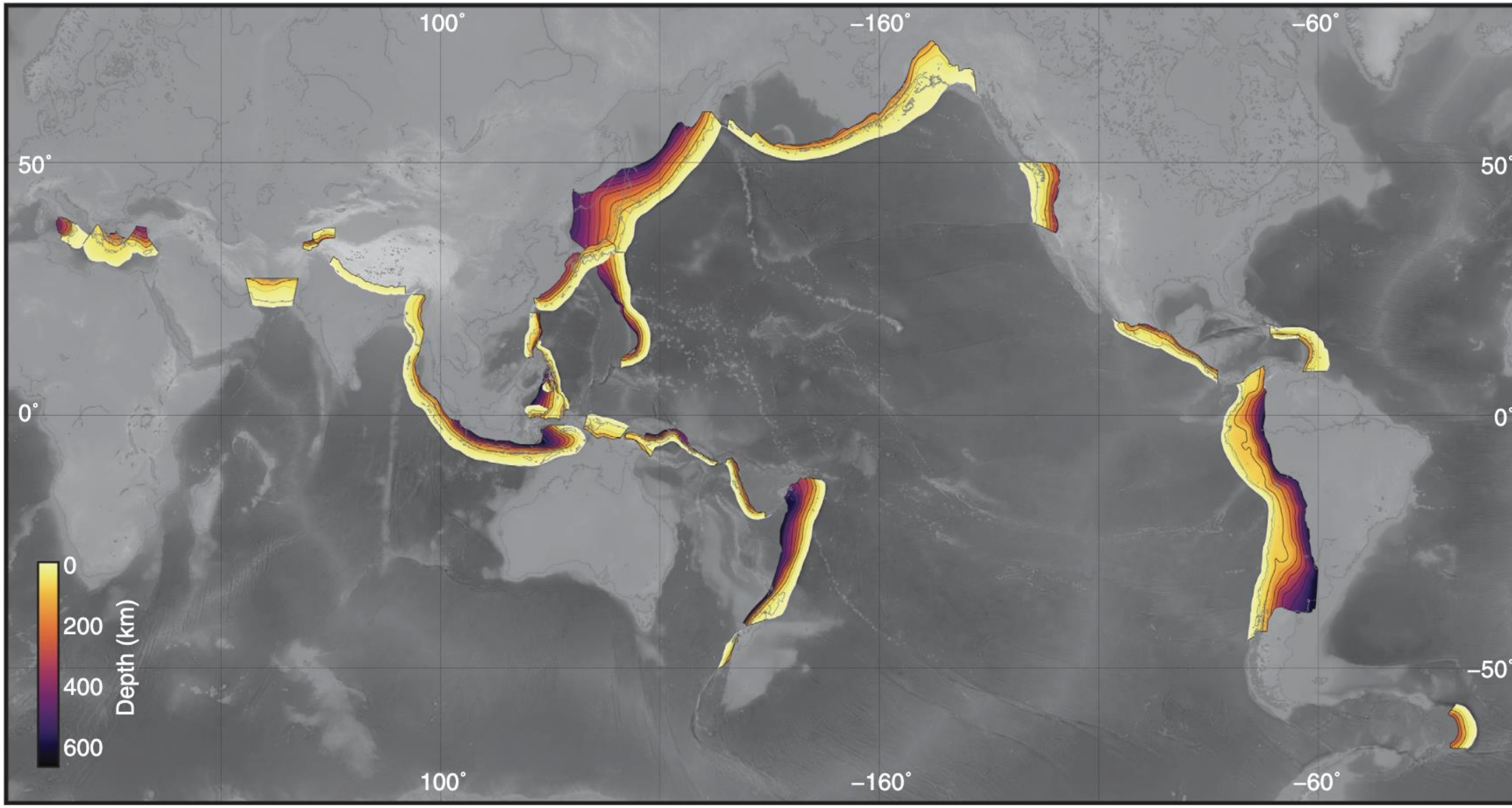
- *Note: Lots and lots of other geological constraints: e.g., exhumed rocks, deformation fabrics, arc petrology, …*

Earthquakes: Benioff Zones



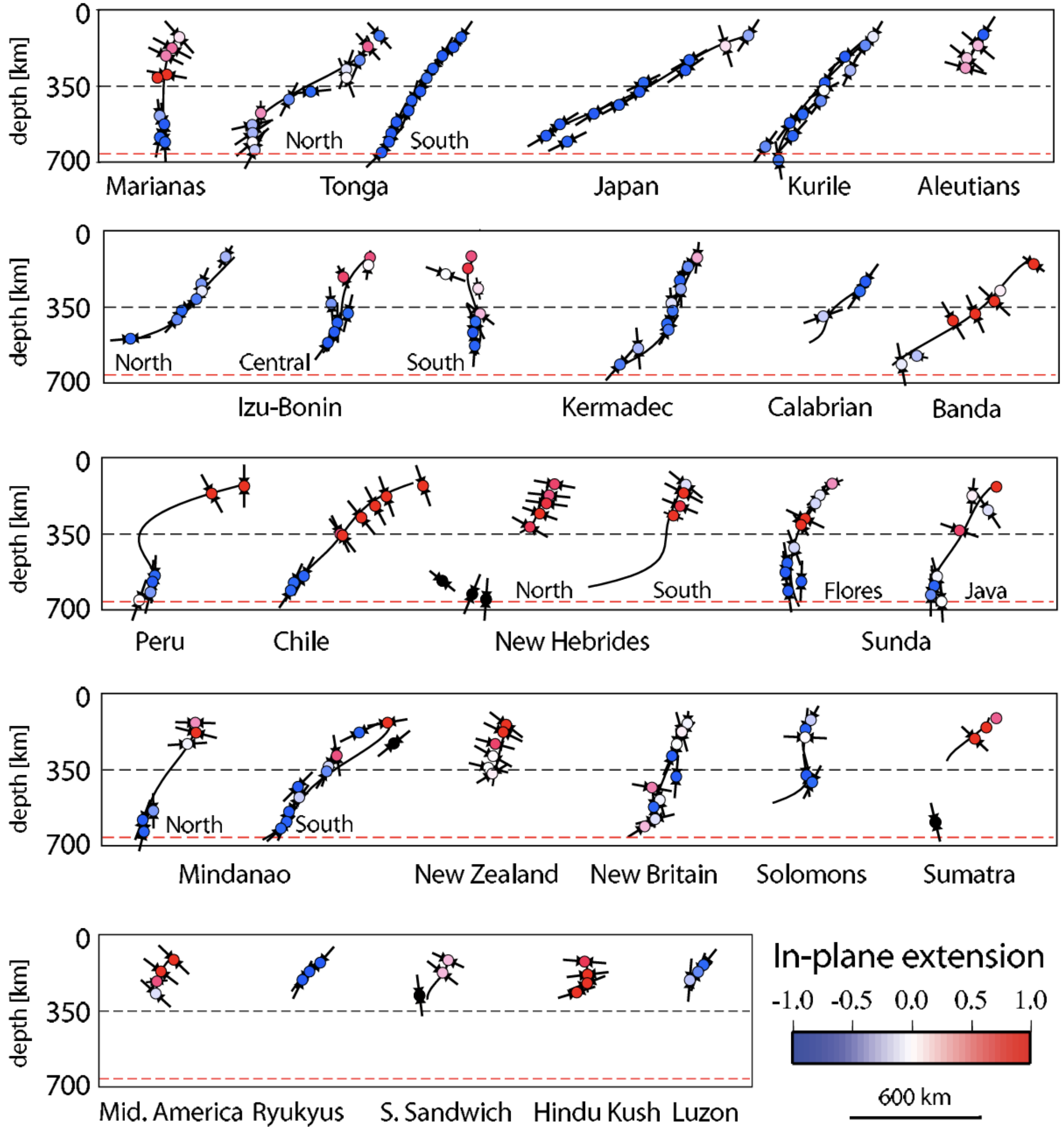
Benioff, 1949

Earthquakes: Benioff Zones



Slab2: Hayes at al., 2018

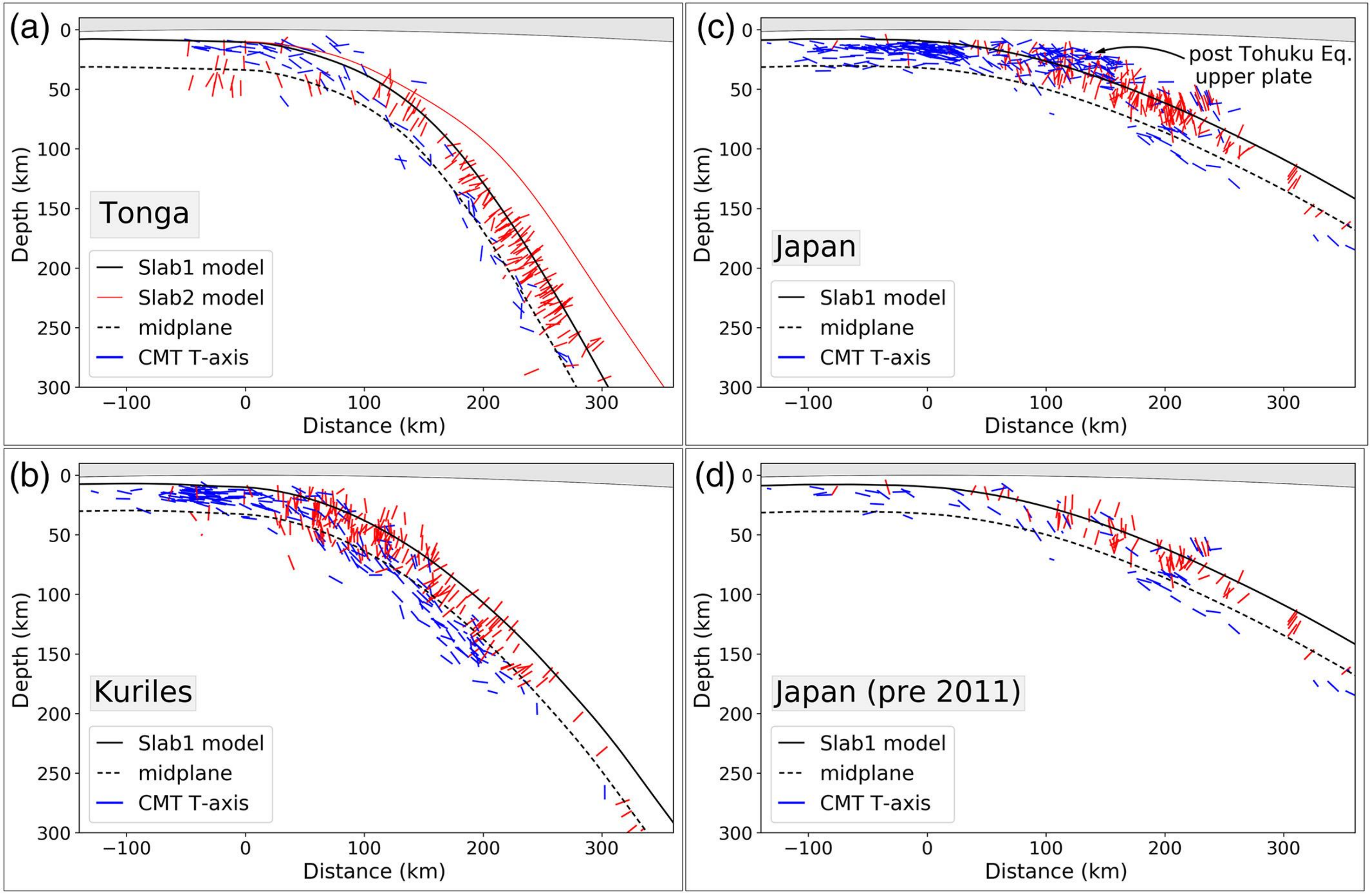
Earthquakes: Slab stress



Alpert et al., 2010

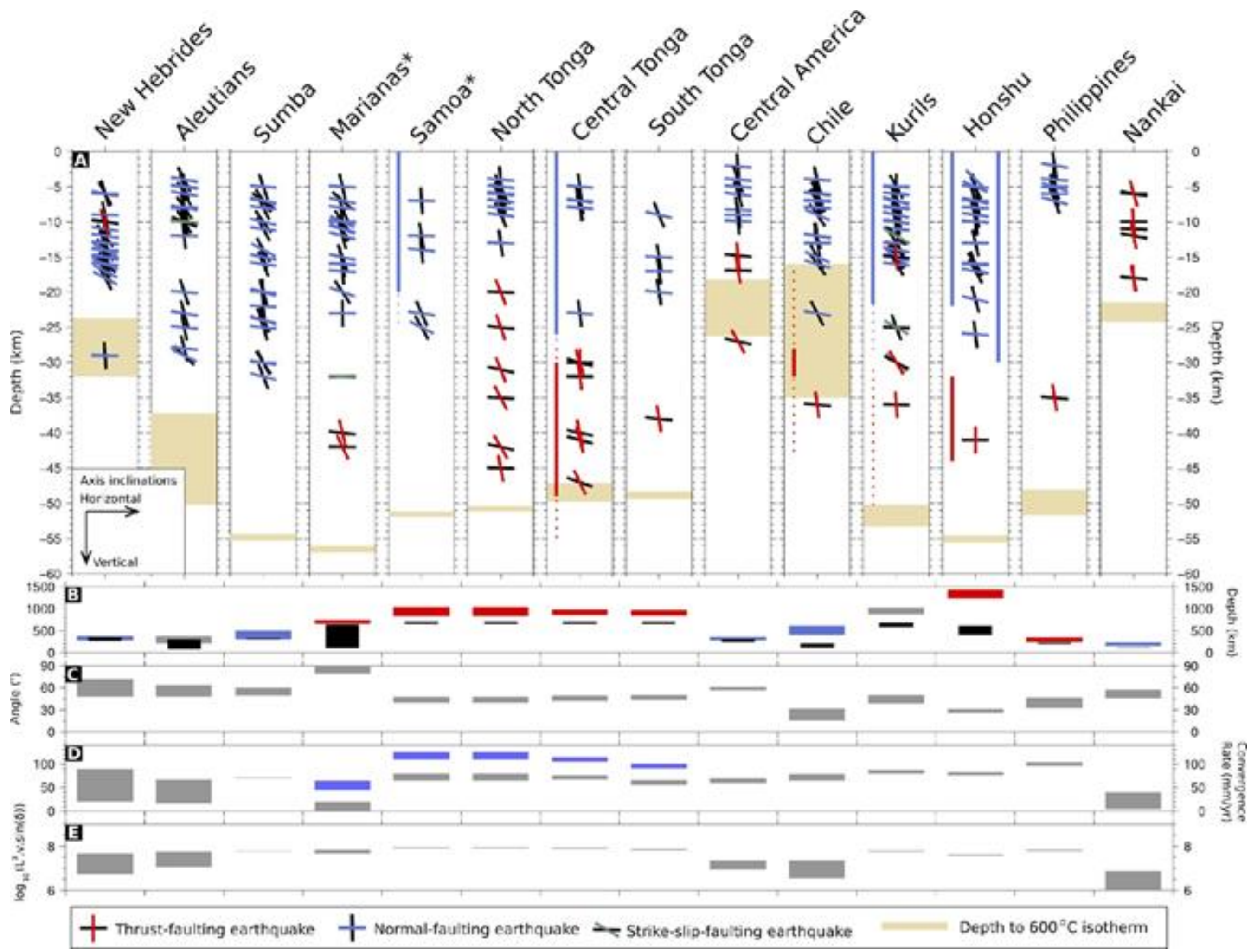
Cf. Isacks & Molnar, 1971

Earthquakes: Slab stress



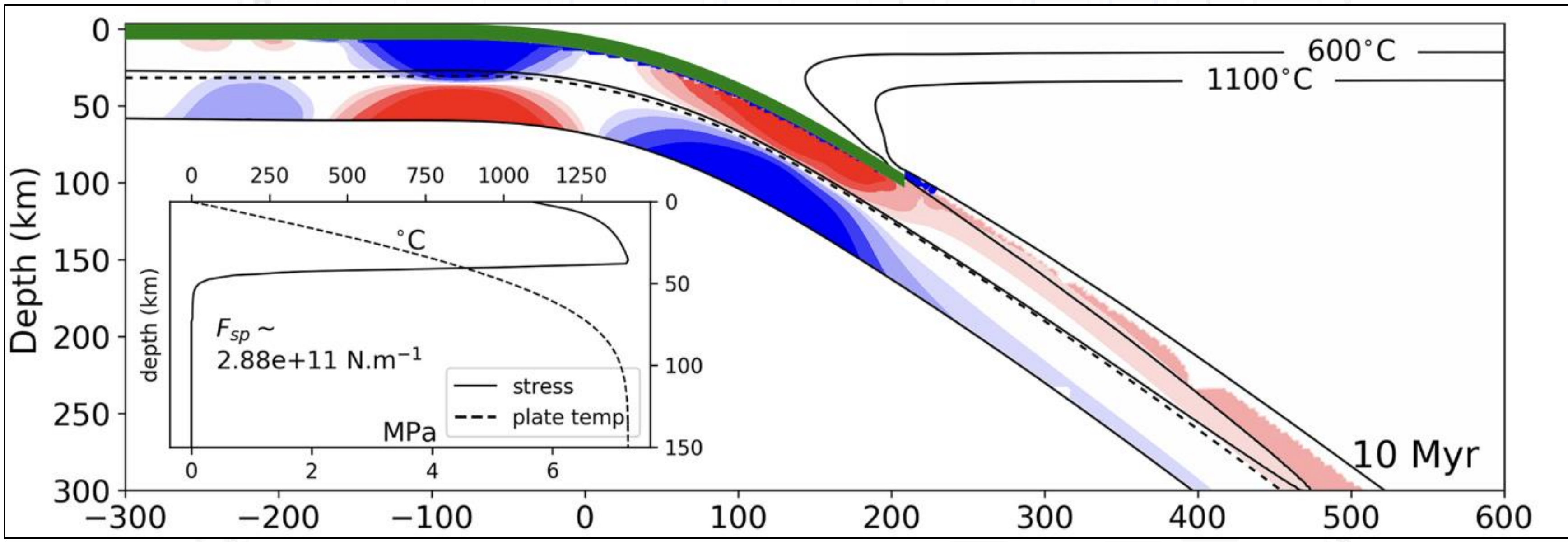
Sandiford et al., 2020

Earthquakes: Slab stress



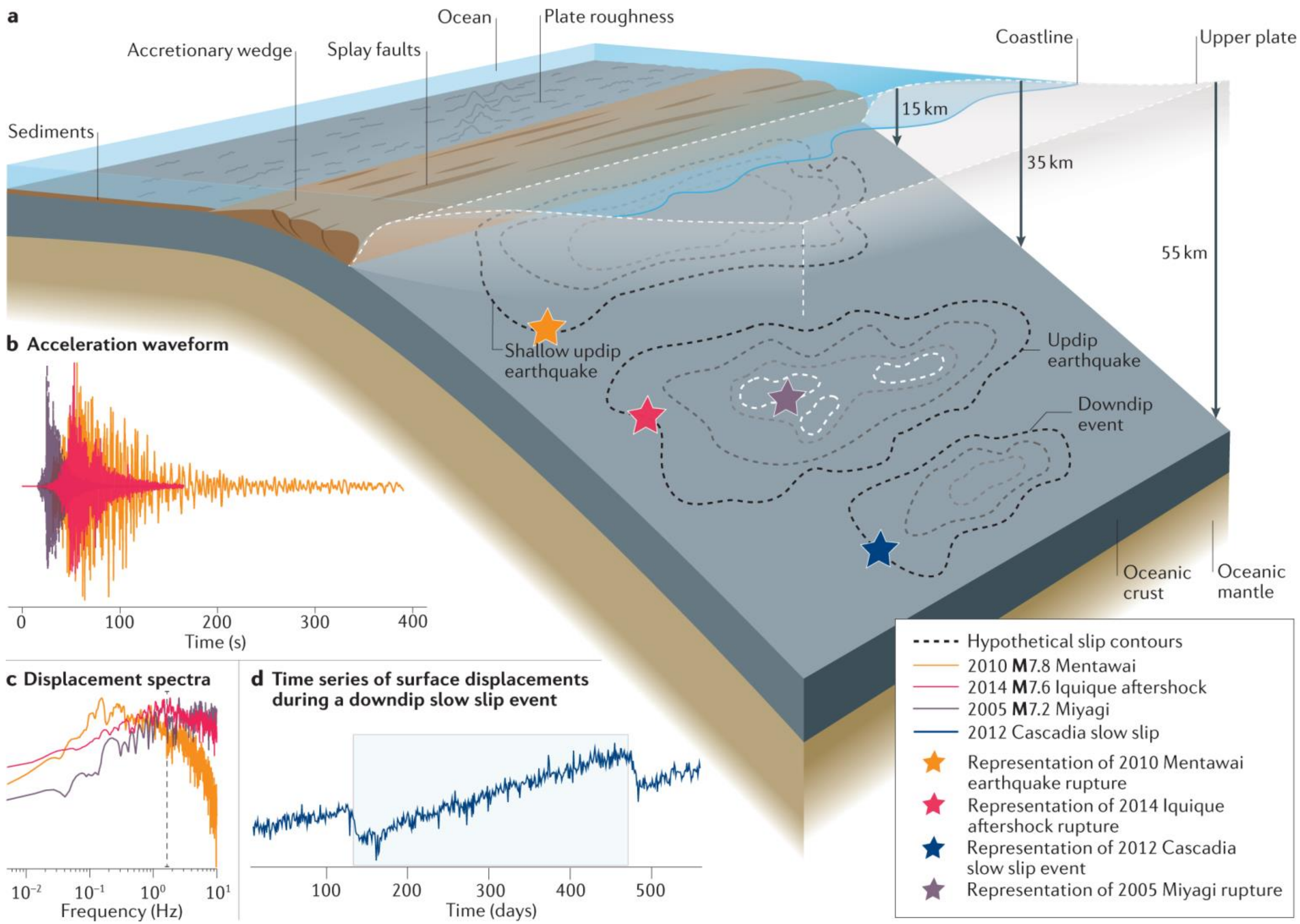
Outer rise earthquakes – Craig et al., 2014

Earthquakes: Slab stress



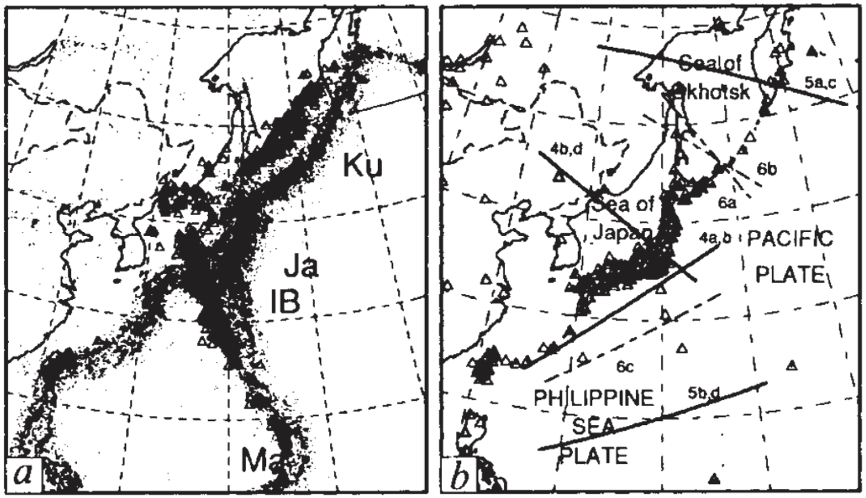
Sandiford et al., 2020

Earthquakes: Plate boundary events

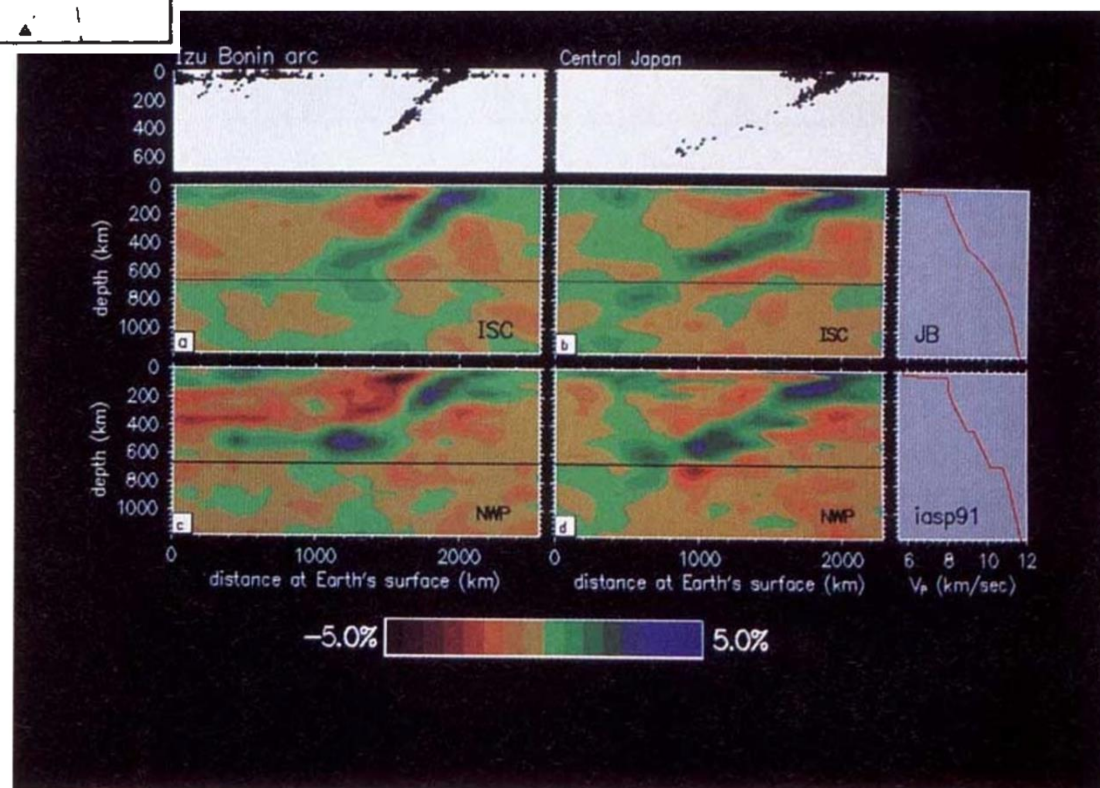


Wirth et al., 2022

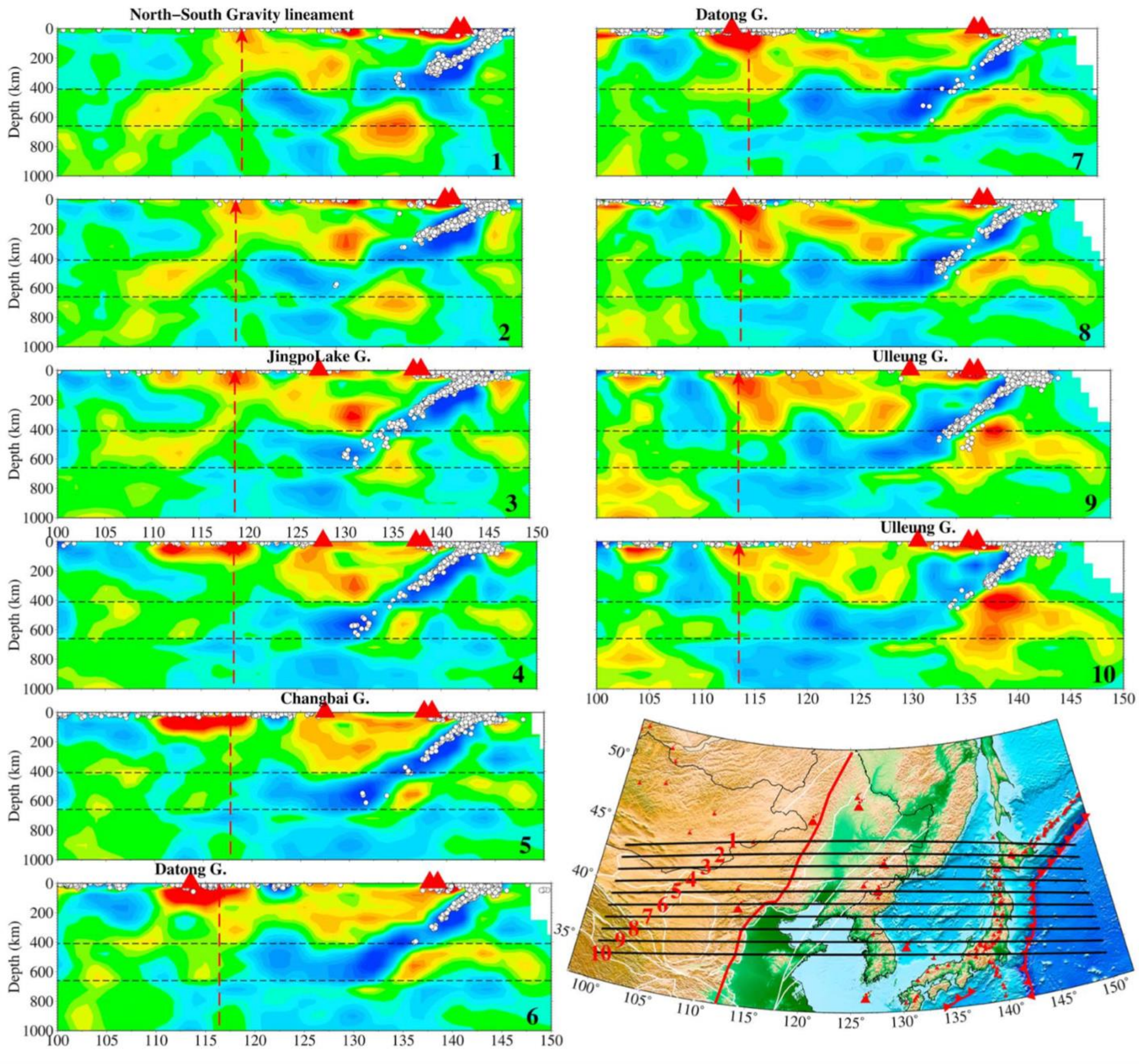
Tomography



Van der Hilst et al., 1991

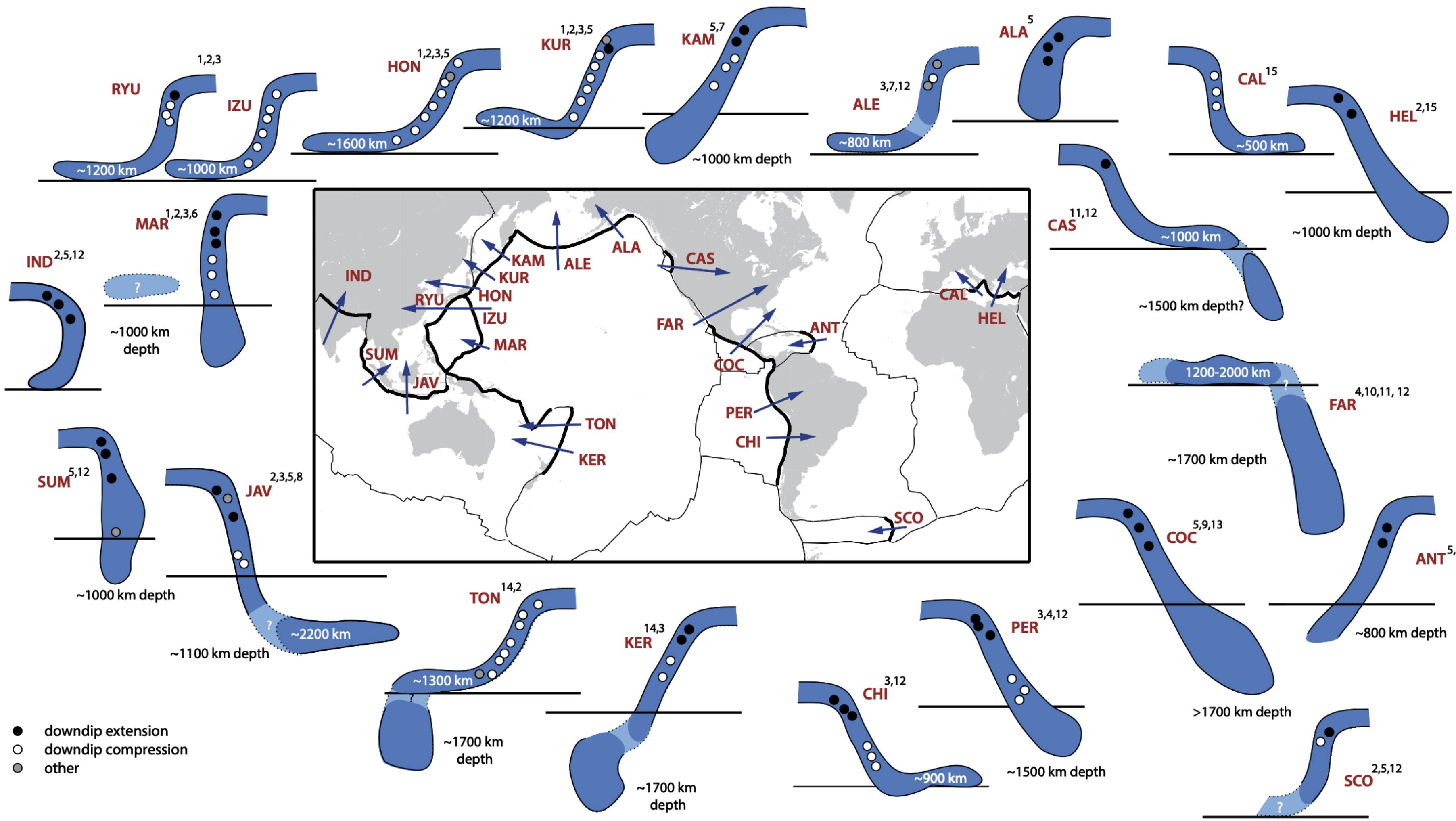


Tomography



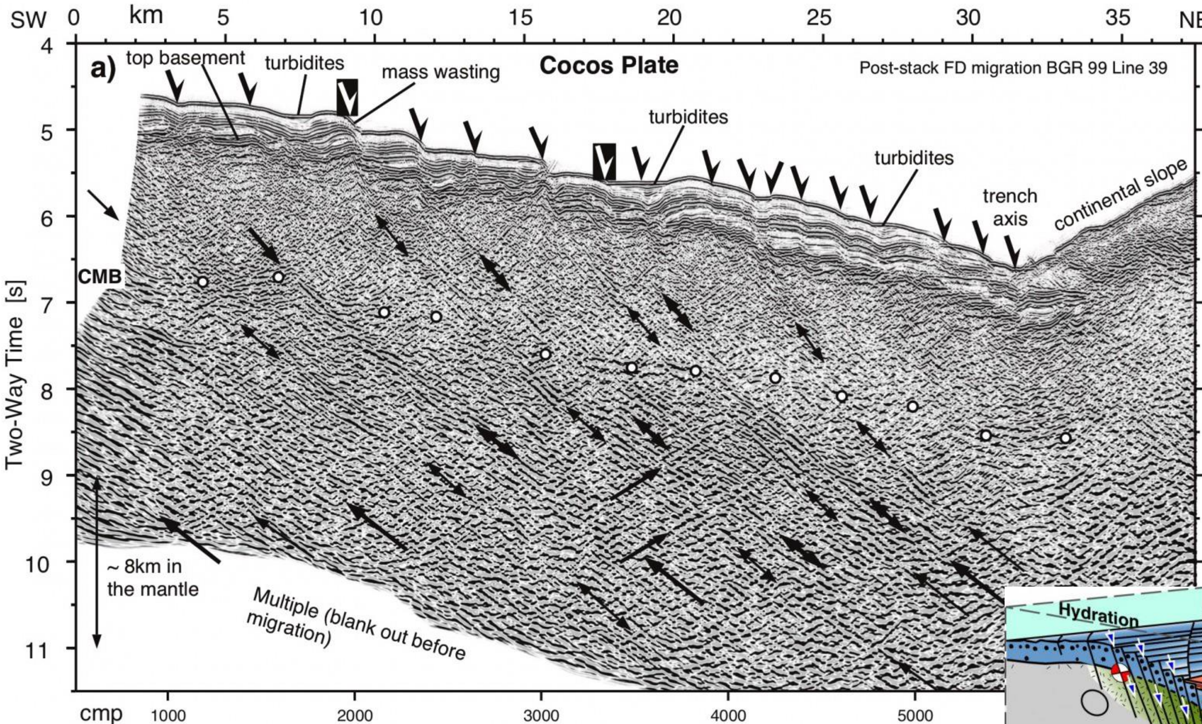
Ma et al., 2019:
P-Wave tomography

Tomography



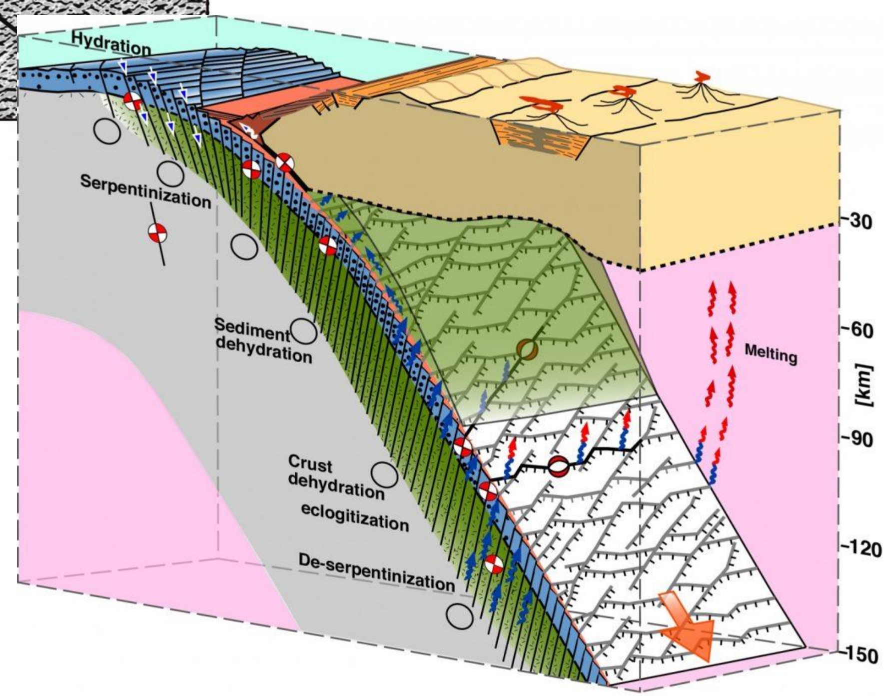
Goes et al., 2017

Active source

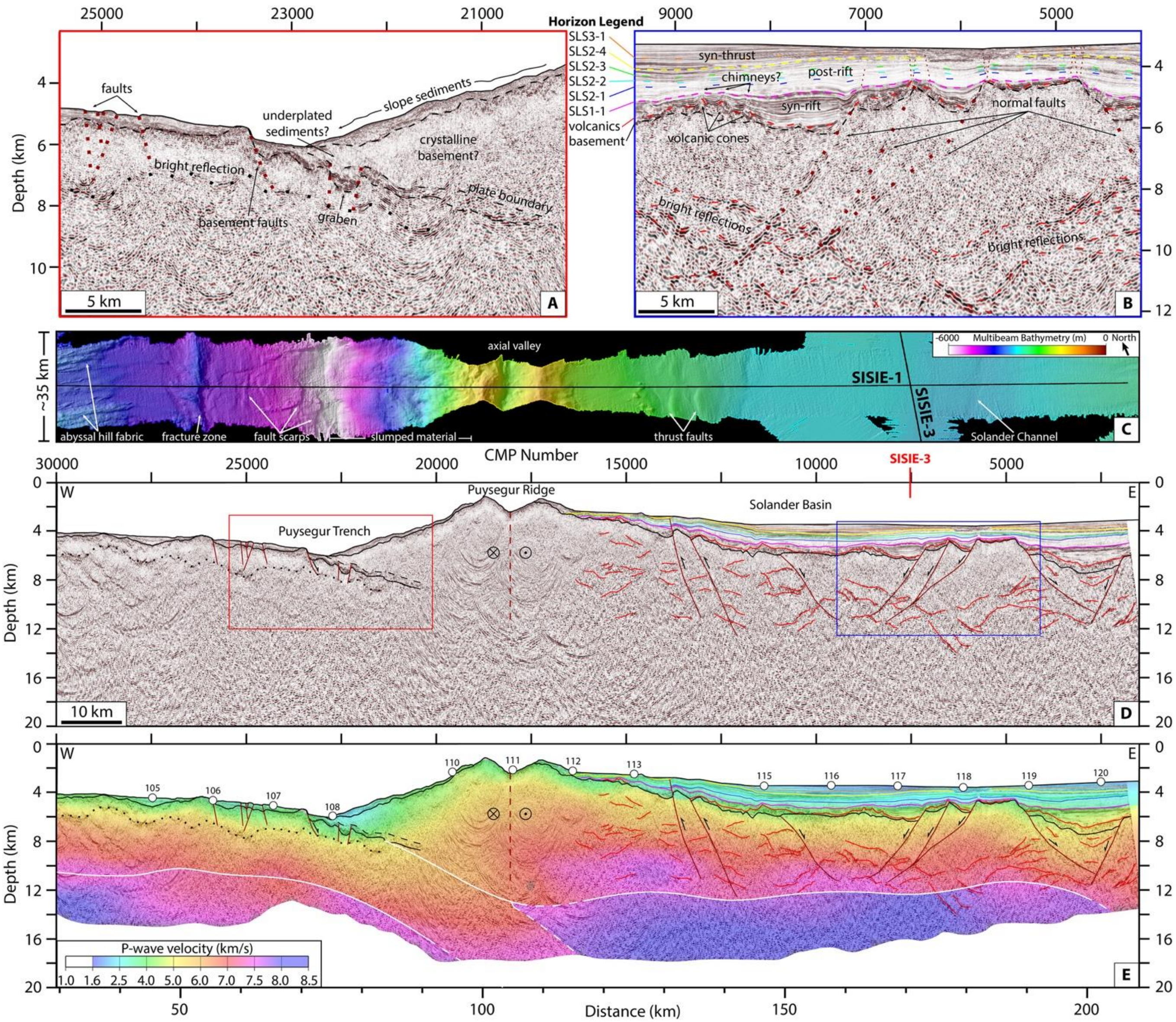


Ranero et al., 2003

"Bending-related faulting and mantle serpentinization at the Middle America trench"



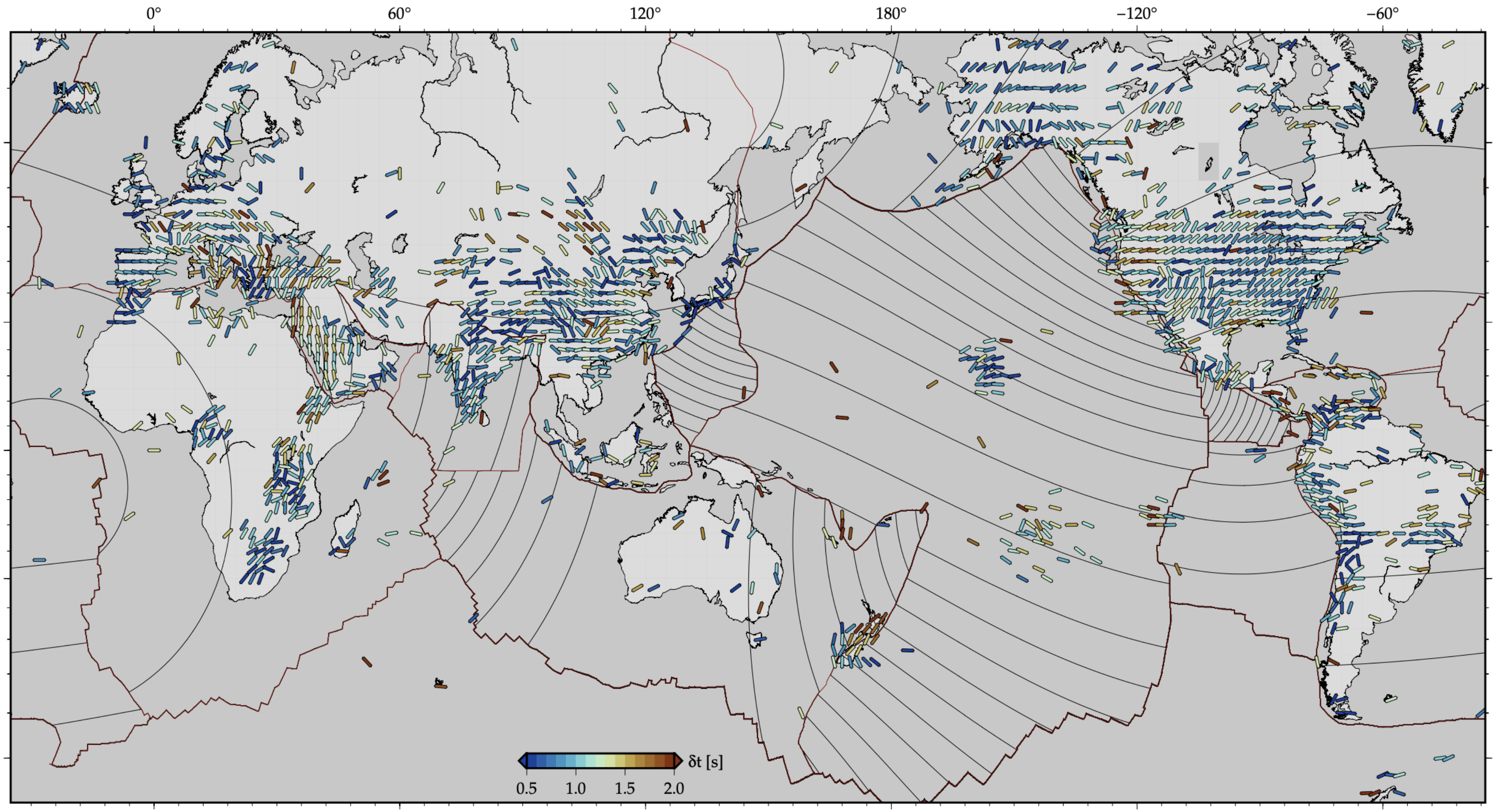
Active source



Shuck et al., 2021

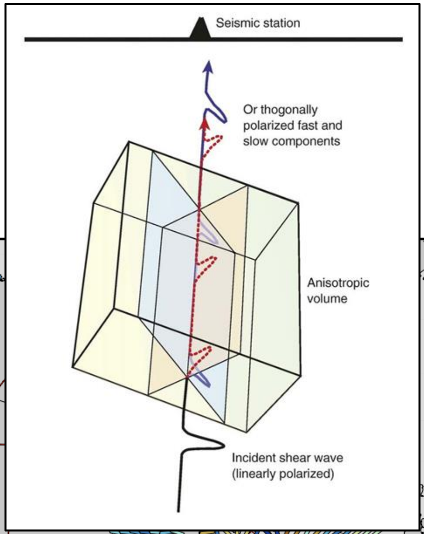
"Strike-Slip Enables Subduction Initiation Beneath a Failed Rift: New Seismic Constraints From Puysegur Margin, New Zealand"

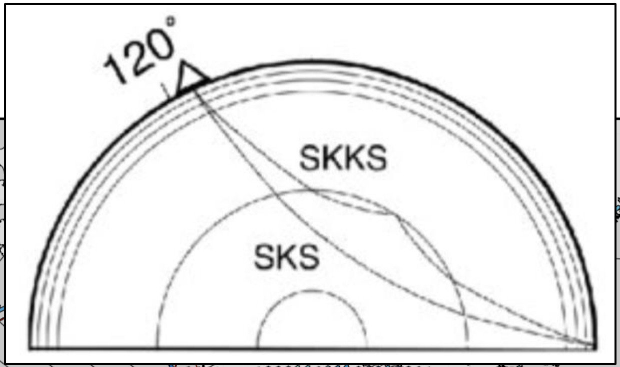
Seismic anisotropy

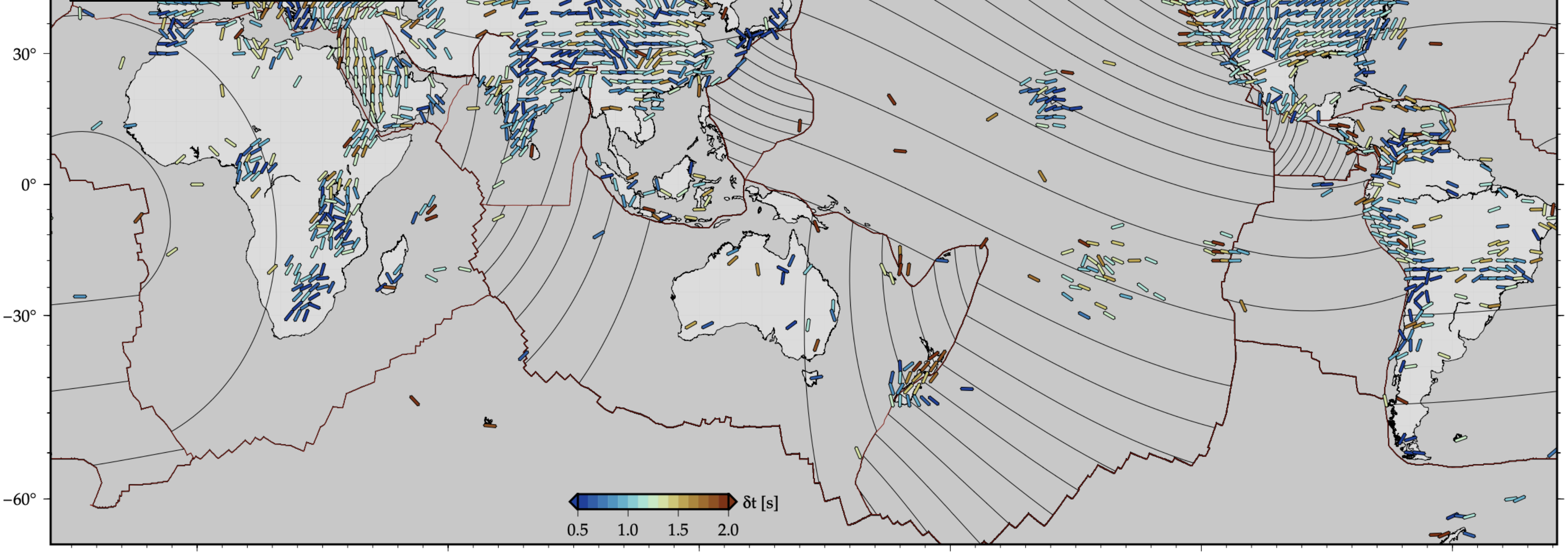


SKS splitting measurements, indicating “fast axes” (Becker et al., 2012 compilation)

Seismic anisotropy







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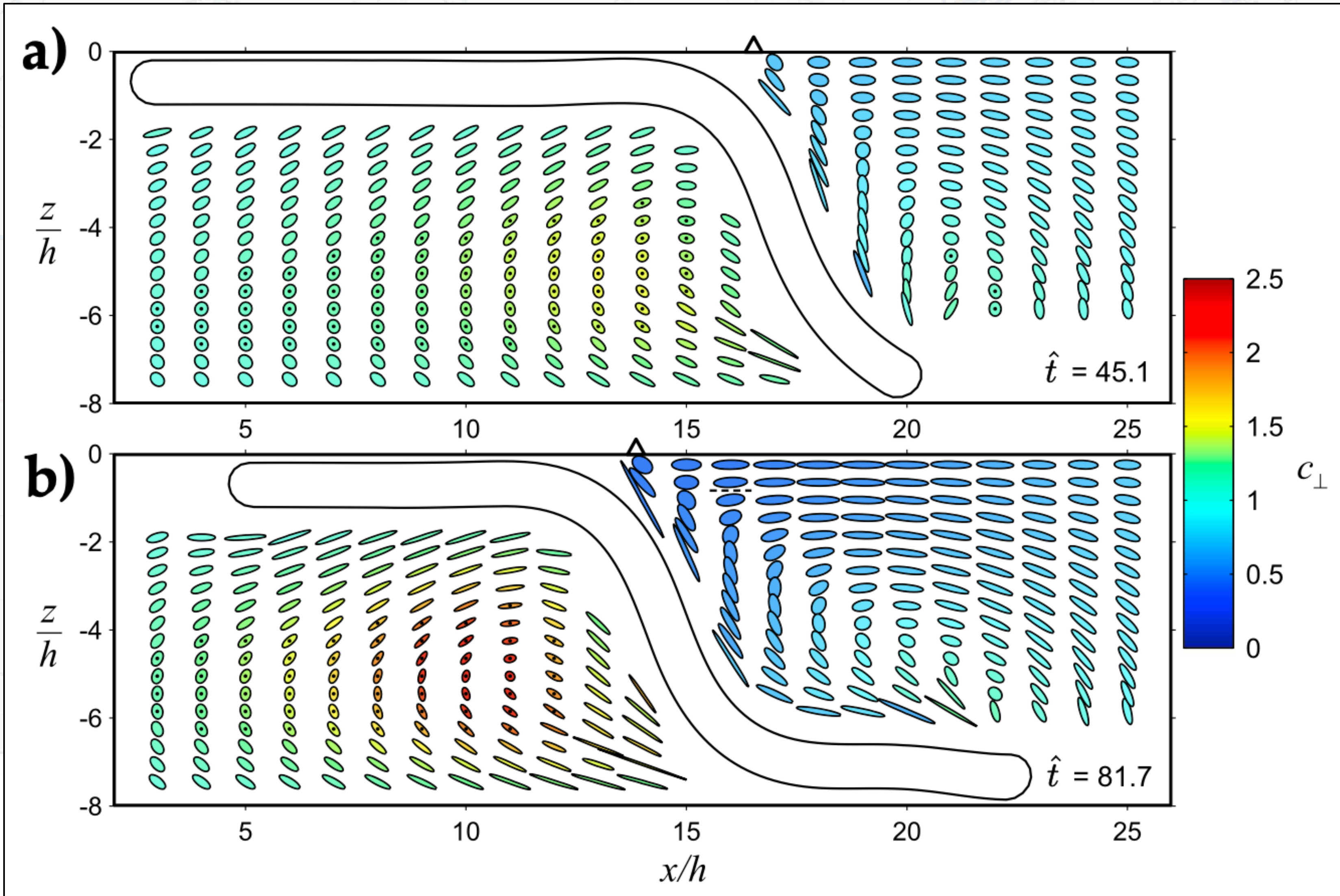
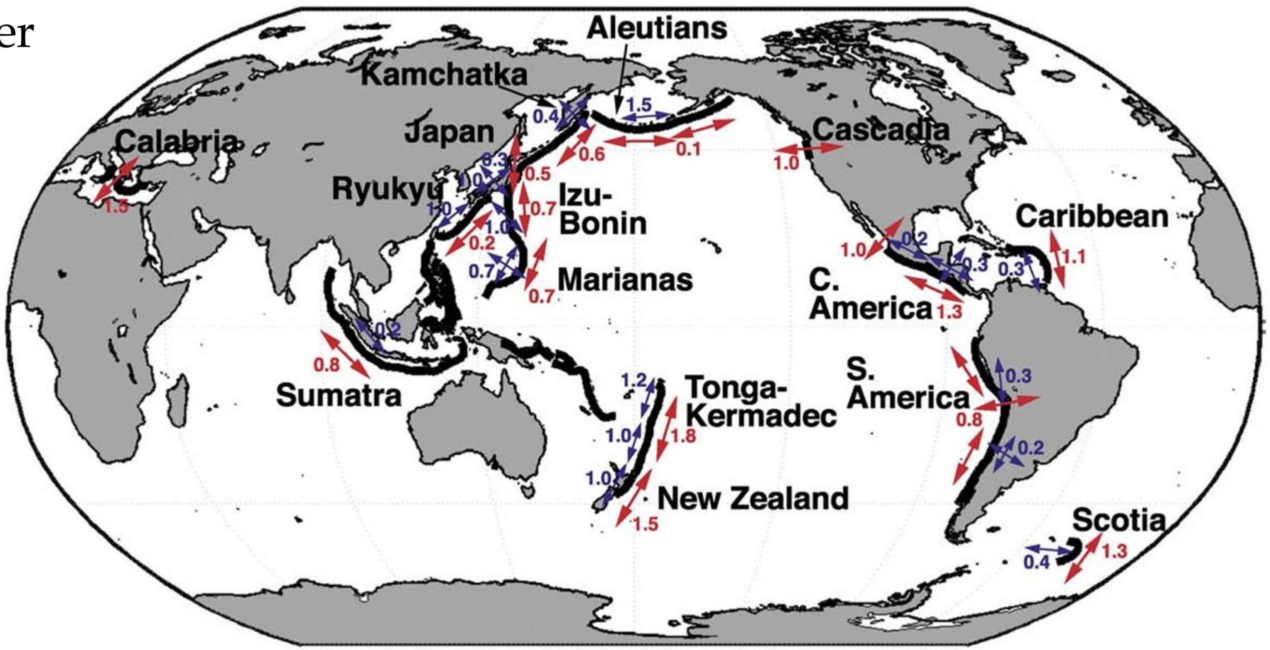
Seismic anisotropy

Li et al. (2014): Development of finite strain visualized by ellipses for two different timesteps of a slab rollback experiments.



Long and Silver compilation



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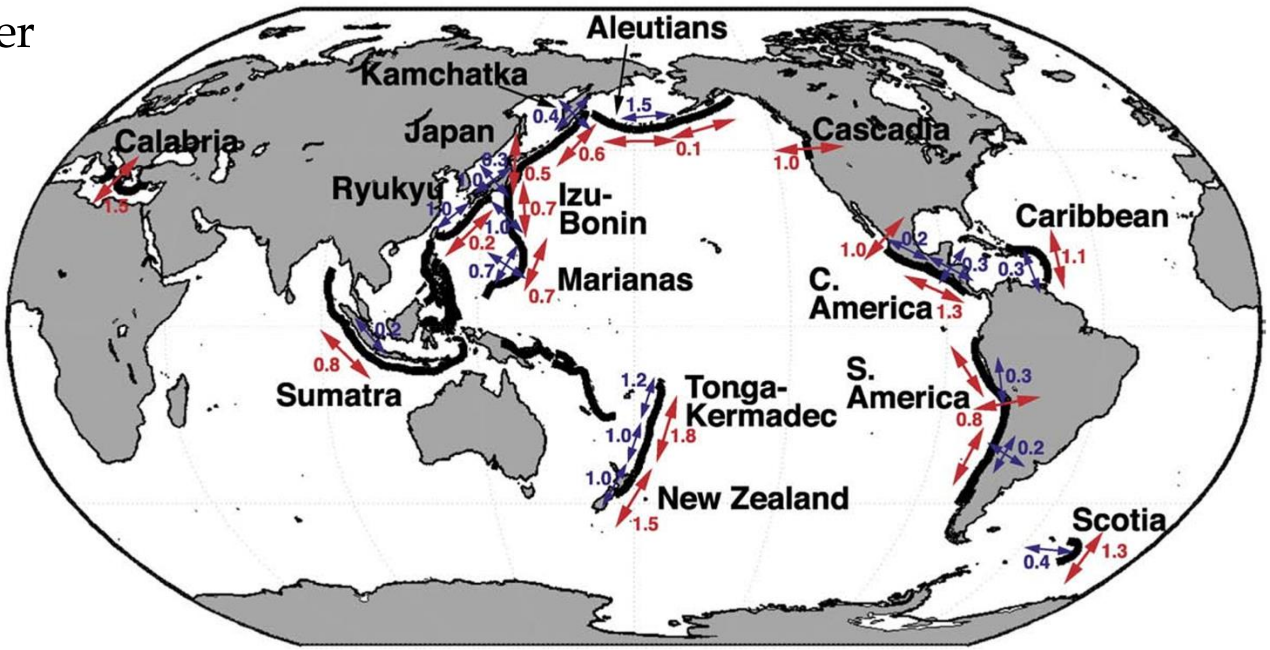
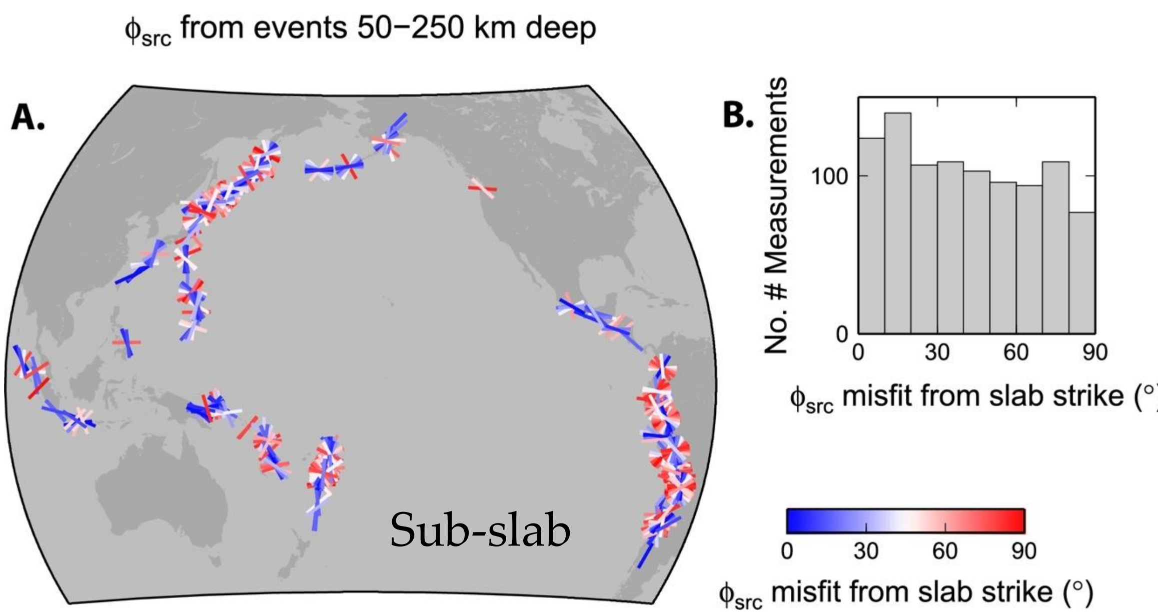


Walpole et al., 2017



What can we use to constrain the processes?

- ***Direct geological observations***
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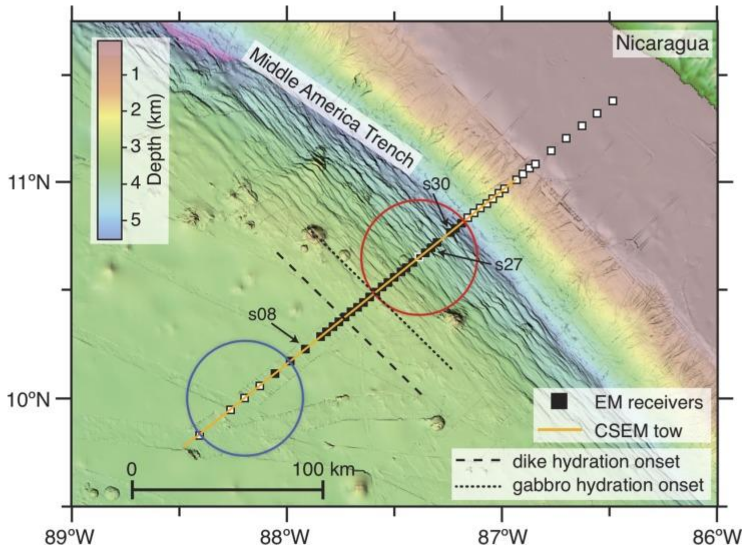
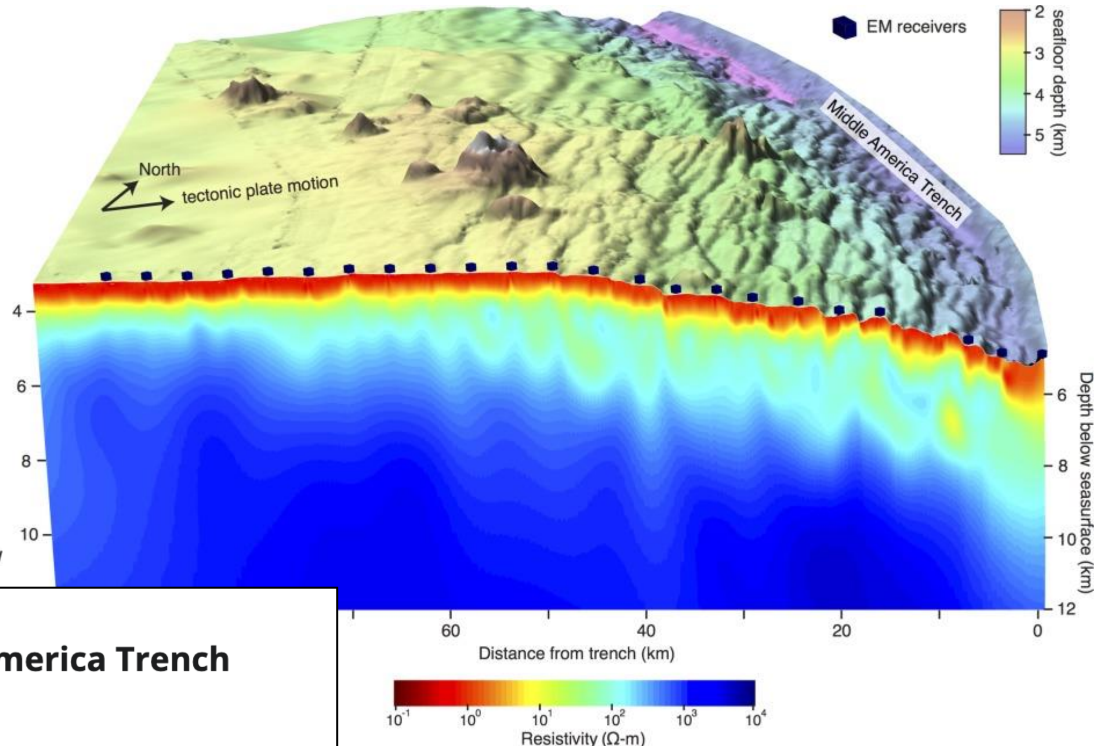
Magnetotelluric / Electromagnetic / Magnetic

Naif et al., 2015





Research Article | Free Access

Water-rich bending faults at the Middle America Trench

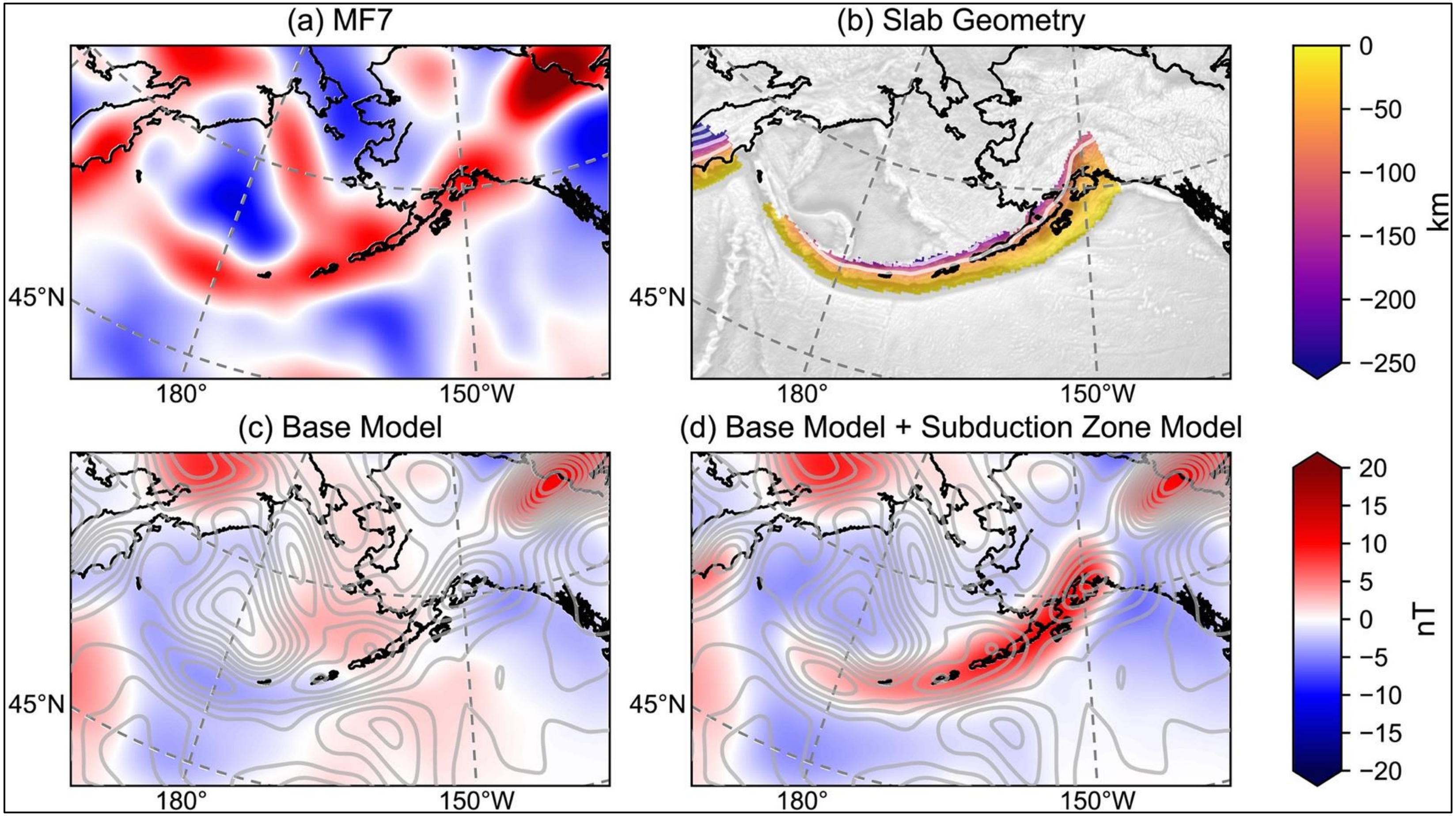
Samer Naif, Kerry Key, Steven Constable, Rob L. Evans

First published: 21 July 2015 | https://doi.org/10.1002/2015GC005927 | Citations: 79

CSEM: uses <u>controlled source</u> electromagnetic induction (high freq.) to map crustal resistivity variations, imaging fluid pathways and quantify porosity

MT: uses <u>passive source</u> (seafloor recordings of Earth's naturally occurring electric and magnetic fields are used to estimate electrical conductivity) lower frequency.

Magnetotelluric / Electromagnetic / Magnetic



Williams & Gubbins, 2019 (cf. Blakely et al., 2005):

Long-wavelength magnetic anomalies observed at satellite altitude.
Due to serpentinite (which contains magnetite)?

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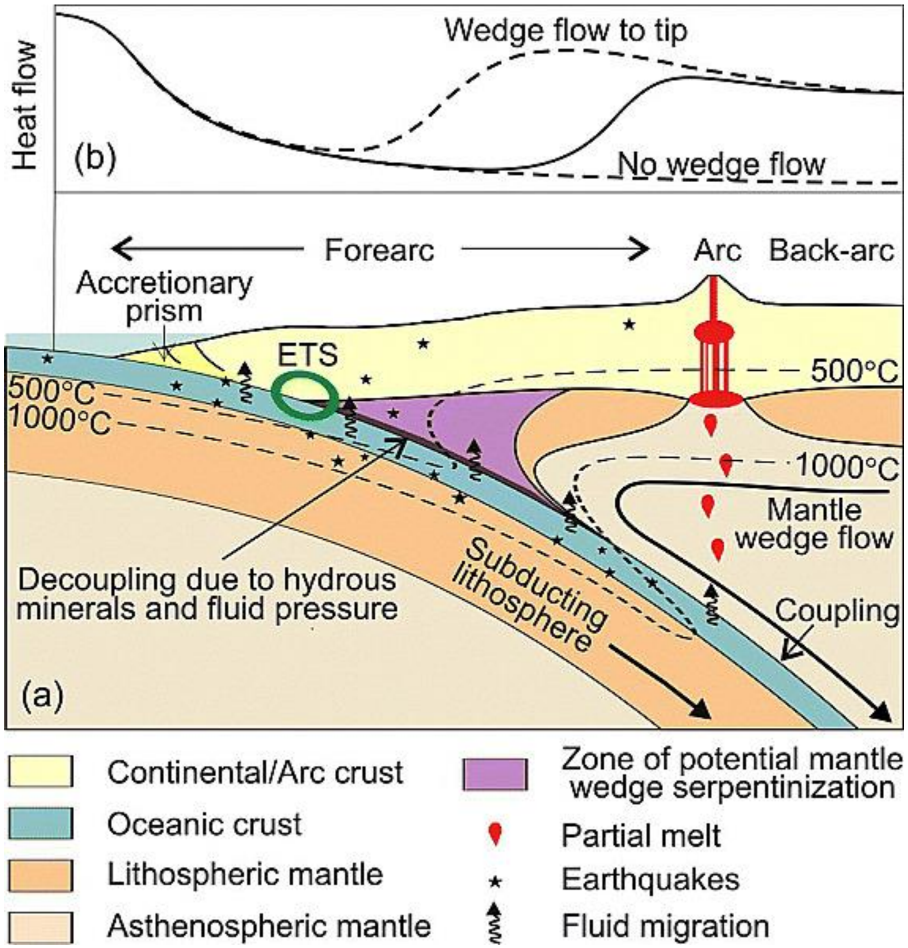
Surface heat flow

$$q = -k\nabla T$$



Wada and Wang, 2009

Surface heat flow

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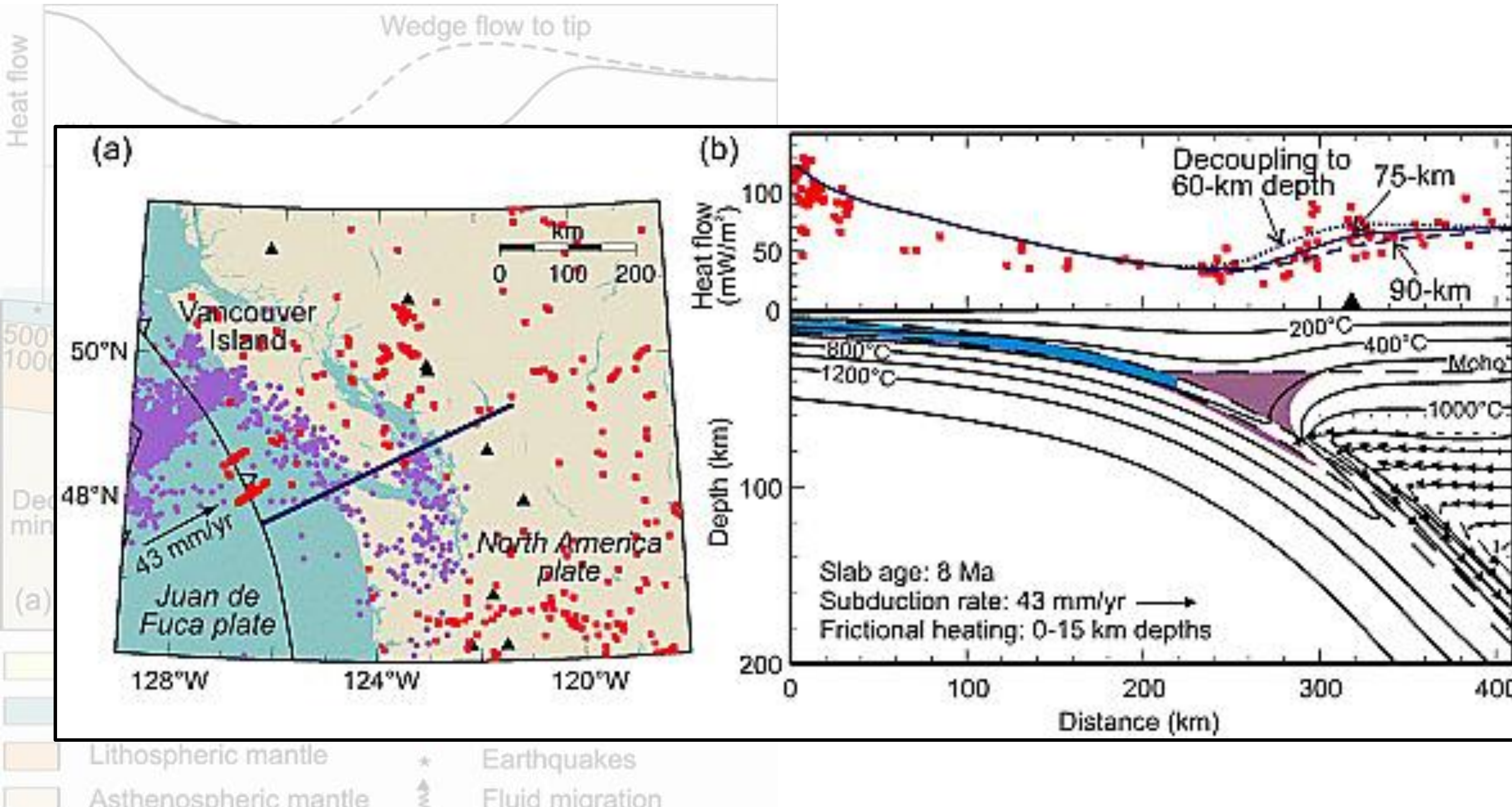

Wada and Wang, 2009

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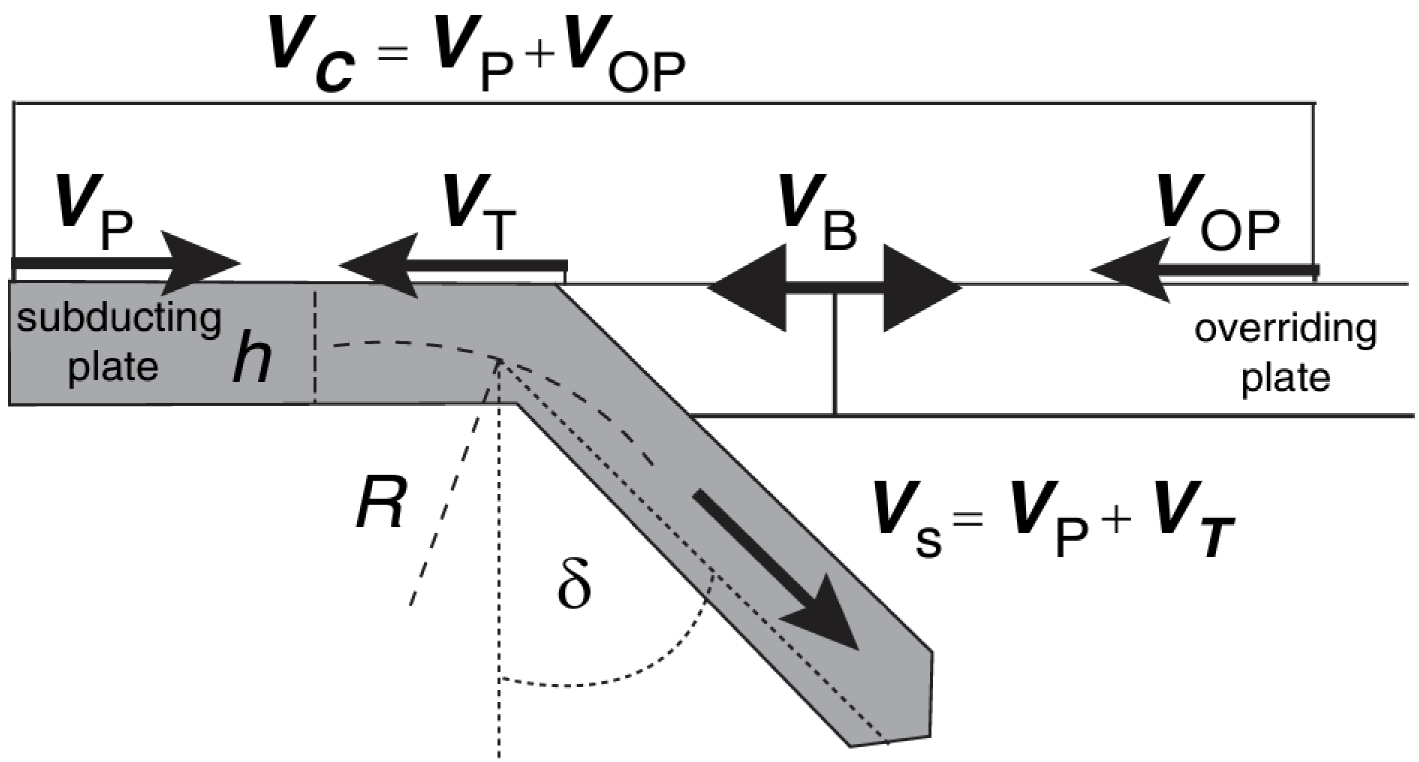
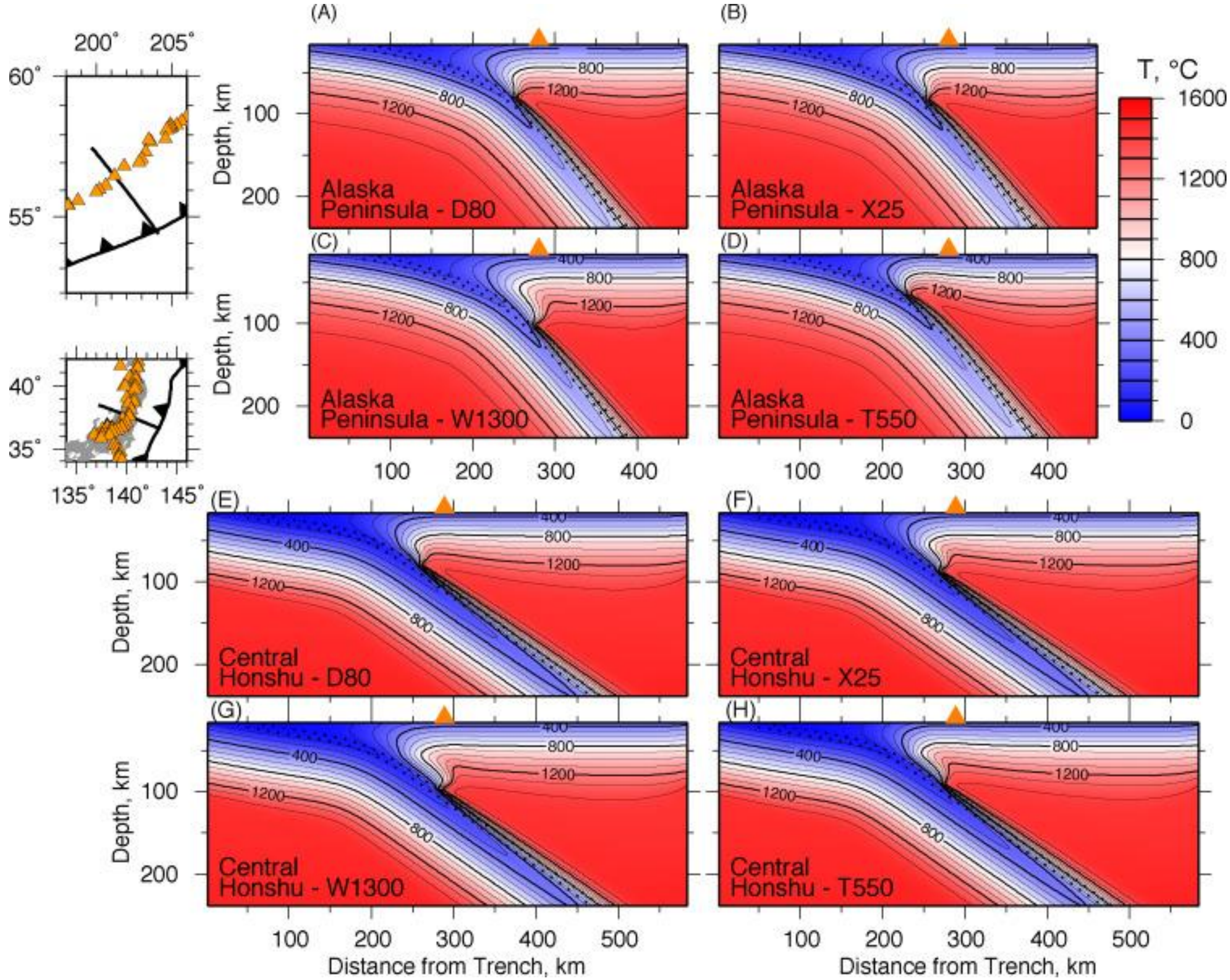
Subduction kinematics and dips



$V_C = V_P + V_{OP}$
V_P
V_T
V_B
V_{OP}
subducting plate
h
overriding plate
R
δ
$V_s = V_P + V_T$

Why care?

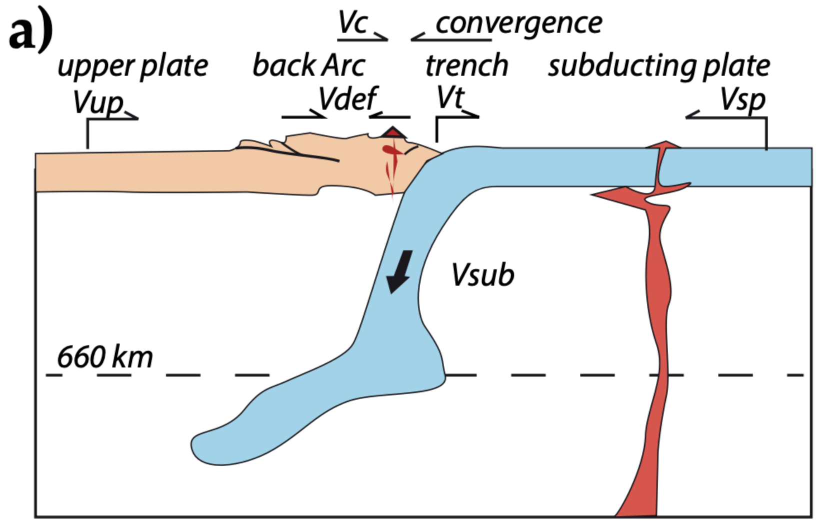
e.g., thermal structure (and the <u>many</u> associated processes)



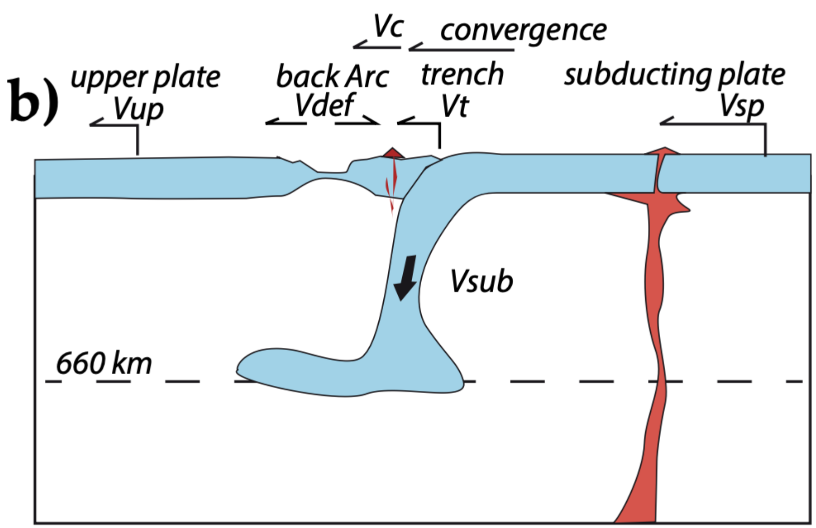
Syracuse et al., 2010

Why care?

e.g., tectonics



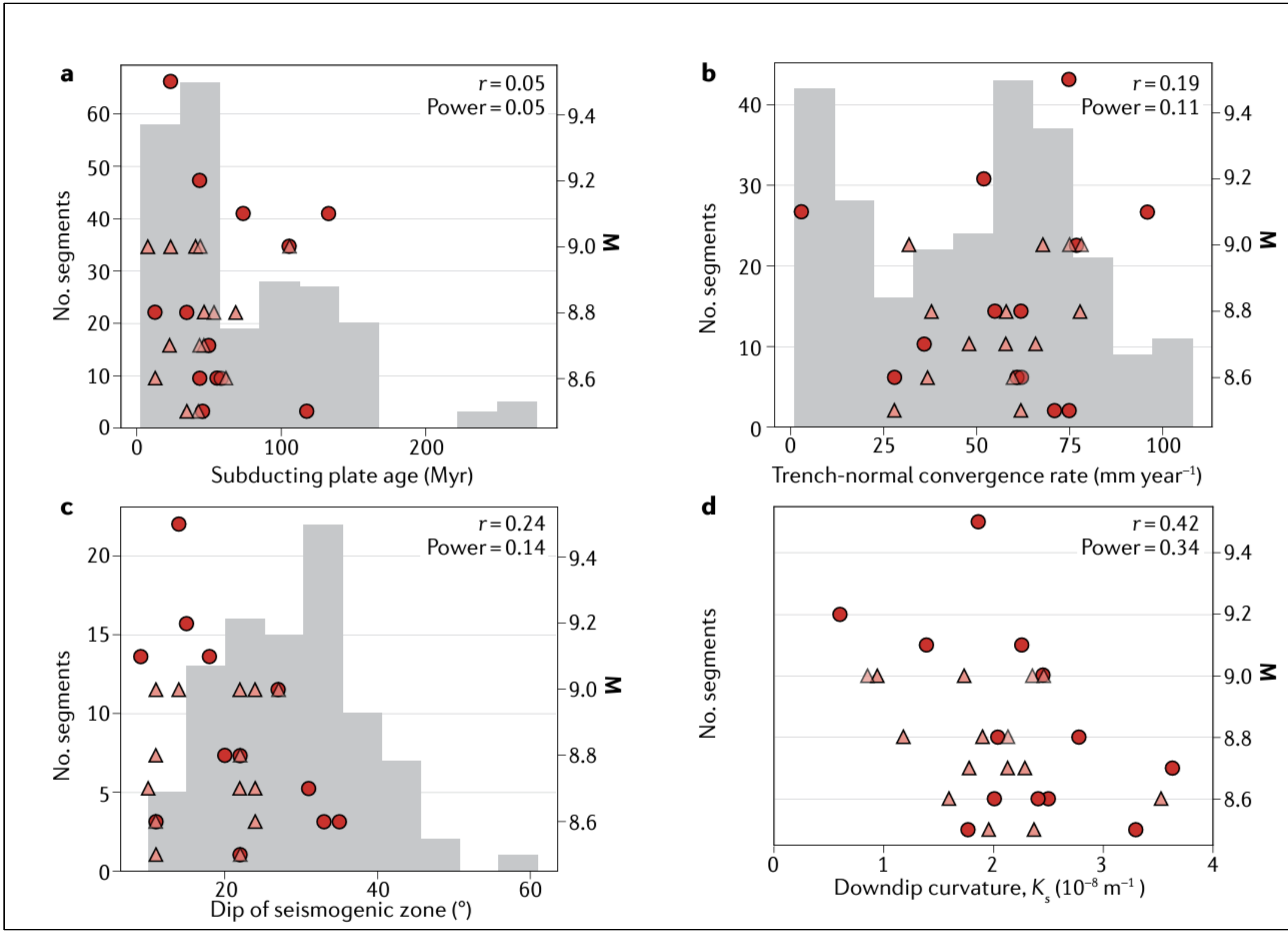
Andean-type



Marianas-type

Why do we care?

e.g., great EQs



Wirth et al., 2022

Relationships between variables

REVIEWS OF GEOPHYSICS, VOL. 24, NO. 2, PAGES 217–284, MAY 1986

Relations Among Subduction Parameters

RICHARD D. JARRARD

Lamont-Doherty Geological Observatory, Palisades, New York

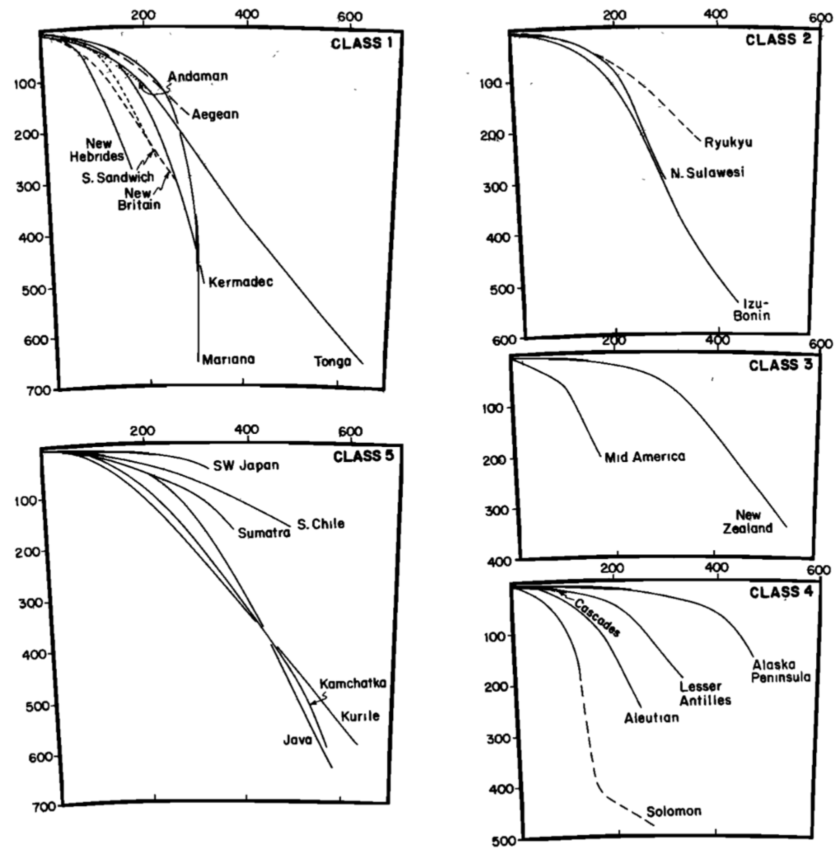
Symbol	Subduction Zone: Segment Name	Subduction Zone: Reference Position Lat., Long.	Upper Plate: Azimuth Perpendicular Trench	Crust	Strain Class	Slab: DipS	Slab: DipI	Slab: DipD	M_w'	Trench: Depth	Trench: Δd	Slab Extent: Horizontal	Slab Extent: Depth	Length Slab
AEG	Aegean	36, 22	49	C	1	20 ± 3	25 ± 3	43	···	···	···	290	180	340
MAK	Makran	24, 60	6	C	···	8	12	···	···	···	···	430	80	440
AND	Andaman	9, 92	84	C	1	19	22	···	···	···	···	270	140	310
SUM	Sumatra	−2, 98	53	C	5	16	19	50 ± 5	7.9	5.9	0.7	370	170	380
JAV	Java	−11, 112	8	T	5	16	21	63	7.1	7.45	2.15	570	630	870
SUL	North Sulawesi	2, 122	185	O	2	18	26	68	···	···	···	290	300	460
SAN	Sangihe	3, 126	280	O	···	···	···	56	···	···	···	620 ± 20	670	920
PHL	Philippine	8, 127	258	T	···	43	41	···	···	10.06	4.10	100	130 ± 20	170
RYK	Ryukyu	25, 128	318	C	2	19	23	45	8.0	7.51	1.97	300	280	440
SJP	SW Japan	33, 135	329	C	5	10	···	···	8.6	4.8	0.19	330	75	345
NZL	New Zealand	−40, 178	300	C	3	12	18	50	7.8	···	···	440	270	540
KER	Kermadec	−34, −178	289	O	1	23	30	71	8.1	10.05	4.49	330	500	640
TON	Tonga	−22, −174	290	O	1	23	28	57	8.3	10.8	5.24	670	650	940
NHB	New Hebrides	−17, 167	73	O	1	36	44	73	7.9	7.07	2.56	190	280	330
SOL	Solomon	−7, 155	40	O	4	35 ± 5	42 ± 5	84 ± 4	···	8.94	4.42	300	520	600
NBR	New Britain	−6, 150	338	O	1	30 ± 5	35 ± 5	58	···	8.24	3.73	250	290	390
PAL	Palau	7, 135	315	O	(4)	···	···	···	···	8.05	3.55	···	···	···
YAP	Yap	8, 138	295	O	(4)	···	···	···	···	8.53	···	···	···	···
MAR	Marianas	17, 148	270	O	1	19	24	81	7.2	9.66	4.95	310	700	860
IZU	Izu-Bonin	30, 143	262	O	2	22	28	65 ± 9	7.2	9.70	3.54	580	600	860
NJP	NE Japan	39, 144	282	C	6	15	19	27	8.35	8.0	1.95	1340	600	1480
KUR	Kurile	45, 152	320	C	(5)	22	28	50	8.8	9.78	4.27	650 ± 40	600 ± 40	890
KAM	Kamchatka	53, 162	301	C	(5)	19	25	54	9.0	7.5	2.0	580 ± 30	600 ± 30	860
ALU	Central Aleutians	50.5, 180	0	O	4	25	31	64	8.7	7.14	1.64	250	270	370
AKP	Alaska Peninsula	60, −152	285	C	4	9	13	51	···	···	···	470	155	530
ALA	Alaska	62, −149	328	C	6	7	10	···	9.1	···	···	620	160	650
CAS	Cascades	45, −125.5	87	C	4	9 ± 4	···	···	···	···	···	97	34	103
WMX	SW Mexico	17, −103	23	C	6	19	25	···	···	5.29	1.79	210	90	230
SMX	SE Mexico	15.5, −97	19	C	6	14	18	53	···	5.12	1.62	400	210	480
NIC	Middle America	12.5, −91	24	C	3	30	38	65	8.4	6.66	2.56	170	210	280
ANT	Lesser Antilles	16, −59	250	O	4	16	22	51	7.5	7.0	1.8	320	200	410
COL	Colombia	5, −78	105	C	6	22	26	38	8.8	4.0	0.8	315	215	390
ECU	Ecuador	−2, −81	101	C	6	···	(31)	(32)	···	···	···	···	210	···
PER	Peru	−10, −80	55	C	6	14	13	(5)	8.6	6.3	1.6	710	190	730
NCH	North Chile	−21, −71	67	C	7	20	21	30	8.65	8.05	3.35	810	600	1040
CCH	Central Chile	−30, −72	100	C	7	16	14	(5)	8.65	6.4	2.2	720	180	730
SCH	South Chile	−38, −74	105	C	5	13	16	30	9.5	4.7	0.6	490	170	520
TDF	Tierra del Fuego	−49, −77	93	C	(3)	···	···	···	···	···	···	···	···	···
SCO	South Sandwich	−58, −24	270	O	1	31	38	67	7.0	8.26	3.81	220	250	350

Symbol	Age Slab	Age Tip	Time Since Tip Subducted: C	Time Since Tip Subducted: M	Descent Angle: C	Descent Angle: M	Arc: Age Arc	Arc: Gap $a-t$	RC	Rate Perpendicular to Trench*: V_c C	V_c M	V_{cba} C	V_{cba} M	V_{oa} C	V_{oa} M	Rollback C	Rollback M
AEG	···	···	8.9	10.0	73	100	11 ± 1	210	2	0.7	0.4	3.8	3.4	−1.1	−0.1	2.0	2.9
MAK	97	87	11.9	11.9	···	···	46	480	···	3.7	3.7	3.7	3.7	−0.3	−0.4	−0.3	−0.4
AND	72 ± 5	51 ± 7	9.7	11.9	···	···	100 ± 40	270	7	2.1	1.4	3.2	2.6	−0.5	−0.1	0.6	1.1
SUM	55 ± 5	45 ± 7	6.1	6.8	50	48	27 ± 3	300	22	6.2	5.6	6.2	5.6	0.0	−0.2	0.0	−0.2
JAV	138 ± 10	107 ± 10	10.6	10.7	68	61	27 ± 3	300	39	8.2	8.1	8.2	8.1	0.7	−0.3	0.7	−0.3
SUL	38	9 ± 6	15.3	15.3	···	···	7 ± 4	150	6	3.0	3.0	3.0	3.0	···	···	···	···
SAN	···	···	···	···	···	···	13 ± 5	···	7	···	···	···	···	0.6	0.0	···	···
PHL	···	···	3.7	2.1	···	···	6 ± 4	250	18	4.6	8.0	4.6	8.0	0.3	0.1	0.3	0.1
RYK	49	37 ± 7	14.7	9.2	64	45	55 ± 5	150	14	3.0	4.8	3.0	4.8	1.1	0.0	1.1	0.0
SJP	21	3 ± 3	26.5	17.2	···	···	175 ± 5	300	4	1.3	2.0	1.3	2.0	1.2	0.0	1.2	0.0
NZL	98	97 ± 5	16.4	18.0	24	18	21 ± 3	280	50	3.3	3.0	3.3	3.0	−3.7	−5.3	−3.7	−5.3
KER	113	114	10.4	11.3	87	79	30 ± 2	165	50	5.1	4.7	10.5	10.1	−2.5	−4.0	2.9	1.4
TON	120 ± 20	110 ± 30	9.6	10.0	74	67	24 ± 7	185	45	7.5	7.2	12.5	12.2	−1.2	−2.7	3.8	2.3
NHB	52	45	···	···	···	···	8 ± 3	140	30	(8.8)	(8.4)	(9.0)	(8.6)	(6.3)	(6.7)	(6.8)	(6.9)
SOL	50 ± 10	45 ± 16	5.0	5.1	98	96	8 ± 3	100	12	12.0	11.8	12.0	11.8	3.0	2.5	3.0	2.5
NBR	50 ± 10	47 ± 14	2.7	2.6	76	70	8 ± 3	125	6	4.3	4.5	14.7	14.9	−5.8	−7.1	4.6	3.3
PAL	31 ± 3	···	···	···	···	···	45 ± 5	···	3	0.6	0.6	0.6	0.6	−3.2	−7.1	−3.2	−7.1
YAP	33	···	···	···	···	···	45 ± 5	···	4.5	1.2	1.2	1.2	1.2	−3.9	−8.1	−3.9	−8.1
MAR	155	134	9.4	17.1	87	66	45 ± 5	225	8	6.0	3.4	10.3	7.7	−3.3	−6.5	1.0	−2.2
IZU	146	122	11.3	13.6	57	45	45 ± 5	210	85	7.6	6.3	7.6	6.3	−1.2	−3.0	−1.2	−3.0
NJP	130	94	14.9	14.5	29	28	115 ± 5	300	11	9.9	10.2	9.9	10.2	0.7	0.2	0.7	0.2
KUR	119	89	10.2	10.4	56	49	82 ± 16	190	15	8.7	8.6	8.7	8.6	1.1	−0.2	1.1	−0.2
KAM	90 ± 15	72 ± 18	9.8	10.0	60	54	153 ± 10	225	15	8.8	8.6	8.8	8.6	1.0	0.0	1.0	0.0
ALU	54	48 ± 15	6.2	6.3	84	72	56 ± 6	190	14	6.0	5.9	6.0	5.9	2.1	0.9	2.1	0.9
AKP	46	50 ± 10	12.9	13.6	46	48	160 ± 10	400	14	4.1	3.9	4.1	3.9	−0.5	−0.3	−0.5	−0.3
ALA	46	48 ± 10	10.3	10.7	···	···	160 ± 10	470	···	6.3	6.1	6.3	6.1	1.2	0.8	1.2	0.8
CAS	8	9	3.0	3.0	···	···	175 ± 10	280	90	3.4	3.4	3.4	3.4	2.2	1.8	2.2	1.8
WMX	15	14	3.9	4.1	···	···	90 ± 3	240	·15	5.9	5.6	5.9	5.6	1.9	2.1	1.9	2.1
SMX	14	14	6.7	6.9	65	68	90 ± 3	380	15	7.2	7.0	7.2	7.0	1.6	1.9	1.6	1.9
NIC	23 ± 5	23 ± 5	4.3	4.4	59	63	100 ± 10	150	10	6.5	6.4	6.5	6.4	−0.8	−0.3	−0.8	−0.3
ANT	68	78	11.1	11.1	80	67	48 ± 4	260	5.5	3.7	3.7	3.7	3.7	1.8	1.1	1.8	1.1
COL	15 ± 10	8 ± 10	5.7	5.6	56	59	242 ± 5	270	173	6.8	6.9	6.8	6.9	2.5	2.9	2.5	2.9
ECU	32	···	···	···	···	···	226 ± 19	275	6	7.9	7.7	7.9	7.7	2.5	3.0	2.5	3.0
PER	45	57	8.9	9.5	···	···	226 ± 19	···	19	8.2	7.7	8.2	7.7	1.5	2.7	1.5	2.7
NCH	82	112	10.4	11.7	35	43	226 ± 19	300	140	10.0	8.9	10.0	8.9	1.6	2.9	1.6	2.9
CCH	48	68	7.4	8.6	···	···	226 ± 19	···	10	9.8	8.5	9.8	8.5	2.0	2.8	2.0	2.8
SCH	26 ± 5	30 ± 6	5.4	6.3	36	42	226 ± 19	300	55	9.7	8.2	9.7	8.2	1.7	2.5	1.7	2.5
TDF	20	···	···	···	···	···	150 ± 6	230	7	2.3	2.1	2.3	2.1	1.2	2.3	1.2	2.3
SCO	49	74	4.6	4.6	116	111	30	150	3	0.9	0.9	7.9	7.9	−0.4	−1.1	6.6	5.9

Relationships between variables

TABLE 3. Strain Classification

Class	Description	Subduction Zones
1	active back-arc spreading	South Sandwich New Britain Marianas New Hebrides Tonga Kermadec Andaman Aegean
2	very slow back-arc spreading	Ryukyu Izu-Bonin North Sulawesi
3	mildly tensional	Middle America New Zealand (Tierra del Fuego?)
4a	neutral	Lesser Antilles Solomon Cascades (Palau?) (Yap?)
4b	gradient: mildly tensional to mildly compressional	Aleutians Alaska Peninsula
5	mildly compressional	SW Japan Java Sumatra South Chile (Kurile?) (Kamchatka?)
6	moderately compressional	Colombia Ecuador Peru Alaska NE Japan SE Mexico (SW Mexico?)
7	very strongly compressional	North Chile Central Chile



Jarrard, 1986

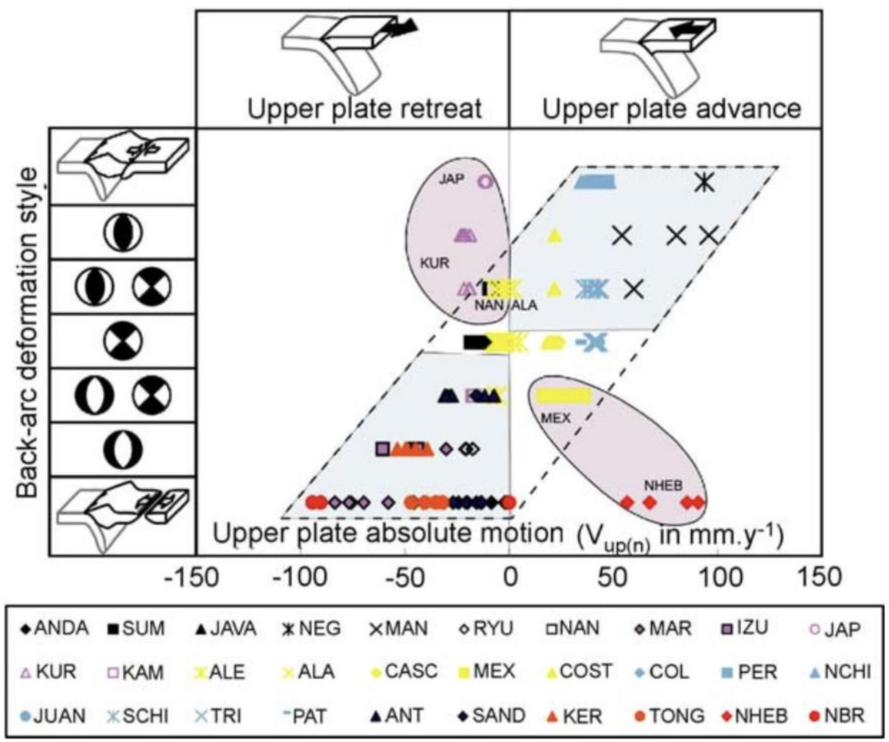
Relationships between variables

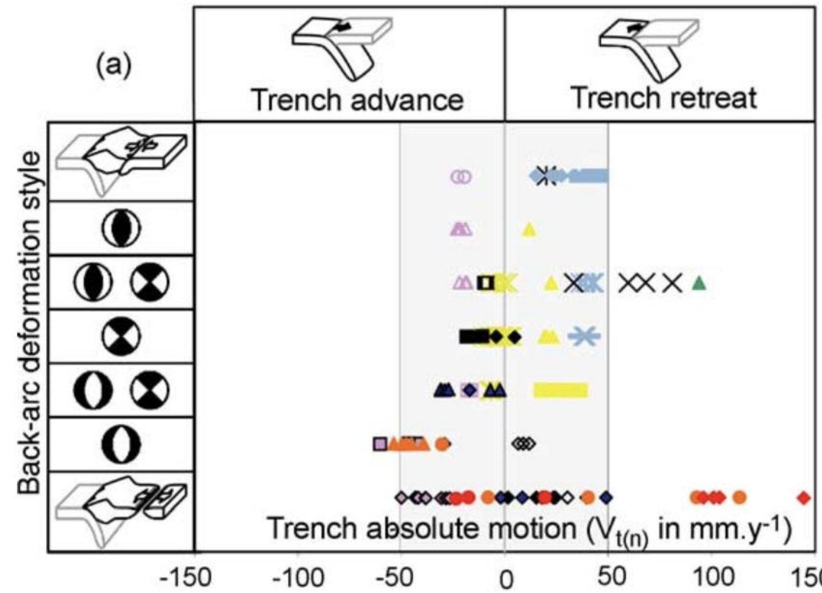
Clues to the dynamics of the subduction process are found in the many measurable parameters of modern subduction zones. Based on a critical appraisal of the geophysical and geological literature, 26 parameters are estimated for each of 39 modern subduction zones. To isolate causal relationships among these parameters, multivariate analysis is applied to this data set. This analysis yields empirical quantitative relations that predict strain regime and strike-slip faulting in the overriding plate, maximum earthquake magnitude, Benioff zone length, slab dip, arc-trench gap, and maximum trench depth. Excellent correlation is found between length of the Benioff zone and the product of convergence rate and age of the downgoing slab. This relationship is consistent with the conductive heating model of Molnar et al. (1979), if the model is modified in one respect. The rate of heating of the slab is not constant; it is substantially slower during passage of the slab beneath the accretionary prism and overriding plate. The structural style in the overriding plate is determined by its stress state. Though the stress state of overriding plates cannot be quantified, one can classify each individual subduction zone into one of seven semiquantitative strain classes that form a continuum from strongly extensional (class 1, back-arc spreading) to strongly compressional (class 7, active folding and thrusting). This analysis indicates that strain class is probably determined by a linear combination of convergence rate, slab age, and shallow slab dip. Interplate coupling, controlled by convergence rate and slab age, is an important control on strain regime and the primary control on earthquake magnitude. Arc-parallel strike-slip faulting is a common feature of convergent margins, forming a forearc sliver between the strike-slip fault and trench. Optimum conditions for the development of forearc slivers are oblique convergence, a compressional environment, and a continental overriding plate. The primary factor controlling presence of strike-slip faulting is coupling; strongly oblique convergence is not required. The rate of strike-slip faulting is affected by both convergence obliquity and convergence rate. Maximum trench depth is a response to flexure of the underthrusting plate. The amount of flexural deflection at the trench depends on the vertical component of slab pull force, which is very sensitive to slab age and shallow slab dip. Shallow slab dip conforms to the cross-sectional shape of the overriding plate, which is controlled by width of the accretionary prism and duration of subduction. Deep slab dip is affected by the mantle trajectory established at shallow depth but may be modified by mantle flow. Much of the structural complexity of convergent margins is probably attributable to terrane juxtaposition associated with temporal changes in both forearc strike-slip faulting and strain regime. Empirical equations relating subduction parameters can provide both a focus for future theoretical studies and a conceptual and kinematic link between plate tectonics and the geology of subduction zones.

Jarrard, 1986

A bit more recently…

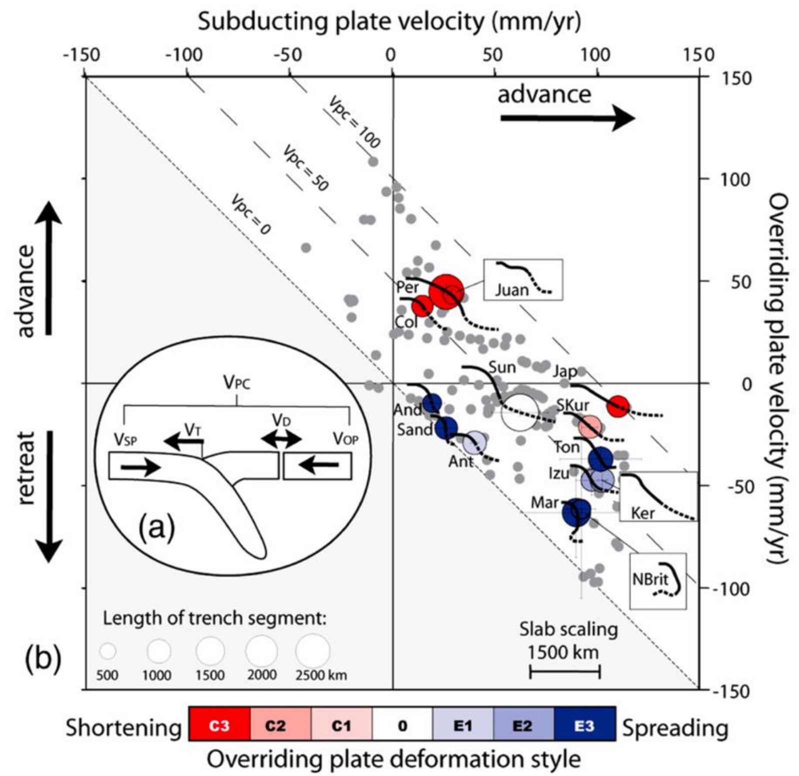
Interplay between trench motion, far-field OP motion, and back-arc deformation

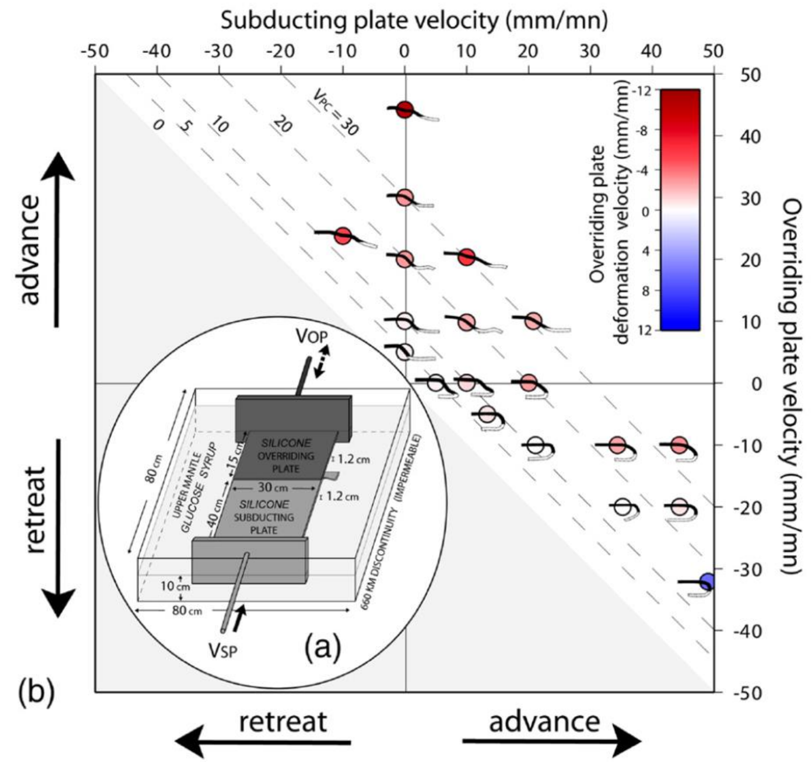




Heuret & Lallemand, 2005; Lallemand et al., 2005; Heuret et al., 2007, 2011

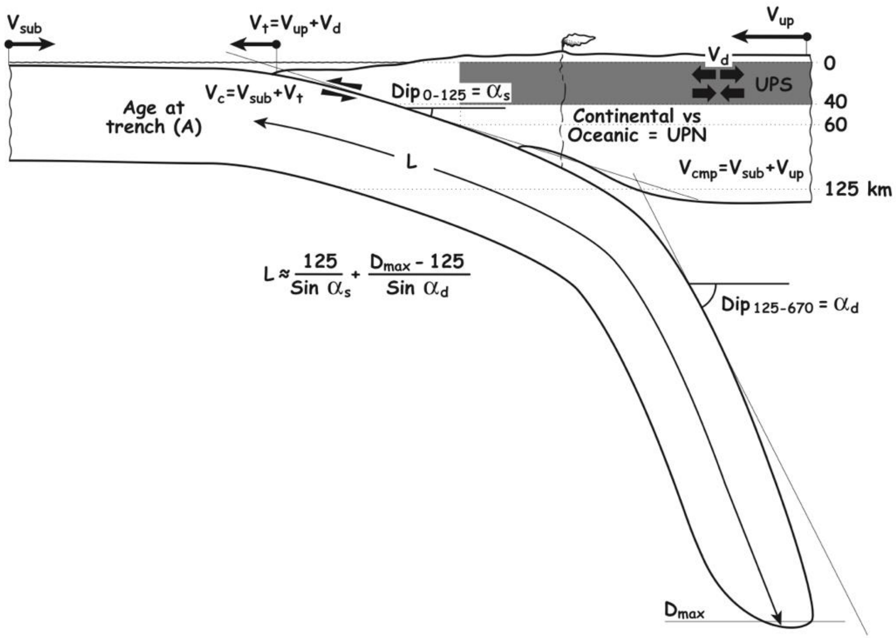
Elements of this can be reproduced within numerical and/or analog models:





Heuret & Lallemand, 2005; Lallemand et al., 2005; **Heuret et al., 2007**, 2011

Dip trickier…



Heuret & Lallemand, 2005; **Lallemand et al., 2005**; Heuret et al., 2007, 2011

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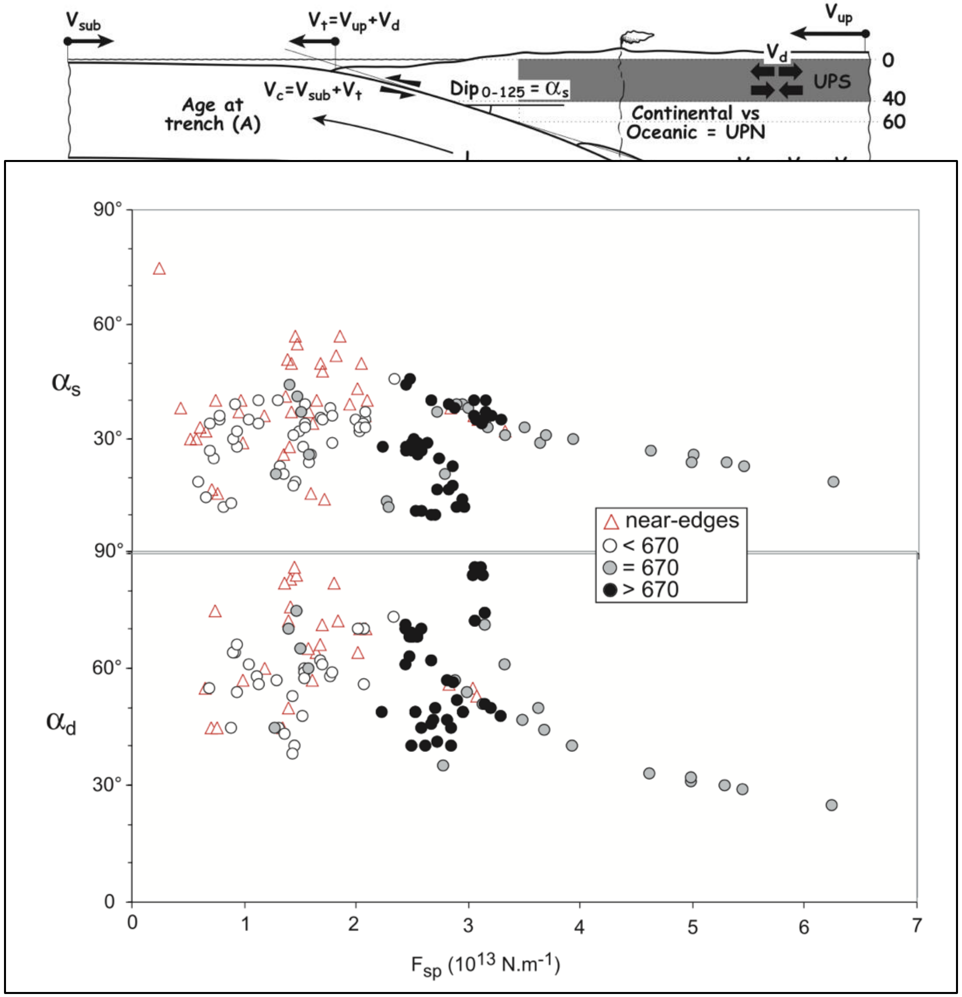
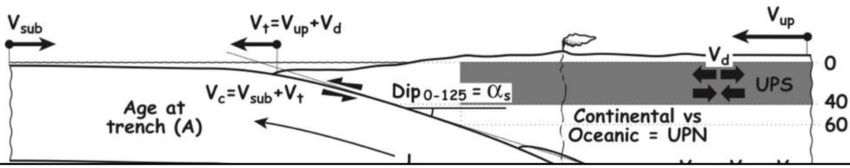
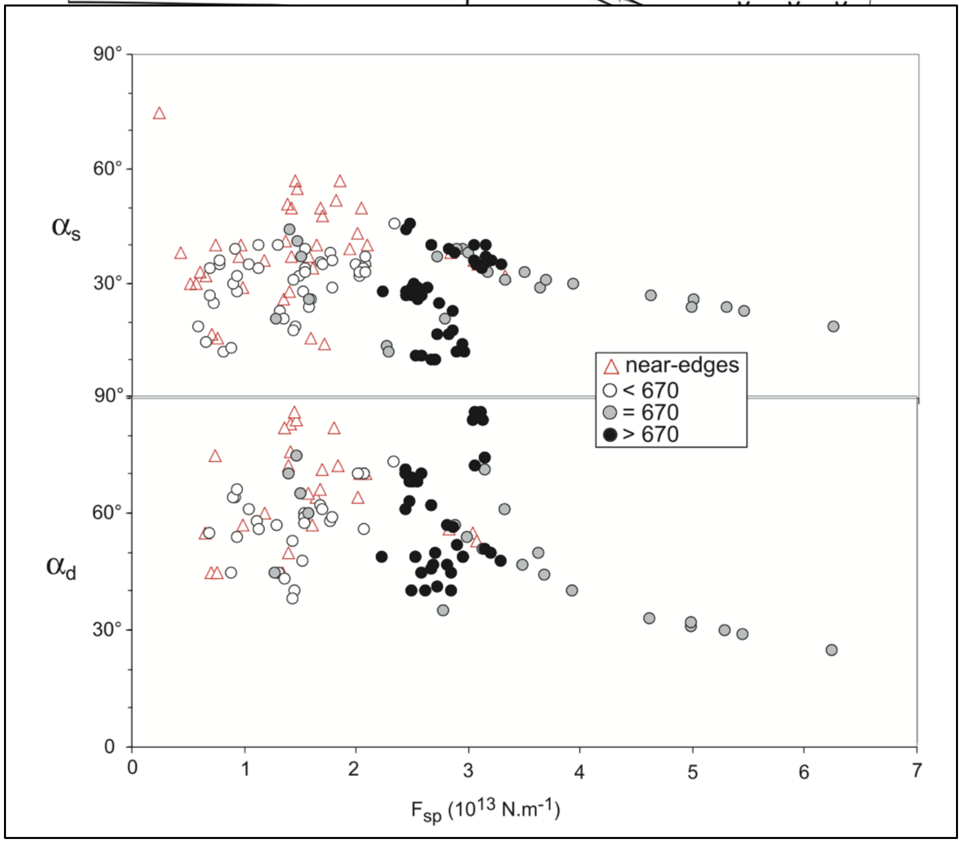
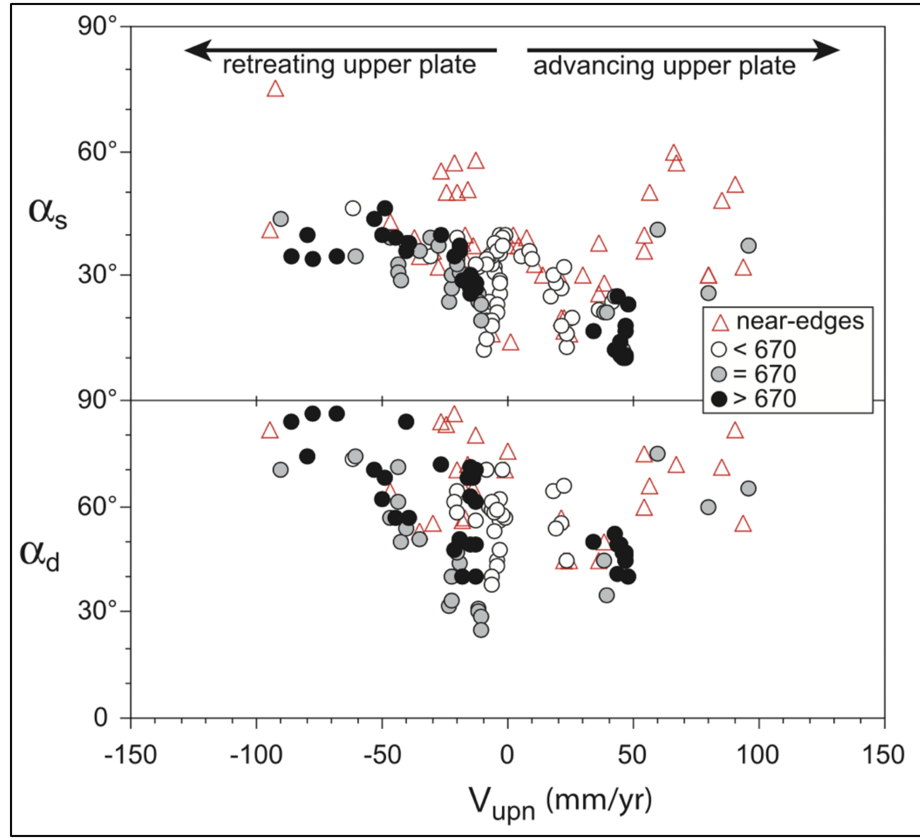


Heuret & Lallemand, 2005; **Lallemand et al., 2005**; Heuret et al., 2007, 2011

Dip trickier…



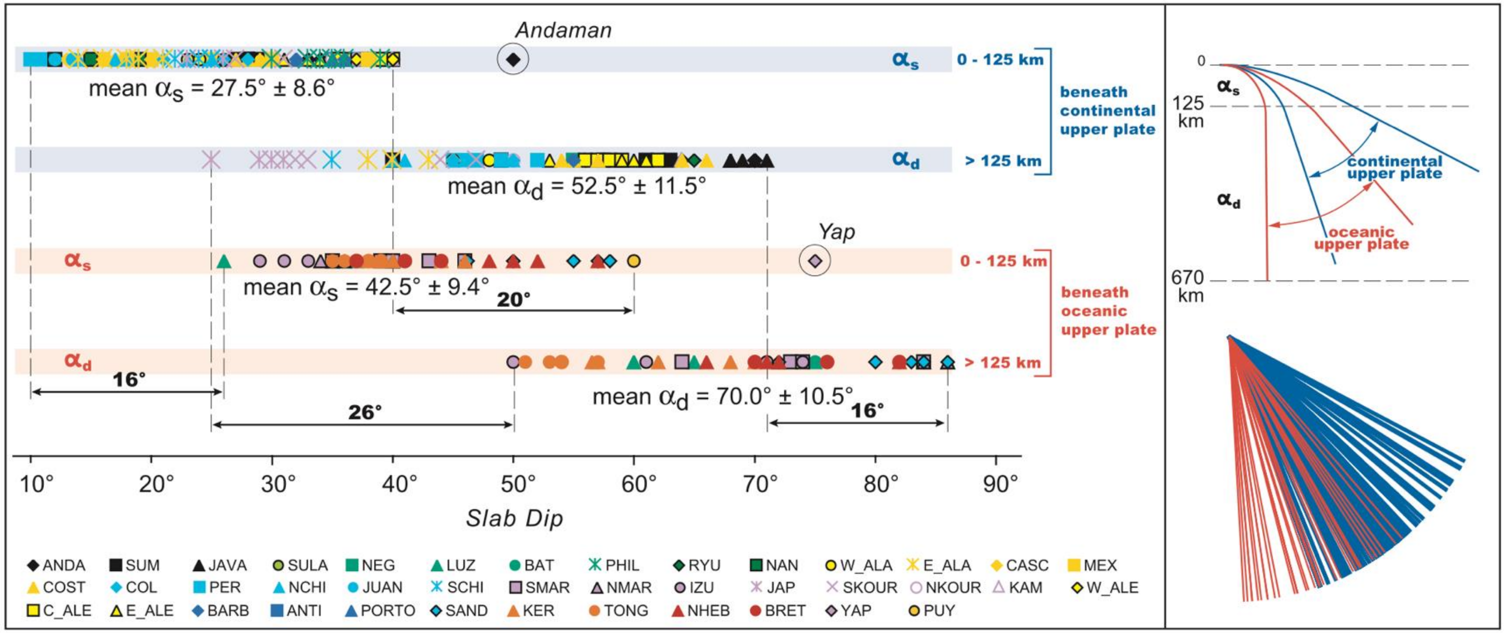


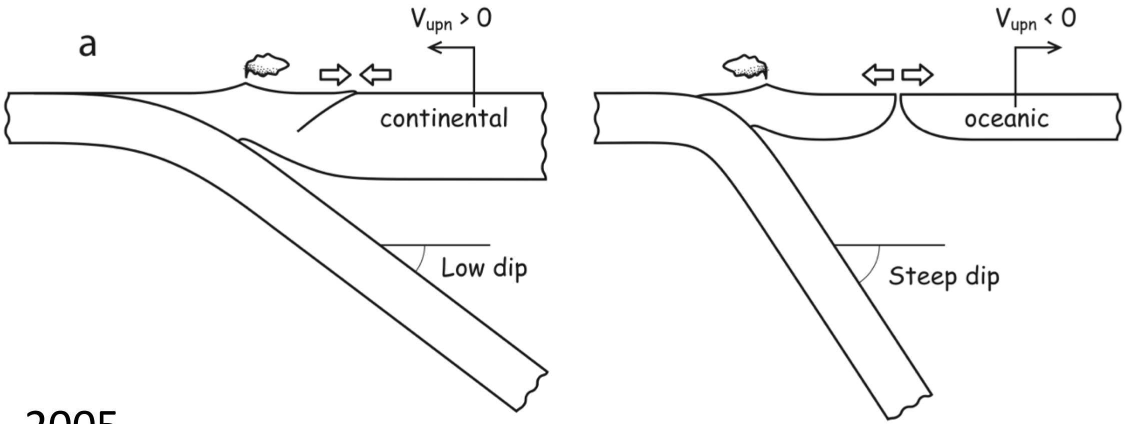


Heuret & Lallemand, 2005; **Lallemand et al., 2005**; Heuret et al., 2007, 2011

Dip trickier…

Upper plate type?

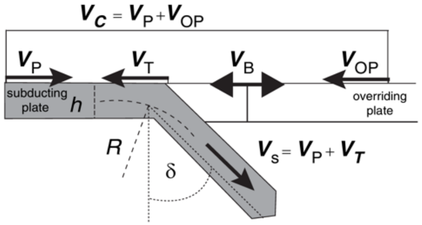


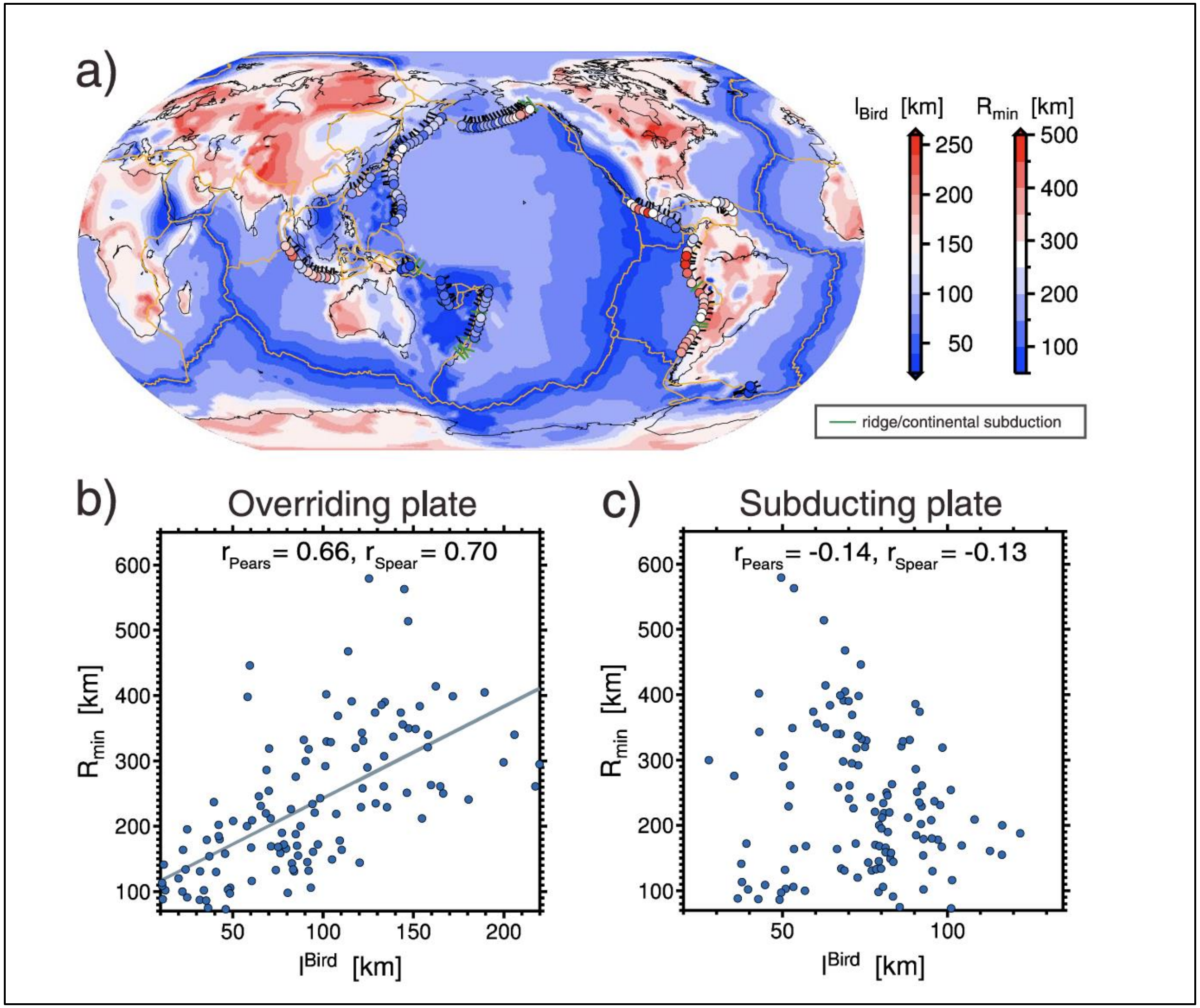


Lallemand et al., 2005

Dip trickier…

Upper plate thickness?

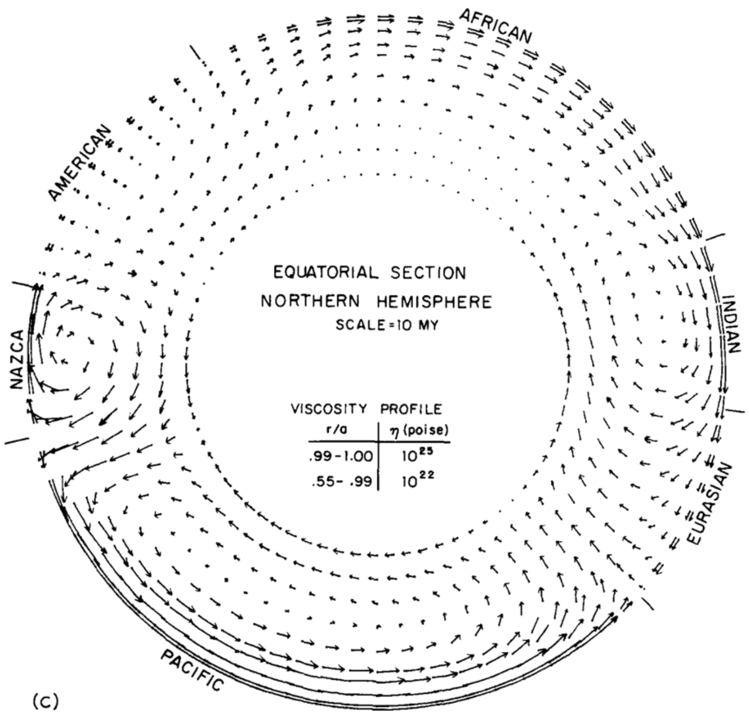


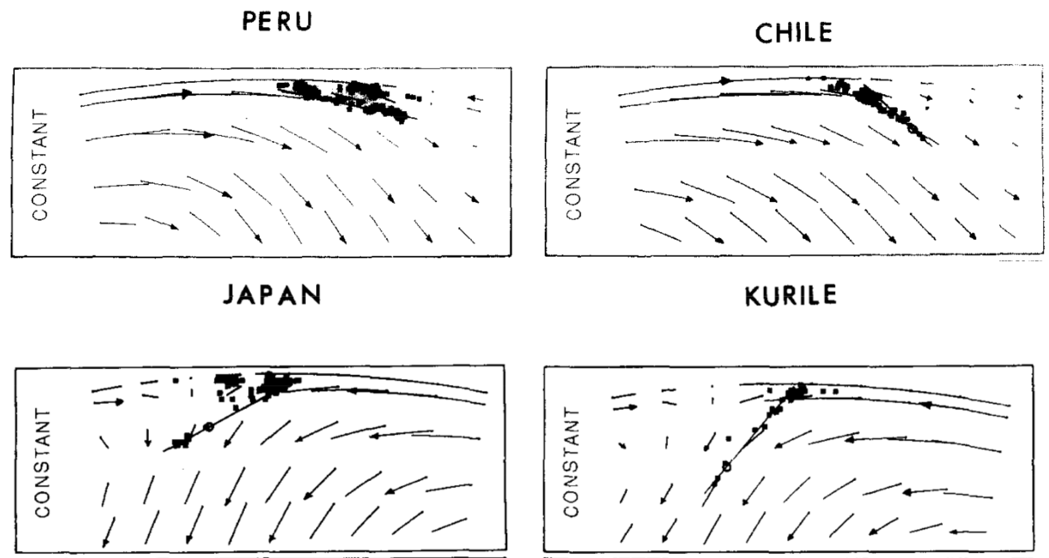


Holt et al., 2015

Dip trickier…

Large-scale mantle flow?





Hager & O'Connell, 1978

Dip trickier…

Friday: Subduction duration!?

Geochemistry, Geophysics, Geosystems

ADVANCING EARTH AND SPACE SCIENCE

RESEARCH ARTICLE

10.1029/2019GC008862

Subduction Duration and Slab Dip

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Key Points:

- Slab dip depends on subduction duration, where older subduction systems tend to have shallower slabs
- Long-term subduction duration is more significant than the latest reinitiation age in controlling slab dips
- The nature of overriding plate, continental versus oceanic plate, slab age, and convergence rate could influence dip angles

Supporting Information:

- Supporting Information S1
- Table S1
- Table S2

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Citation:

Abstract The dip angles of slabs are among the clearest characteristics of subduction zones, but the factors that control them remain obscure. Here, slab dip angles and subduction parameters, including subduction duration, the nature of the overriding plate, slab age, and convergence rate, are determined for 153 transects along subduction zones for the present day. We present a comprehensive tabulation of subduction duration based on isotopic ages of arc initiation and stratigraphic, structural, plate tectonic and seismic indicators of subduction initiation. We present two ages for subduction zones, a long-term age and a reinitiation age. Using cross correlation and multivariate regression, we find that (1) subduction duration is the primary parameter controlling slab dips with slabs tending to have shallower dips at subduction zones that have been in existence longer; (2) the long-term age of subduction duration better explains variation of shallow dip than reinitiation age; (3) overriding plate nature could influence shallow dip angle, where slabs below continents tend to have shallower dips; (4) slab age contributes to slab dip, with younger slabs having steeper shallow dips; and (5) the relations between slab dip and subduction parameters are depth dependent, where the ability of subduction duration and overriding plate nature to explain observed variation decreases with depth. The analysis emphasizes the importance of subduction history and the long-term regional state of a subduction zone in determining slab dip and is consistent with mechanical models of subduction.