Geophysical constraints on geodynamic processes at convergent margins: A global perspective

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Three types of convergent margins

- **O-O**: Incoming Oceanic
- **C-O**: Overriding Continental
- **C-C**: Continental-continental convergence
Three types of convergent margins
What happens at convergent margins and what are the controls?

"INPUT":

- **Structure of incoming plate**
  - (crust: Moho, seds, topography, mantle: water, LAB, temperature → age for ocean plates...)

- **Structure of overriding plate**
  - (LAB, temperature,...)

- **Convergence rate**
What happens at convergent margins and what are the controls?

"OUTPUT":

- Subduction angle may vary with depth
- Roll-back
  - back-arc basins
- Seismicity
  - Magnitude
  - Depth distribution
- Volcanism
What happens at convergent margins and what are the controls?

**OBSERVABLES:**

- Gravity (FA & B)
- Heat flow
- Seismic Vp, Vs, Q
- Seismicity & volcanism
Gravity

Free Air
- Globally – proximity to isostasy
- No local isostasy at convergent margins

Extreme contrast in grad FA

Bouguer
Heat flow

Interpolation

Point data

No systematic patterns are recognized in heat flow data due to strong heterogeneity of measured values, which are strongly affected by hydrothermal circulation, magmatic activity, crustal faulting, horizontal heat transfer, and also due to low number of heat flow measurements across many margins.

Data coverage
Vs in the mantle

75 km
Low upper mantle Vs seismic velocities beneath the convergent margins are restricted to the upper 150 km and may be related to mantle wedge melting which is confined to shallow mantle levels.

125 km

175 km

Model of Schaeffer and Lebedev, 2013
Locations of profiles
Topography
Free Air
Bouguer
Seismicity, M>4.0
Heat flow
Vs@75, 125, 175 km
Continent-ocean convergent margins

**Alaska**
- CO, 66 mm/y
- SE, <PAE>, NW
- Topography (m)
- Free air (mGal)
- Bouguer anomaly (mGal)
- Moho & EQ depth (km)
- Heat flow (mW/m²)
- VS (% PREM)

**Central Am.**
- CO, 78 mm/y
- W, <CA>, E
- Topography (m)
- Free air (mGal)
- Bouguer anomaly (mGal)
- Moho & EQ depth (km)
- Heat flow (mW/m²)
- VS (% PREM)

**Andes N**
- CO, 68 mm/y
- W, <SA1>, E
- Topography (m)
- Free air (mGal)
- Bouguer anomaly (mGal)
- Moho & EQ depth (km)
- Heat flow (mW/m²)
- VS (% PREM)

**Andes C**
- CO, 72 mm/y
- W, <SA2>, E
- Topography (m)
- Free air (mGal)
- Bouguer anomaly (mGal)
- Moho & EQ depth (km)
- Heat flow (mW/m²)
- VS (% PREM)

**Andes S**
- CO, 74 mm/y
- W, <SA3>, E
- Topography (m)
- Free air (mGal)
- Bouguer anomaly (mGal)
- Moho & EQ depth (km)
- Heat flow (mW/m²)
- VS (% PREM)
Continent-continent convergent margins and plate boundary zones

Gibraltar

CC (PBZ), 05 mm/y

Hellenic arc

CC (PBZ), 10 mm/y

W. N. Am.

CC (PBZ), 23 mm/y

Tibet-Himalayas

CC (PBZ), 46 mm/y
Convergence rate & Age of ocean floor

Convergence rate is small for C-C

Age of the ocean floor based on Mueller et al., 2008.
Rates based on the MORVEL plate velocity model, DeMets et al., 2010
**Convergence rate**

Is larger when overriding plate is oceanic

**O-O:**
- Broad range
- Uniform distribution

**C-O:**
- Broad range
- Two peaks at ca. 45 and 75 mm/y

**C-C:**
- Small values
- Two peaks: sharp at ca. 5 mm/y and broad at 30-50 mm/y
Subduction angle

Mariana Type

Chilean Type

a) Normal-Angle Subduction

b) Low-Angle Subduction

Oceanic Crust
Trench
Accretionary Wedge
Forearc Basin
Volcanic Arc
Foreland Fold-and-Thrust Belt
Lithosphere
Hot Fluids
Continental Craton
Asthenosphere
No Volcanic Arc
Foreland Basement Uplifts
Compression

SLAB PROFILES

CENTRAL PERU
CHILE
TONGA
BONIN
NEW HEBRIDES
FLORES
EASTERN ALEUTIANS

VOLCANIC FRONT

400km

km

400km

JAPAN

300

200

100

400

500

600
Subduction angle: sub-Moho

vs age of incoming plate

O-O:
Depends on the age of incoming plate (smaller for older plates)

C-O: No correlation

O-O:
Marianna Sandwich New Zeal. N
Sandwich New Caled.
Subduction angle: sub-Moho vs convergence rate

O-O: Depends on convergence rate (higher for higher rates)

C-O: Similar trend with weak correlation

Marianna and Chile belong to different types (O-O and C-O) -> comparing apples and pears?

Steeply dipping slabs are characteristic:
• of young oceanic subducting plates;
• of oceanic plates with high convergence rate, with slab rotation towards a near-vertical dip angle at depths below ca. 500 km at very high convergence rate.
Subduction angle: below 200 km

vs convergence rate

**O-O:**
Depends on convergence rate (higher for higher rates)

**C-O:** No correlation
Subduction angle: below Moho and >200 km

O-O: Dip angles for sub-Moho and deep portions are different, but correlated

C-O: No correlation
Seismicity: Magnitude

Lower M for C-C
Seismicity: Depth

Shallow for C-C
Seismicity vs Depth

M$>8$ occur only when the overriding plate is oceanic

(a) Continent-Continent collision
All $<200$ km

(b) Ocean-Ocean boundary
Gap at 300-550 km
Seismicity vs Depth

Distance (km)

EQ depth (km)

WNA

TH

Vrancea

Continent-Continental
(Plate Boundary Zone)
Seismicity vs Depth
Conclusions

1. Systematic patterns across subduction zones:
   • Exist for Free Air and Bouguer;
   • Do not exist for heat flow and Vs in global models
   • -> large variability and “individuality” of subd. Zones

2. Subduction angle correlates only for O-O subd.:
   • Sub-Moho:
     • smaller for older plates;
     • higher for higher conv. rates;
   • Below 200 km:
     • weakly correlates with sub-Moho dip;
     • higher for higher conv. rates

3. Seismicity
   • Gap at ca. 300-520 km at C-O margins