Mass wasting at active continental margins

Jan Behrmann

Due credits to Rieka Harders, David Völker and Jacob Geersen
Factors affecting mass wasting

Types and causes

Significance of earthquakes as trigger
1.3 Submarine canyons
connected to river systems / abandoned active / sediment-filled

Factors affecting mass wasting

San Antonio  Rapel  Mataquito  Maule  Itata  BioBio  Lleulleu  Imperial / Tolten  CalleCalle  Chahuin  Chacao
2. Types and causes

2.3 Lowermost slope collapse (15 / 66)

- Rotational slides
- Cohesive slide blocks and debris cone
- Steep headwall

Reloca Slide (Völker et al. 2009)
1. Role of earthquakes as a trigger

1.4 Worlds most powerful megathrust earthquakes

Seismic segmentation of the forearc

Earthquake recurrence of 100-500 a per segment

Coseismic horizontal and vertical motion of some m → Ideal trigger?

Farias et al., 2010

Feb. 2010

May 1960
1. Factors affecting mass wasting

1.1 Oblique subduction of the Nazca Plate

Frontal accretion → steep lowermost continental slope

Sediment subduction & basal accretion → local uplift of upper slope

Modified from Juan Díaz 2001
1.2 Southern Volcanic Zone (SVZ)

Volcanic ashes constitute 10-40% of the total erupted volumes in the SVZ.
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Volcanic ashes constitute 10-40% of the total erupted volumes in the SVZ
Offshore deposition of tephra layers
Weak layers in the sediment column?

5cm thick ash layer from the lower continental slope:
RV SONNE SO210 #72, 2400 m water depth

SVZ: ~60 large volcanic centres
1. Factors affecting mass wasting

2. Southern Volcanic Zone of Chile (SVZ)
Volcanic ashes constitute 10-40% of the total erupted volumes

Zoned pumice fallout deposit of volcano Antillanca (Nahuel Huapi Tephra); Foto by D. Gilbert
1. Factors affecting mass wasting

Chaiten, Chile, 2nd May 2008

Height of eruption cloud: 19 km

http://www.environmentalgraffiti.com/mountains/
2. Types and causes

Swath bathymetry dataset covering 90% of continental slope

Mapping based on typical morphological features

66 slides between 33°S and 42°S (1000 km)
2. Slide categories

Slides fall into **4 categories**:

1. Slides related to canyon incision
2. Slides on open slopes
3. Lowermost slope collapse
4. "Giant Failures"
2. Types of slides

2.1 Slides at submarine canyons

Several slide generations

Canyon incision destabilizes slopes

→ outward transgression

translation parallel to bedding

→ weak layers
2. Types of slides

2.1 Slides at submarine canyons

Several slide generations

Canyon incision destabilizes slopes
→ outward transgression

translation parallel to bedding
→ weak layers
Sidewall collapse leads to sediment creep
detachment along lithologic reflectors
→ weak layers

2. Types of slides

2.1 Slides at submarine canyons
(29 / 66)
2. Types of slides

< 20 km² in size
Retrogression from canyon walls to open slope
2. Types of slides

2.3 Lowermost slope collapse

Rotational slides
Cohesive slide blocks and debris cone
Steep headwall
2. Types and causes

20-100 km² in size

2.3 Lowermost slope collapse
(15 / 66)

Φ vs latitude, log-scaled by slide area
2. Types and causes

20-100 km² in size

2.3 Lowermost slope collapse (15/66)

\(\Phi \) vs latitude, log-scaled by slide area
2. Types and causes

20-100 km² in size

Exclusively in the Concepción Segment, characterized by...

...frontal/basal accretion, splay faults and strong plate coupling

*J. Geersen et al. (2011). Active Tectonics of the South Chilean Marine Forearc.

\( \phi \) vs latitude, log-scaled by slide area

2.3 Lowermost slope collapse (15 / 66)
2. Types of slides

2.4 Giant failures

(3 / 66)
3. Types of slides

400-1200 km² in size, 250-470 km³

2.4 Giant failures

(3 / 66)
3. Types of slides

400-1200 km² in size, 250-470 km³

Exclusively in the **Nahuelbuta Segment**, characterized by...

...uplift of overriding plate due to N-S compression, prominent continental faults

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**2.4 Giant failures**

(3 / 66)

*J. Geersen et al. (2011). Active Tectonics of the South Chilean Marine Forearc.*
<table>
<thead>
<tr>
<th>Types of slides</th>
<th>Character</th>
<th>Cause (concept)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slides related to canyon incision</td>
<td>Small, translational, canyon wall incision, retrogression, creep</td>
<td>Undercutting, wall collapses, weak layers</td>
</tr>
<tr>
<td>Lowermost slope collapse</td>
<td>Medium-sized, rotational, blocky products, slope stable to 30°, related to Concepción Segment</td>
<td>Frontal accretion and oversteepening, high basal friction, stiff rheology resisting gravitational collapse, plate contact properties</td>
</tr>
<tr>
<td>Giant failures</td>
<td>Huge, affecting the entire slope, products fill the trench, related to Nahuelbuta Segment</td>
<td>Inherited faults in the overriding plate, tectonic uplift and gravitational collapse, upper plate properties</td>
</tr>
</tbody>
</table>
3. Possible effects of the 2010 Maule Earthquake (and other eq)

SFB574 RV SONNE Cruise SO210:
Bathymetric re-mapping of the rupture area
3. The Maule Earthquake

In spite of this extreme event ...

... no new landslide features were identified!

BioBio Slide:
Primary headwall
Secondary slide scars
(Retrogression)
3. The Maule Earthquake

Gravity Coring

3 layers of slide deposits
Approximate age of last event 700-1000 a

Post-slide sedimentation: homogeneous silty clay

Slide deposits: angular clay clasts of different origin

GC14, 228-299cm
3. The Maule Earthquake

Gravity Coring

3 layers of slide deposits
Approximate age of last event 700-1000 a

Old Slide

GC14, 228-299 cm

Post-slide sedimentation: homogeneous silty clay

Slide deposits: angular clay-clasts of different origin
3. The Maule Earthquake
3. The Maule Earthquake

Geochemical Modeling

Simulation of diffusive transport for age estimate (F. Scholz)

Some weeks prior to coring
Rules out main shock as trigger
Two Mw > 5 aftershocks could have served as triggers
Conclusions and Implications

larger landsliding did not occur in response to the Maule Earthquake recent small scale-sliding, however, is present (omnipresent?)

- it is not necessarily the earthquake magnitude that matters triggering is influenced by other factors

For Chile:

- few depocenters on the slope, river systems feed into submarine canyons
- interseismic period is sufficient to accumulate 20-30 cm of new sediment at most

Hypothesis:

Frequent strong ground motion stabilizes the ground if potentially weak layers collapse early after deposition
Occurrence and segmentation of submarine mass wasting phenomena along the Middle America Trench
Why is the MAT an interesting area?

1. Changing ocean plate character along trench. How does this influence the tectonics and the style of mass movements?
2. Minor changes in convergence rates.
3. No changes in basement properties of the continental plate.
4. No changes in the sediment of the continental slope.

A segmented Cocos plate was formed at 2 spreading centers, cut by FZs and influenced by a hotspot.
Segmentation of the **continental slope** and **ocean plate**

Harders et al. (G-cubed, 2011)
- Ocean plate is shallow (1.5-2.5 km deep trench), with sharp ridges and small seamounts.
- Narrow and steep continental slope.
Rotational slump (~4 km wide, 1 km high headwall) with rock avalanche

Type example: Sirena Slump

Cocos Ridge - Osa peninsula segment

Sidescan sonar data superimposed on bathymetric image

Sirena Slump

blocky deposits

defaults and fractures

ra

d = debris flow
ra = rock avalanche

n

1 km

1 km

deformation front

slow deformation?

Harders et al. (G-cubed, 2011)
- 70 km wide continental slope. 20-80 km wide Slumps.
- Ocean plate with seamounts derived from the Galapagos-Hotspot- (2-3km high, 20-30 km wide).
Seamounts - Central Costa Rica Segment

Type example: Jaco and Parrita Slumps and scars

Harders et al. (G-cubed, 2011)
A few translational slides on middle slope

Type example: Hermosa slide

North Nicoya Segment

Smooth ocean floor - North Nicoya Segment

Harders et al. (G-cubed, 2011)
Oceanic bend-faulting - Nicaragua segment

- Ocean plate with ~0.5-1 km high, trench-parallel horst and graben.
- Abundant large translational slides in continental slope.

Harders et al.
(G-cubed, 2011)
Oblique bend-faulting – El Salvador segment

Type example: Small locally-abundant translational slides in upper slope

Harders et al. (G-cubed, 2011)
Propagator topography - Guatemala segment

Type example: Rough relief with slumps across lower and middle slope

- Ocean plate with high (0.8-1.2 km) trench-oblique relief.
- Rugged, faulted continental slope with short slumps

Harders et al. (G-cubed, 2011)
**Characteristic failure type, slope angles and slope width per segment**

<table>
<thead>
<tr>
<th>Segment</th>
<th>Failure Mode</th>
<th>Continental Slope</th>
<th>Main Preconditioning Mechanism</th>
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<tr>
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<td>Cocos Ridge–Osa Peninsula</td>
<td>RA, SP</td>
<td>6.5–20, 8</td>
<td>Regional oversteepening by tectonic erosion. Fractures by ridge relief.</td>
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<tr>
<td>Seamounts–Central Costa Rica</td>
<td>SD</td>
<td>44–73, 56</td>
<td>Local oversteepening and fractures by uplift by subducting seamounts.</td>
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<td></td>
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<td>North Nicoya</td>
<td>SD</td>
<td>52–55, 53</td>
<td>Ash layers.</td>
</tr>
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<td>El Salvador</td>
<td>SD</td>
<td>49–57, 52</td>
<td>Oversteepening by canyon erosion.</td>
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<td>Guatemala</td>
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<th>Segment</th>
<th>Width (km), Minimum–Maximum, Average</th>
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<tr>
<td>Nicaragua</td>
<td>43–51, 48</td>
<td>4.6–5.6, 5.1</td>
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RA, rock avalanche; SP, slump; SD, slide. Slope dip angle has been estimated from profiles of the entire width of the slope.
The segmentation of the distribution of continental slope failures matches the segmentation of the ocean plate character.

Preconditioning factors on a margin characterized by subduction erosion are tectonically controlled by the interaction of oceanic and overriding plates.
6th International Symposium on Submarine Mass Movements and Their Consequences

23rd-25th September, 2013
GEOMAR, Kiel, Germany

Call for Abstracts and 1st Circular

Important Deadlines:

Sep. 14, 2012: Abstract, intended full manuscript contribution
Feb. 1, 2013: Full paper submission
Apr. 12, 2013: Early bird registration
Sep. 2, 2013: Abstract for conference contributions

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