

An aerial photograph of a vast, rugged mountain range, likely the Andes, covered in snow and ice. The peaks are jagged and steep, with deep valleys and ridges visible. The sky is a pale blue, and the overall scene conveys a sense of immense scale and natural beauty.

Universidad de Buenos Aires

# **The Andes: A history of earthquakes and volcanoes**

**Victor A. Ramos**

**Instituto de Estudios Andinos**

**UNIVERSIDAD DE BUENOS AIRES - CONICET**

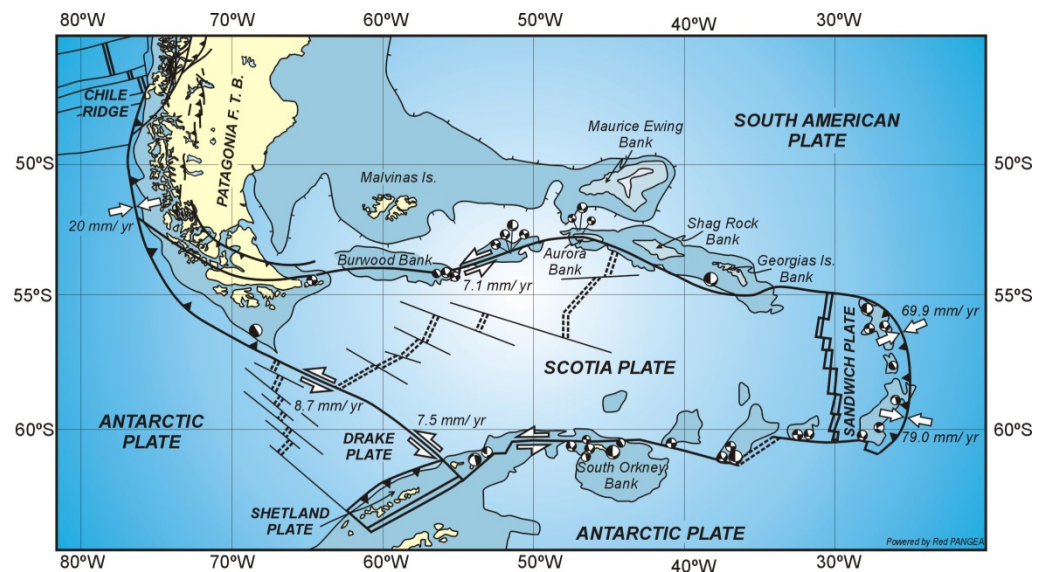
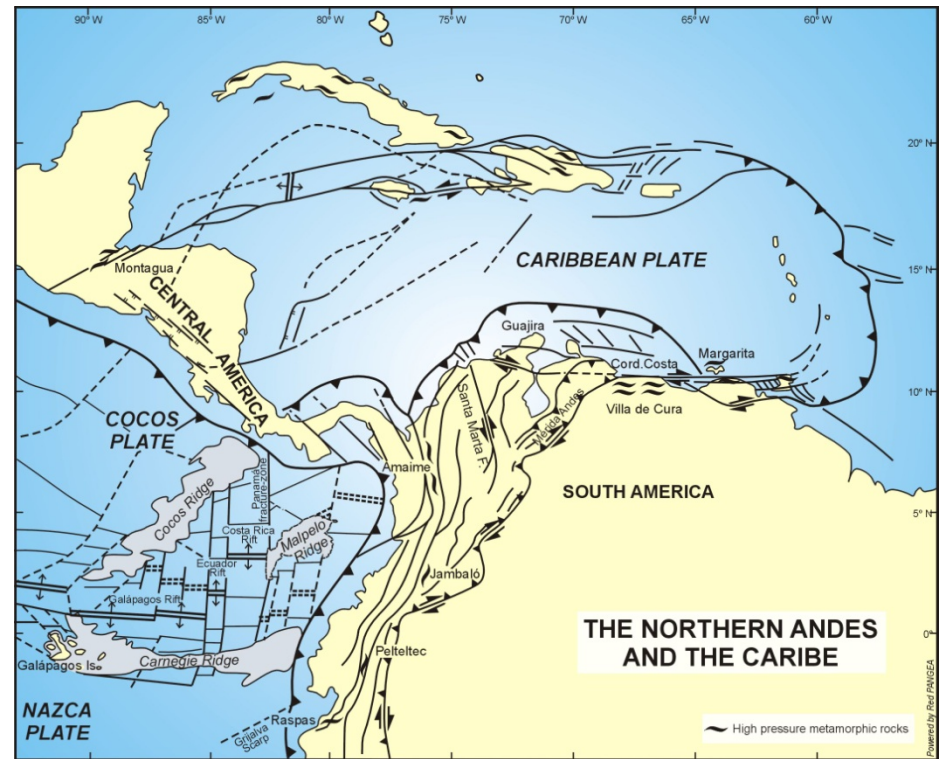




## **Objectives:**

- 1. How the Andes work.**
- 2. We are going to use the Darwin's observations.**
- 3. Earthquakes and volcanoes.**
- 4. The rate of uplift (old times versus Present)**
- 5. The Andes are an active chain!**









**Volcán Galeras**





**Volcán Tungurahua (5.023 m) 1995**





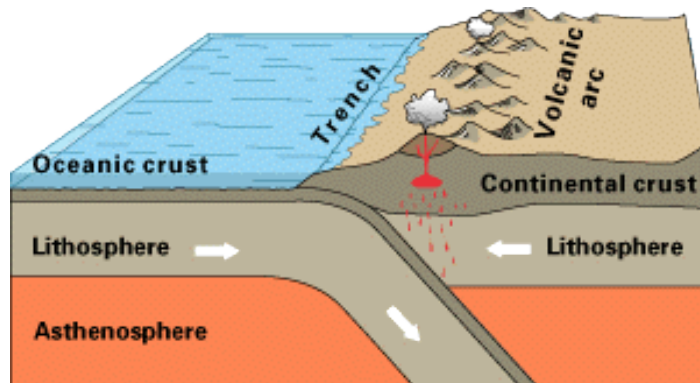
**Volcán Misti**



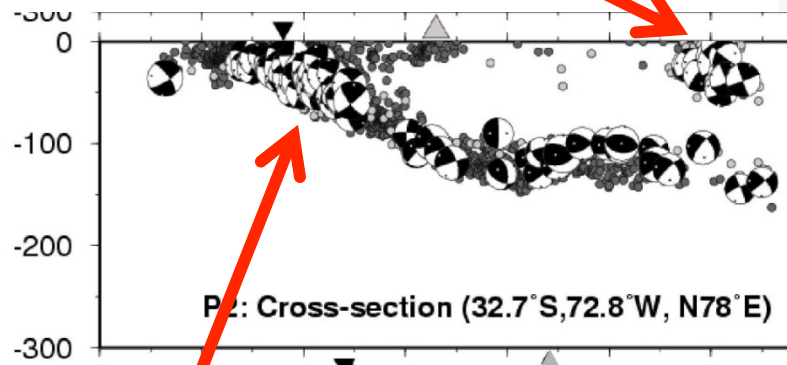


**Volcán Aguas Calientes**

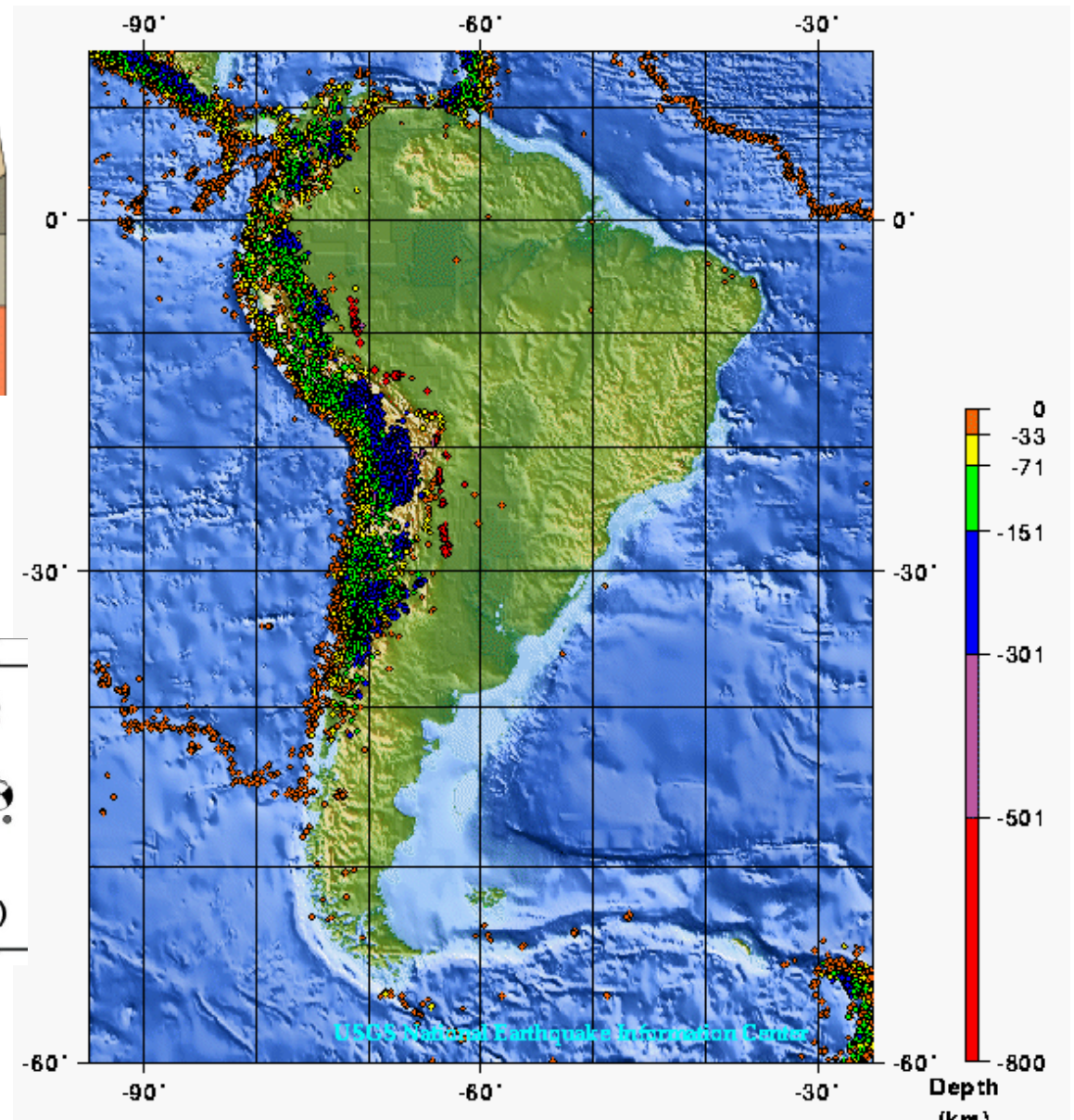
# Subduction



Intraplate earthquakes  
 < 7.5 Richter – Rupture zone of  
 ten of kilometers.



Interplate earthquakes  
 < 9.5 Richter – Rupture zone of  
 hundred of kilometrers



1990-2010





**Nevado de Illimani**





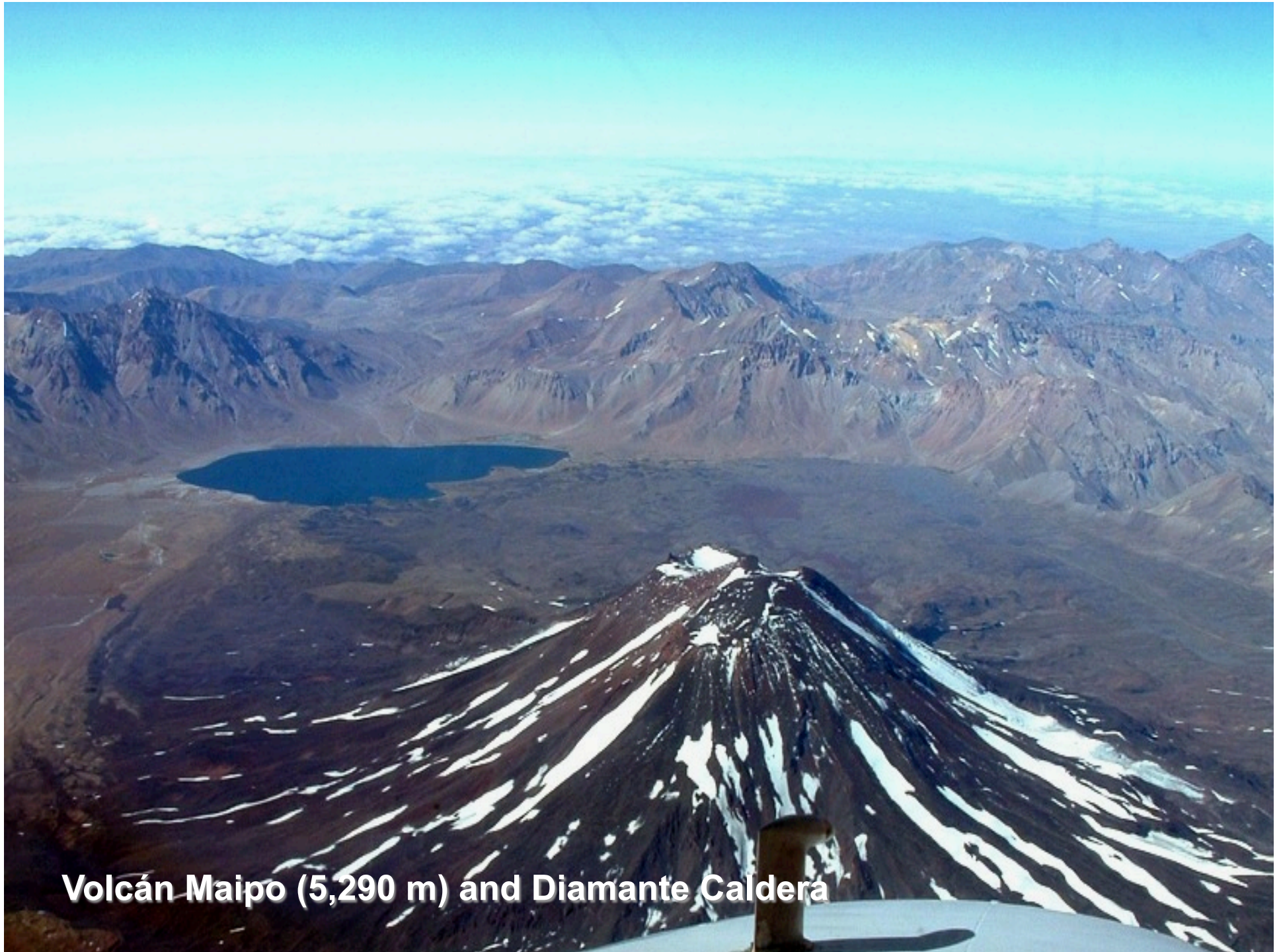
**High Andes of Argentina and Chile**





**Mount Aconcagua – 6,967 m**





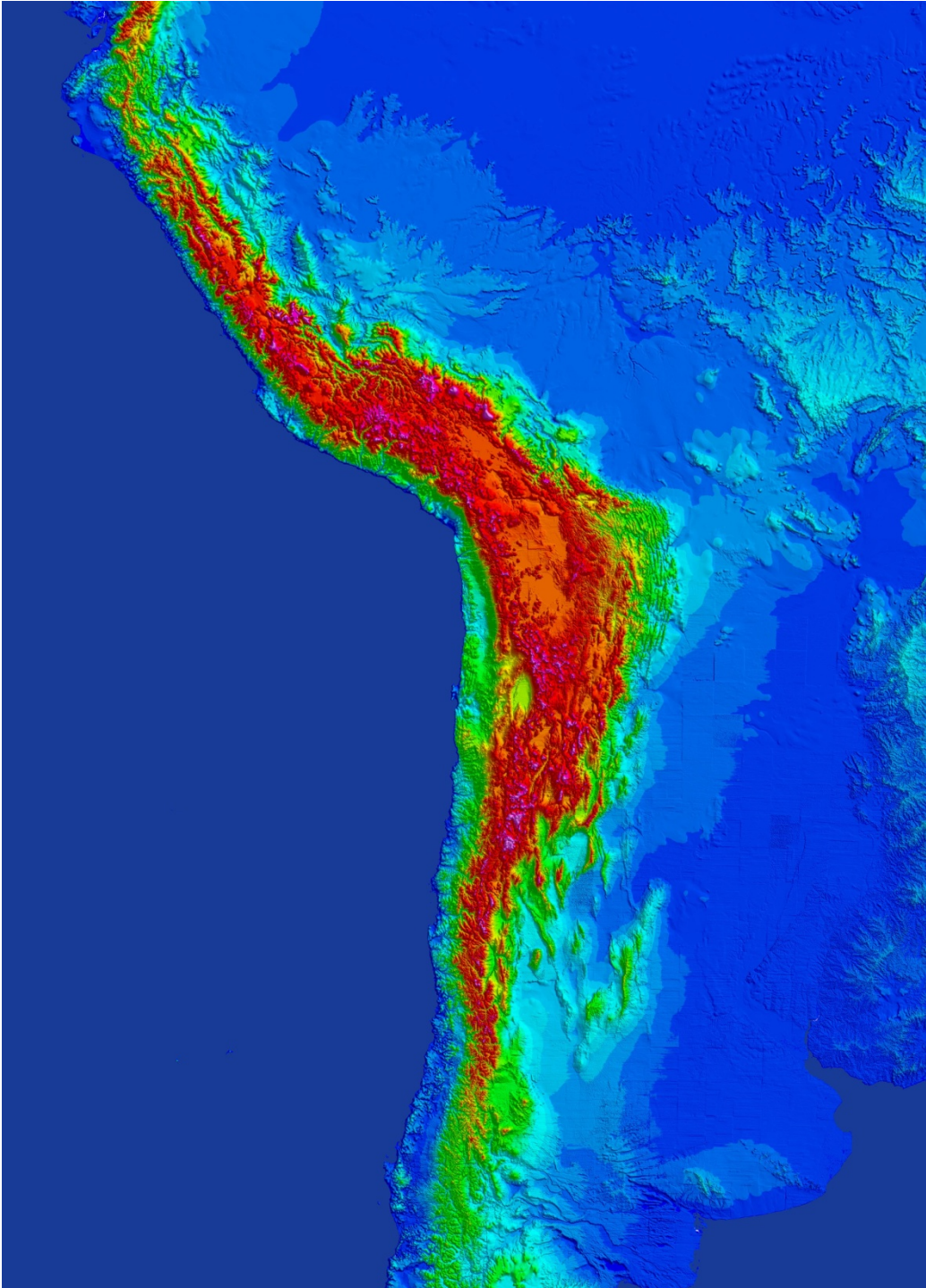
**Volcán Maipo (5,290 m) and Diamante Caldera**





**Volcán Palomo (SVZ)**





# **CENTRAL ANDES**

- **Corresponds to the Andes formed by subduction of oceanic crust beneath the continental margin.**
- **The most classical section coincides with the Andes of Bolivia.**
- **They are characterized by an active volcanic line, a high plateau and extensive sub-Andean mountains.**
- **They were magnificently described by Darwin in 1835.**



Knowledge prior to the Darwin's Voyage:

**Charles Lyell: Uniformitarianism**

***“The present is the key of the past”***

**Principles of Geology (1830-1833) 3 volumes**

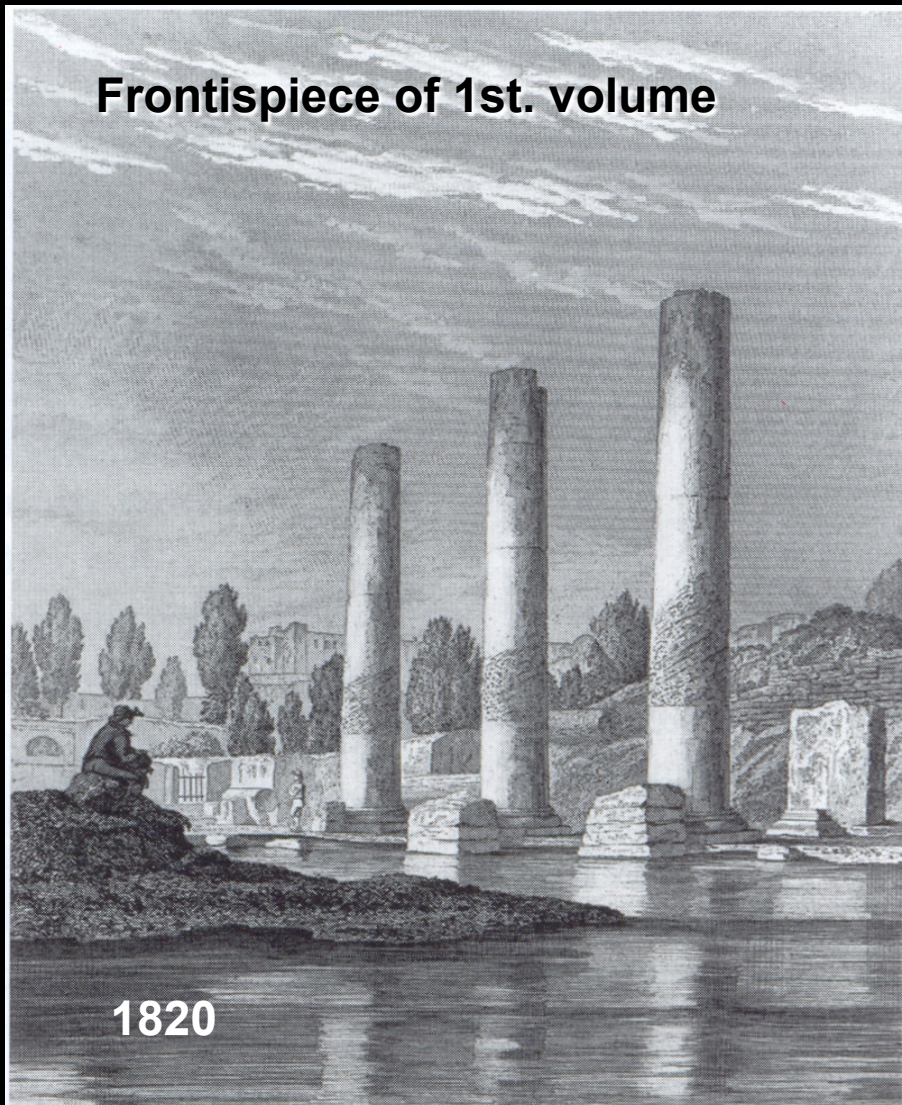




**Previous knowledge:**

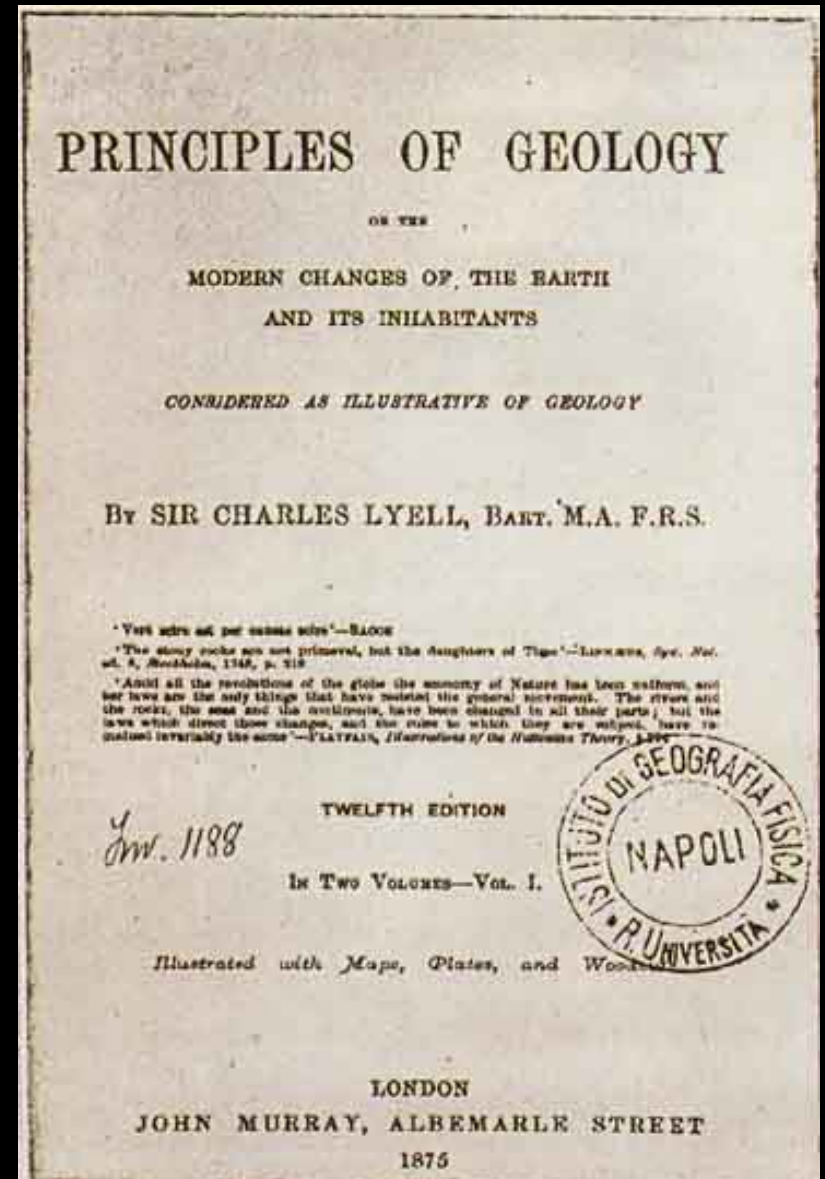
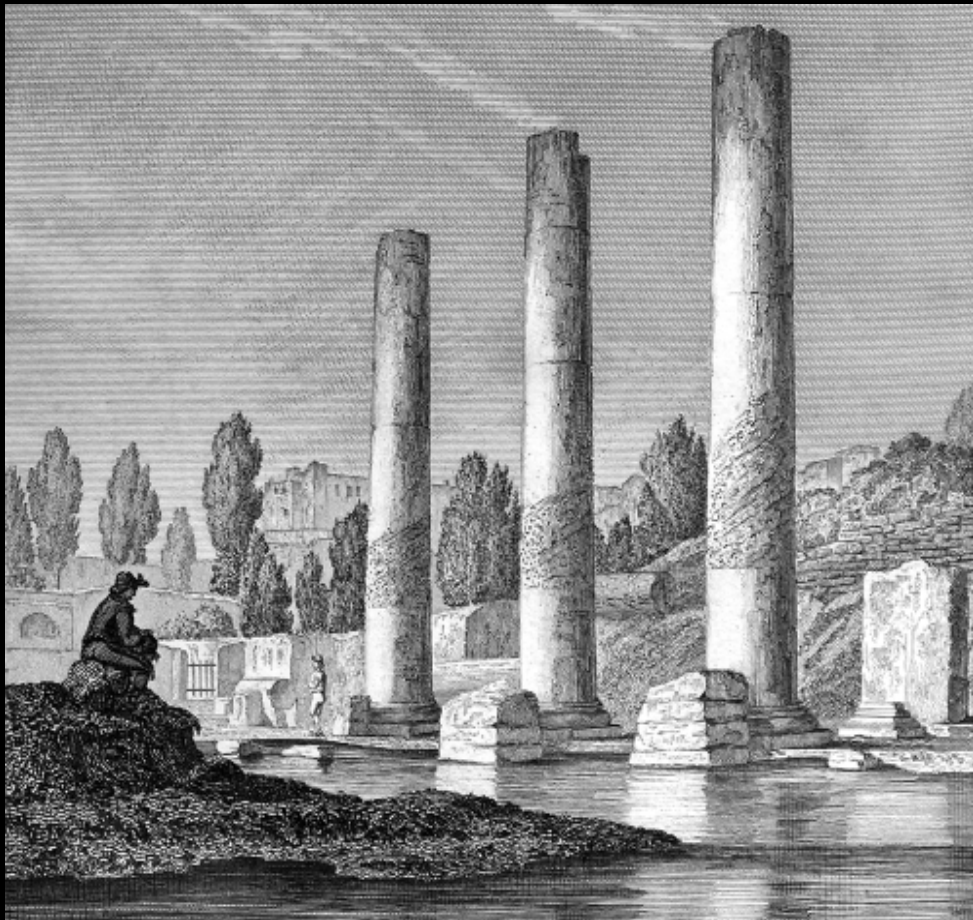
## **Temple of Serapis, near Naples**

**Frontispiece of 1st. volume**



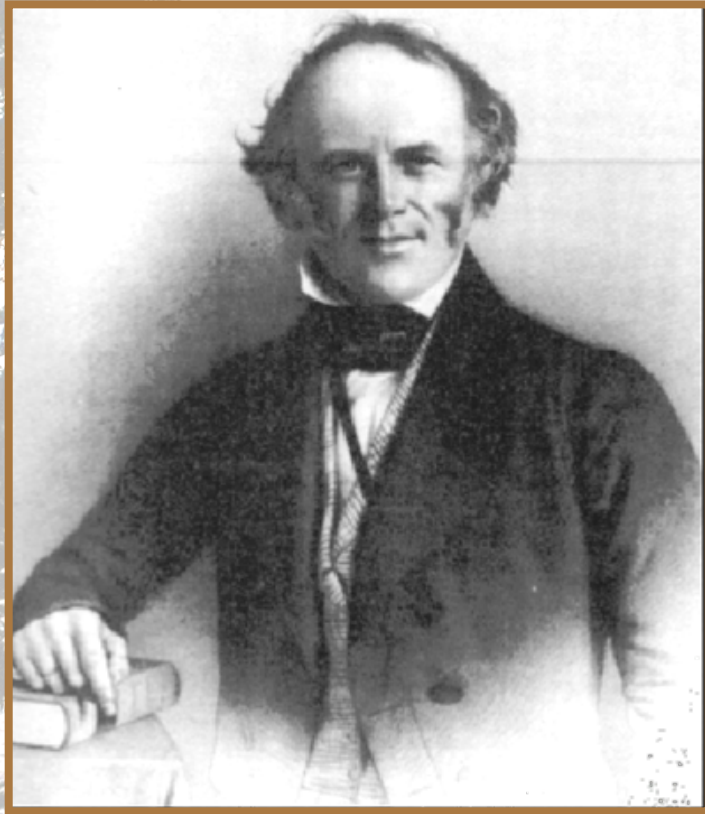


**Vol. 1: Gifted by Captain Fitz Roy**  
**Vol. 2: Recvd. Montevideo 1832**  
**Vol. 3: Recvd. Valparaíso 1835**



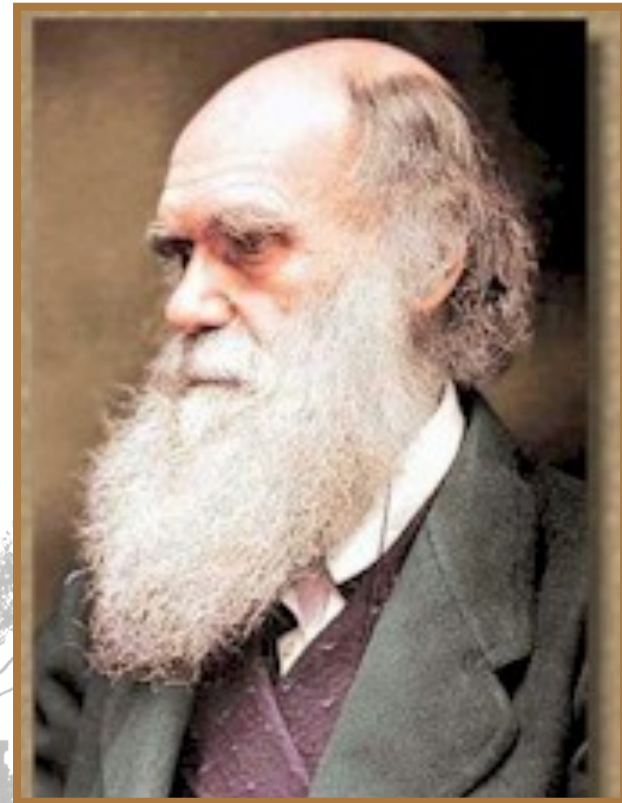
# HOW OLD IS THE EARTH?

100 millions of years to deposit at the present rate the known thickness of the sedimentary basins since the Paleozoic.



Charles Lyell (1833)

300 millions of years to produce the transformations of the known species from simple organisms.



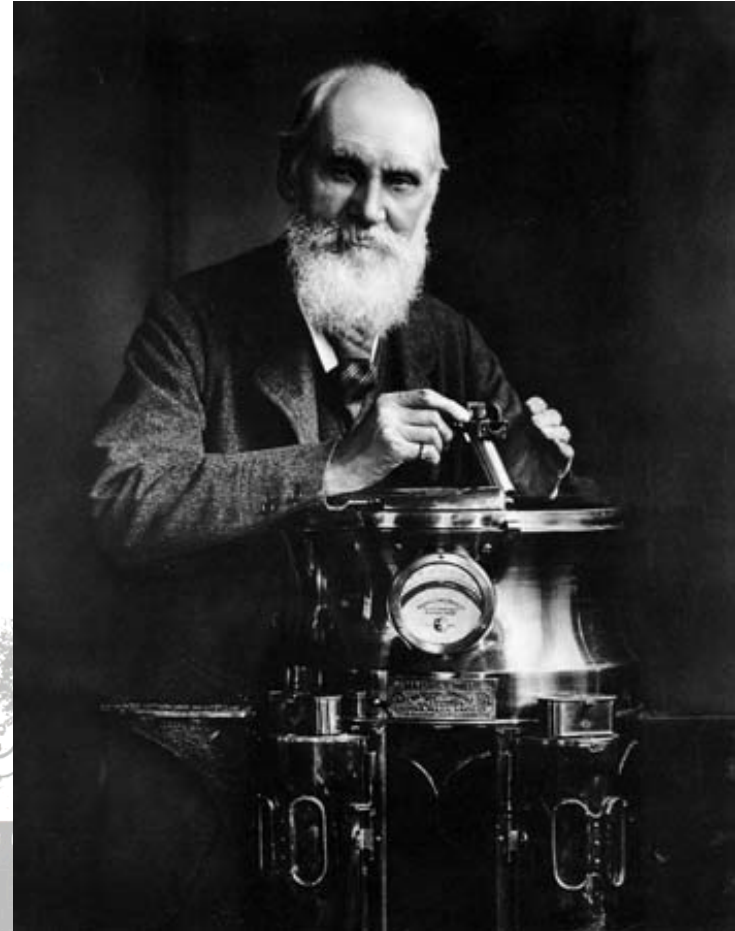
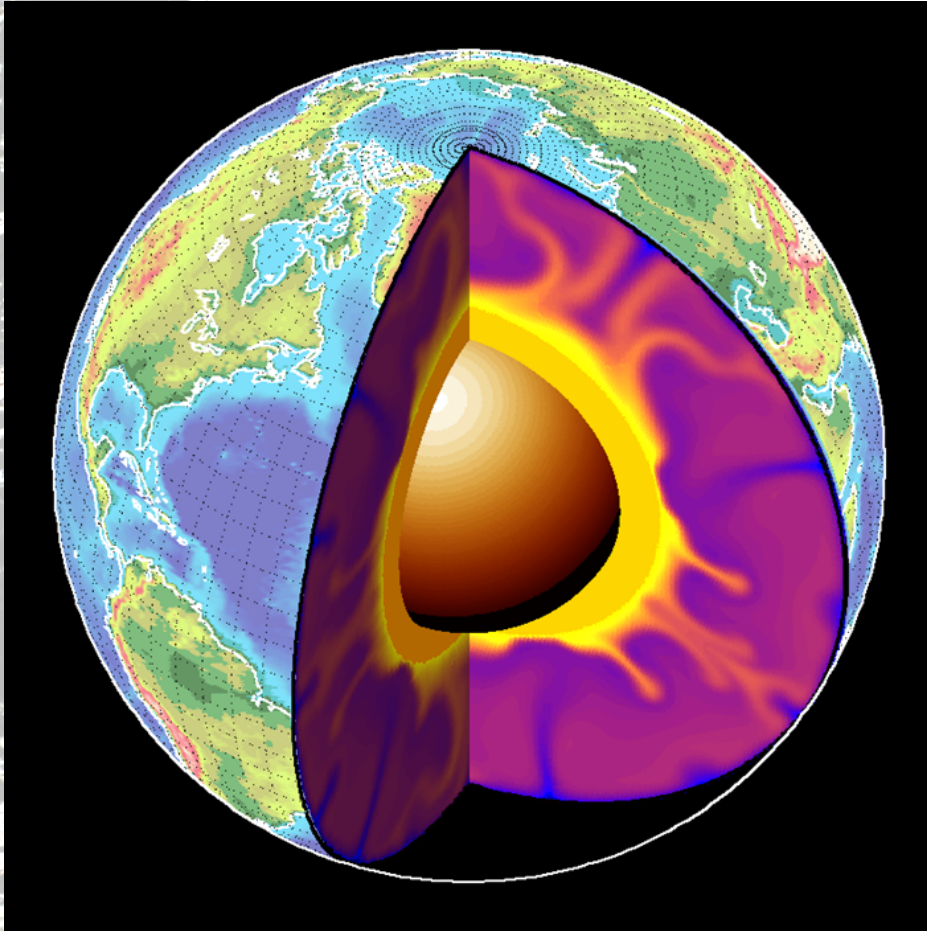
Charles Darwin (1856)

**Lord Kelvin: no more than 25 million years!**



# HOW OLD IS THE EARTH?

25 millions of years based on the conductivity of a molten Earth



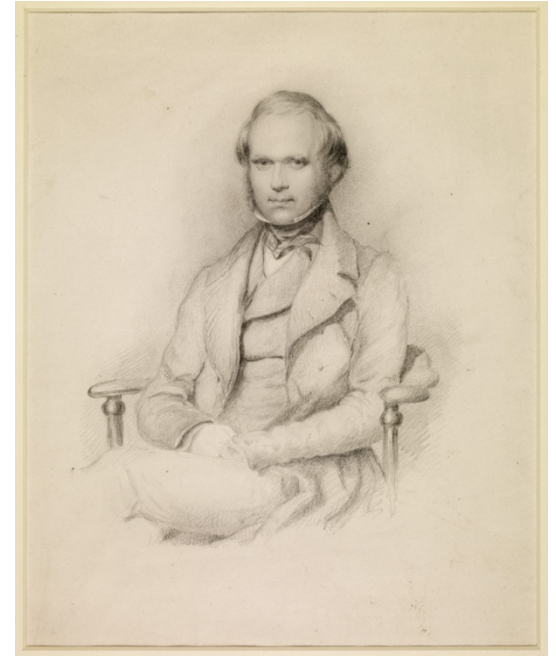
Lord Kelvin (1824-1907)



# Darwin and the Andean uplift:

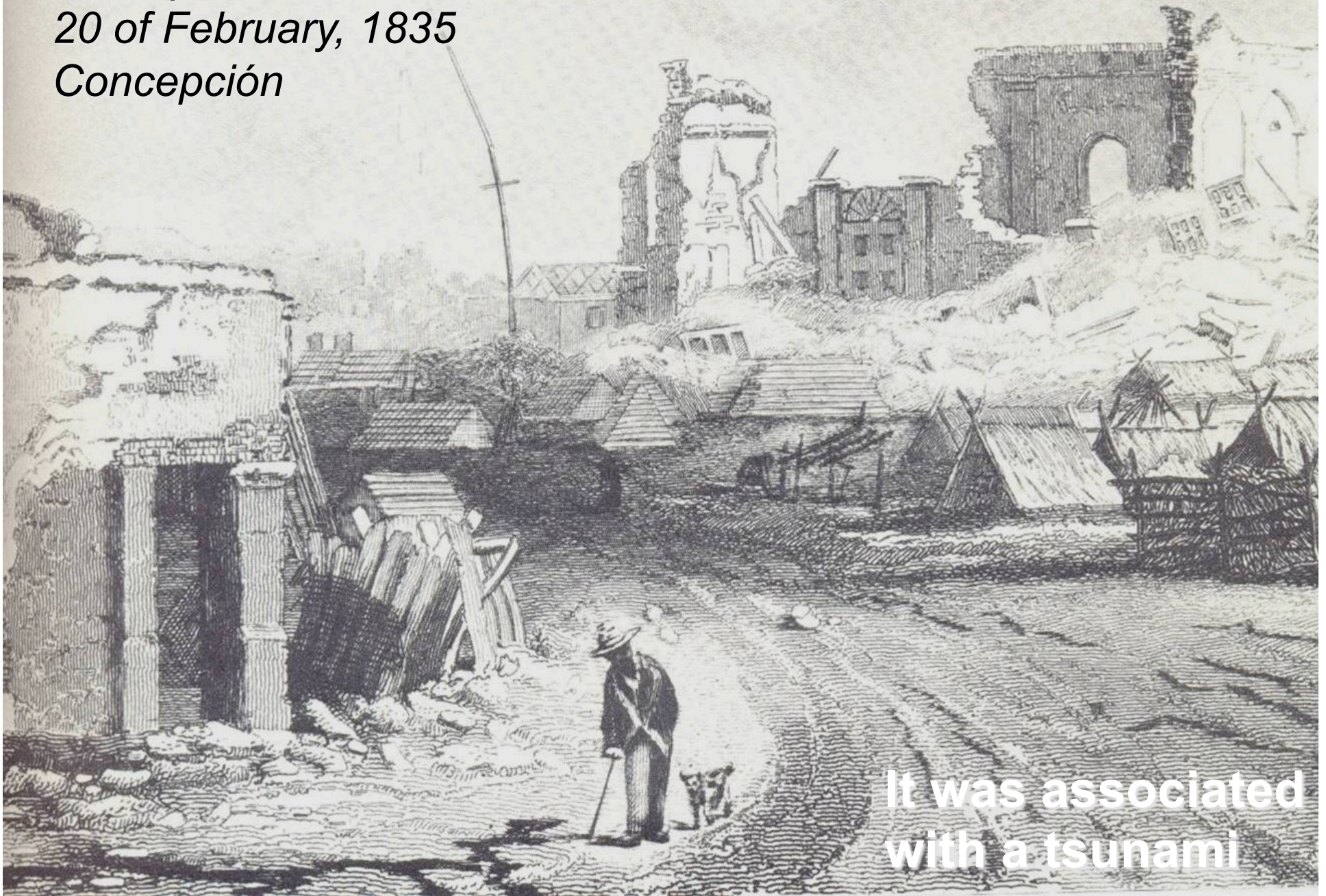
## Which were his key observations?

- The Valdivia - Concepción earthquake
- The eruption of the Osorno Volcano
- The recent uplift of old sea shores in Chiloé
- The excursion across the Andes to Mendoza
- The subsidence of the bottom of the sea





*Earthquake  
20 of February, 1835  
Concepción*



**It was associated  
with a tsunami**





**Earthquake of Concepción (24-01-1939)**





**Earthquake of Concepción (27-02-2010)**

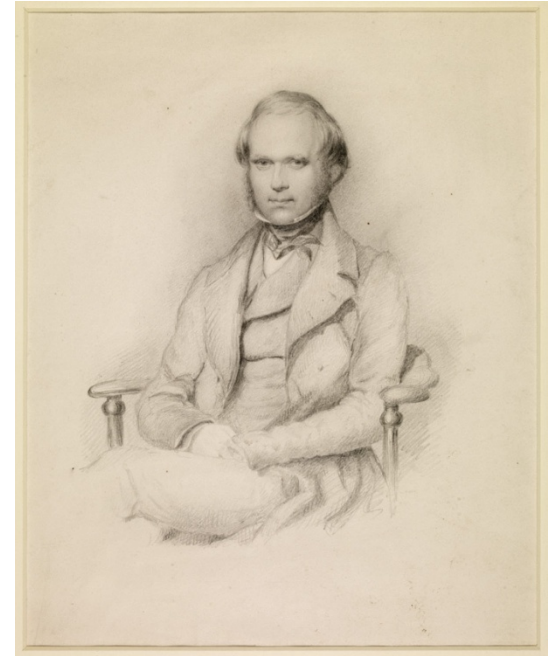


# Darwin and the Andean uplift:

## Which were his key observations?

### The earthquake of Concepción:

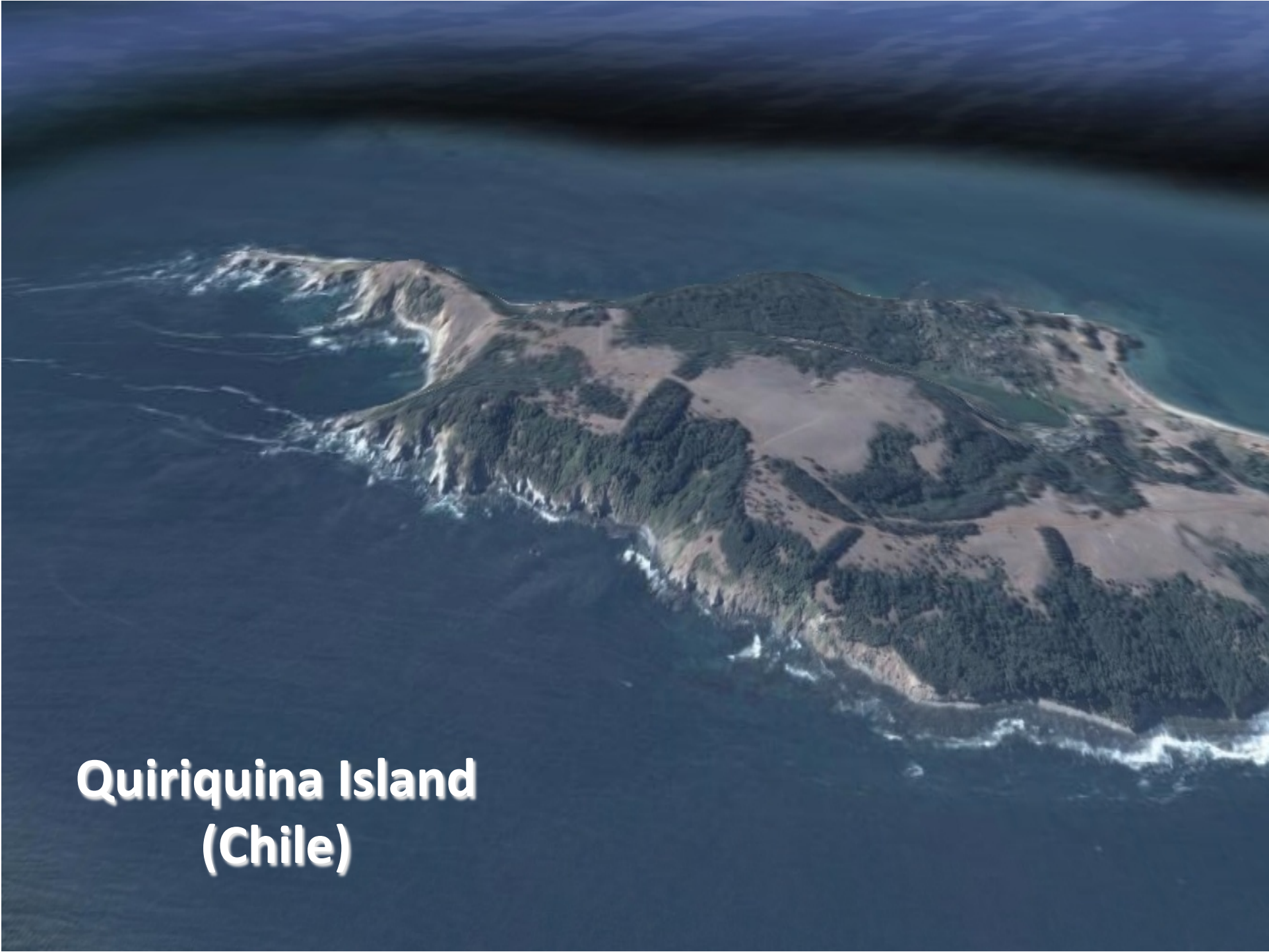
- Total destruction of buildings
- 70 towns destroyed
- A large earthquake, but...



*“In the Quiriquina Island a level of **choros** (mussels) had been raised during the earthquake about 10 feet (3 meters) and they are still seen putrids...”*

*... The earthquakes raised the island surface!*



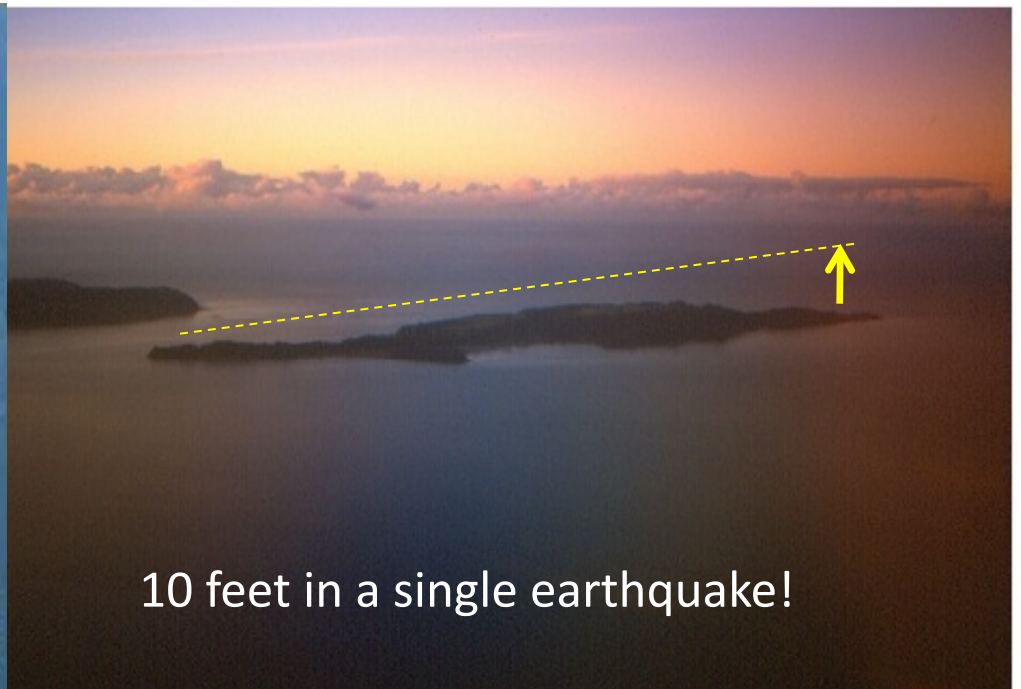


**Quiriquina Island  
(Chile)**





Uplifted  
"choros"



10 feet in a single earthquake!



Quiriquina Island



A topographic map of the southern coast of Chile, focusing on Isla de Chiloé and the surrounding fjord region. The map shows the rugged terrain of the islands and mainland, with green and brown shading indicating elevation. Several towns are marked with black dots and labeled: Puerto Varas, Puerto Montt, Calbuco, Ancud, and Castro. The text 'ISLA DE CHILOÉ' is written in a bold, italicized font across the lower left portion of the map. A white rectangular box at the bottom contains a descriptive text about terraces near Castro.

## ***ISLA DE CHILOÉ***

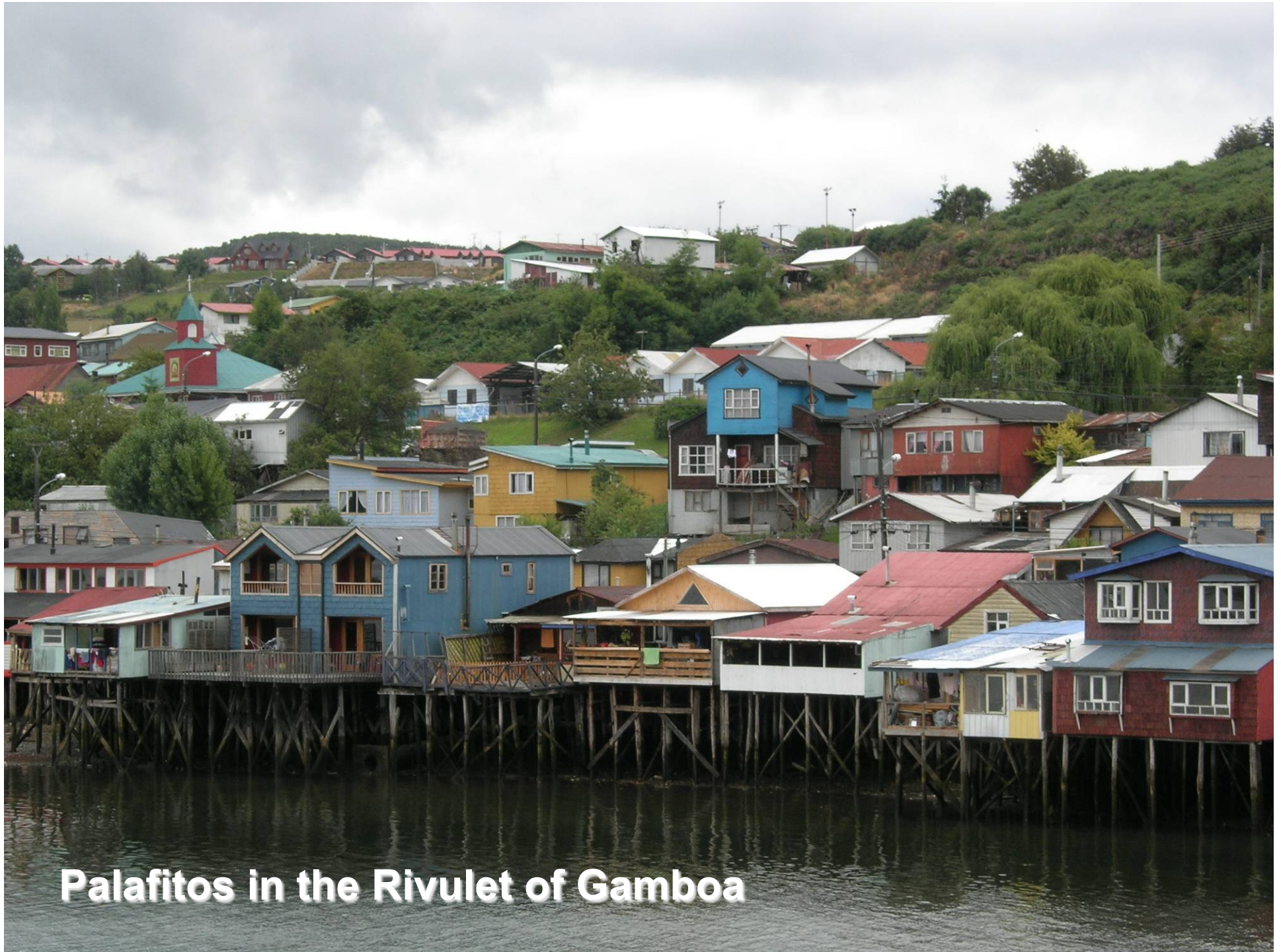
Near Castro, on each side of the creek and rivulet of the Gamboa, three distinct terraces are seen : the lowest was estimated at about one hundred and fifty feet in height, and the highest at about five hundred feet, with the country irregularly rising behind it :





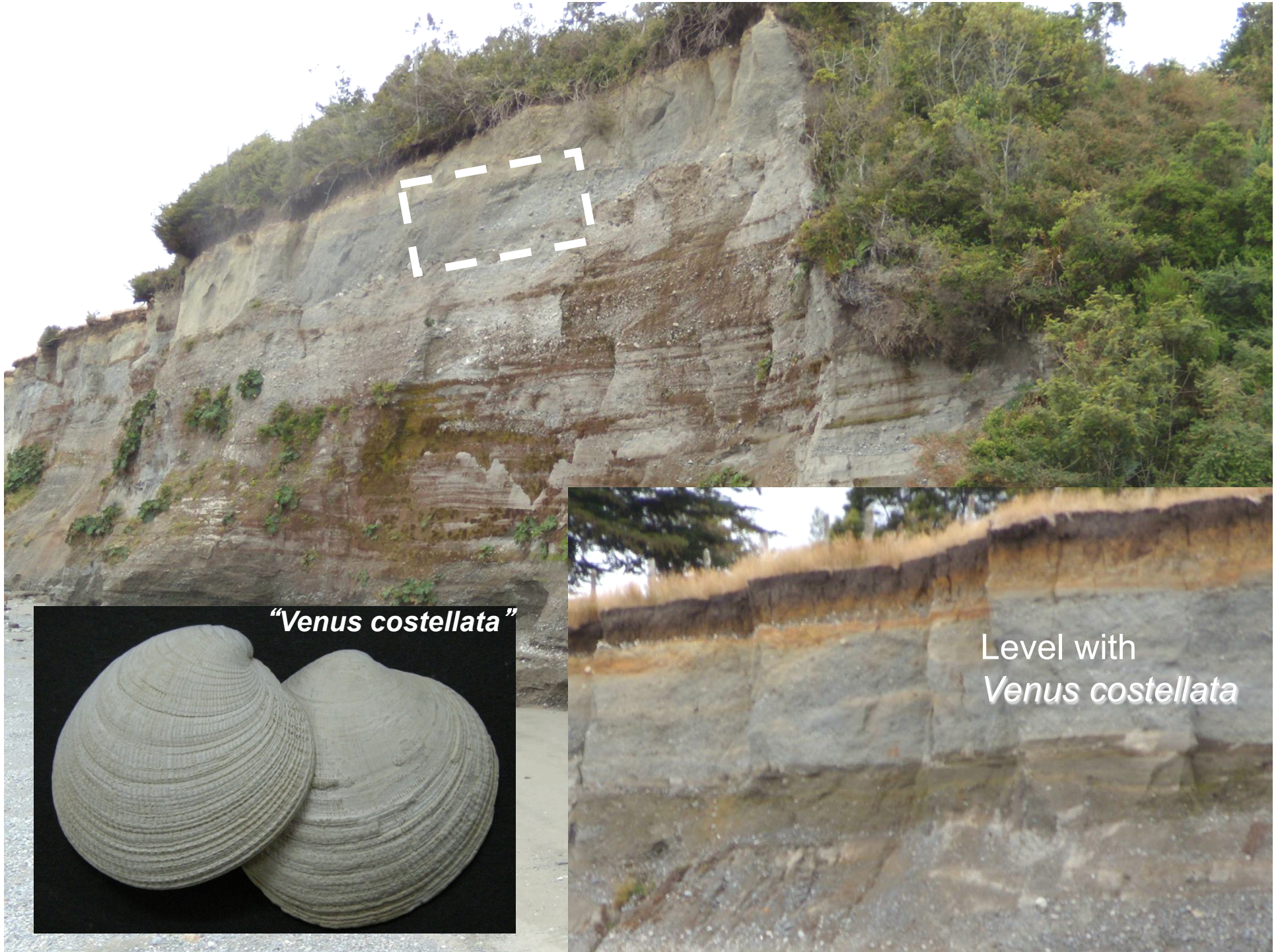
**Puente de Gamboa**





**Palafitos in the Rivulet of Gamboa**





*"Venus costellata"*

Level with  
*Venus costellata*





Third Level  
20 feet

Second Level  
30 feet

First Level  
50 feet

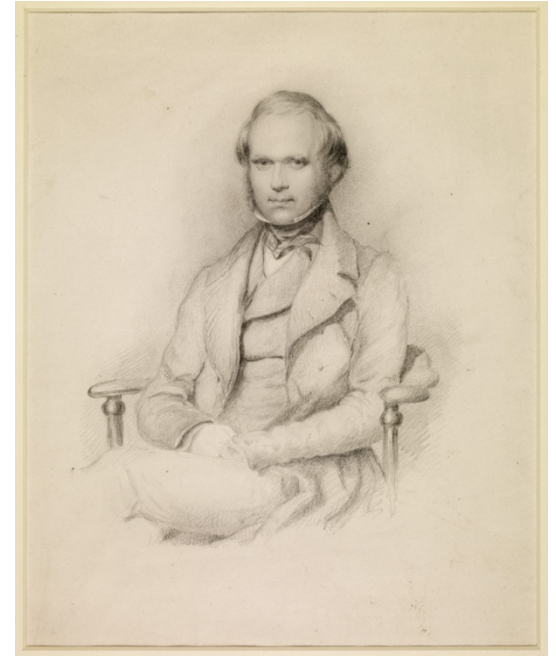
**Villa San Carlos: ... "ten miles south of Castro" ...**



# Darwin and the Andean uplift:

Which were his key observations?

- The recent uplift of old sea shores in Chiloé



*... "There can be no doubt that their three scarpments record pauses in the elevation of the island" ...*

***Darwin associated the uplift with earthquakes!***





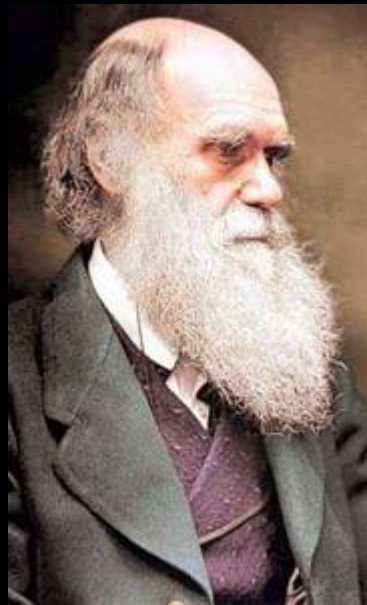
**Osorno Volcano erupted in Nov 29, 1834**

***Present Osorno Volcano seen from Ancud***









**XLII.—***On the Connexion of certain Volcanic Phenomena in South America ; and on the Formation of Mountain Chains and Volcanos, as the Effect of the same Power by which Continents are elevated.*

By CHARLES DARWIN, Esq., Sec., G.S., F.R.S.

[Read March 7th, 1838.]

Plate XLIX.

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On periods of increased volcanic action affecting large areas, p. 610.

Nature of the earthquakes on the coasts of South America, p. 615.

On different kinds of earthquakes ; and conclusions regarding those which accompany elevatory movements, p. 622.

Theoretical considerations on the slow elevation of mountain chains, p. 625.

Concluding remarks, p. 629.

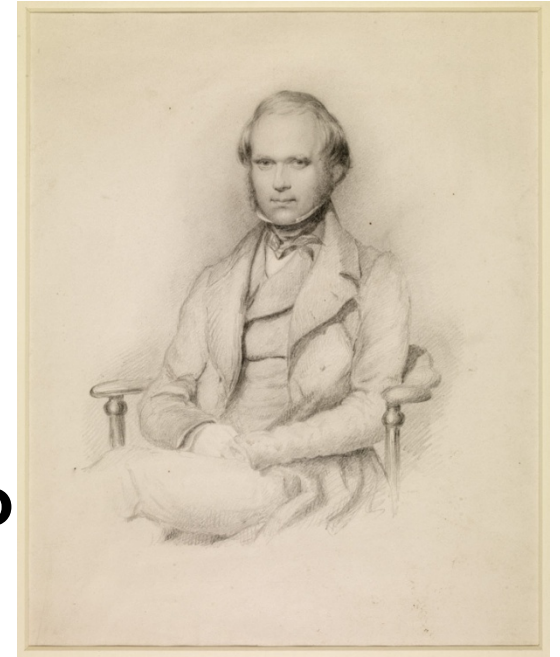
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# Darwin and the Andean uplift:

## Which were his key observations?

- The eruption of the Osorno Volcano  
The volcano erupted in Nov 29, 1834



Tectonophysics 471 (2009) 14–26



Contents lists available at [ScienceDirect](#)

Tectonophysics

journal homepage: [www.elsevier.com/locate/tecto](http://www.elsevier.com/locate/tecto)



Volcanic activity before and after large tectonic earthquakes: Observations and statistical significance

Silke Eggert \*, Thomas R. Walter

Department 2, Section "Earthquake Risk and Early Warning", Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany

***A close link between earthquakes and volcanoes!***

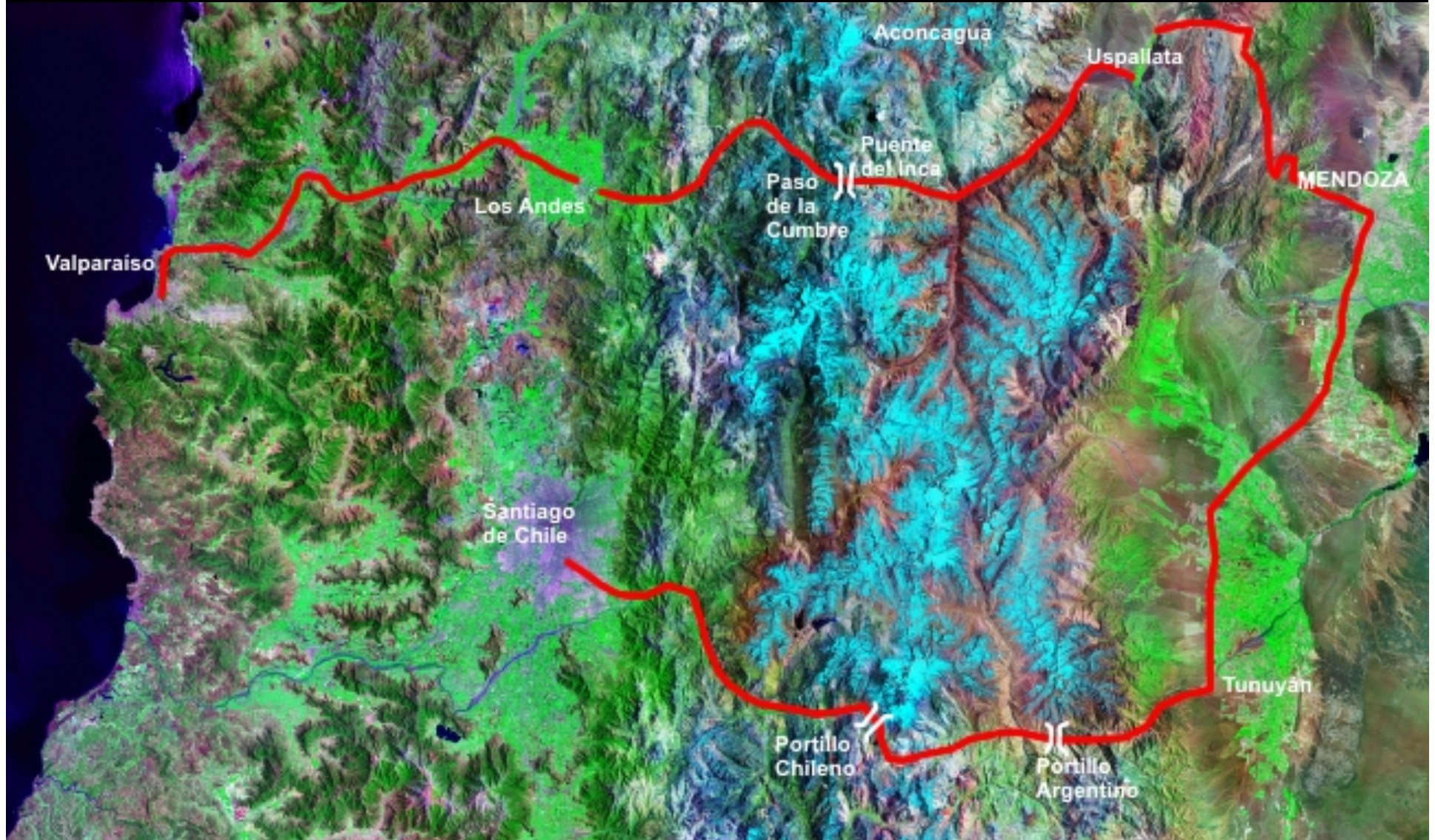


## 405





# DARWIN'S EXCURSION ACROSS THE ANDES

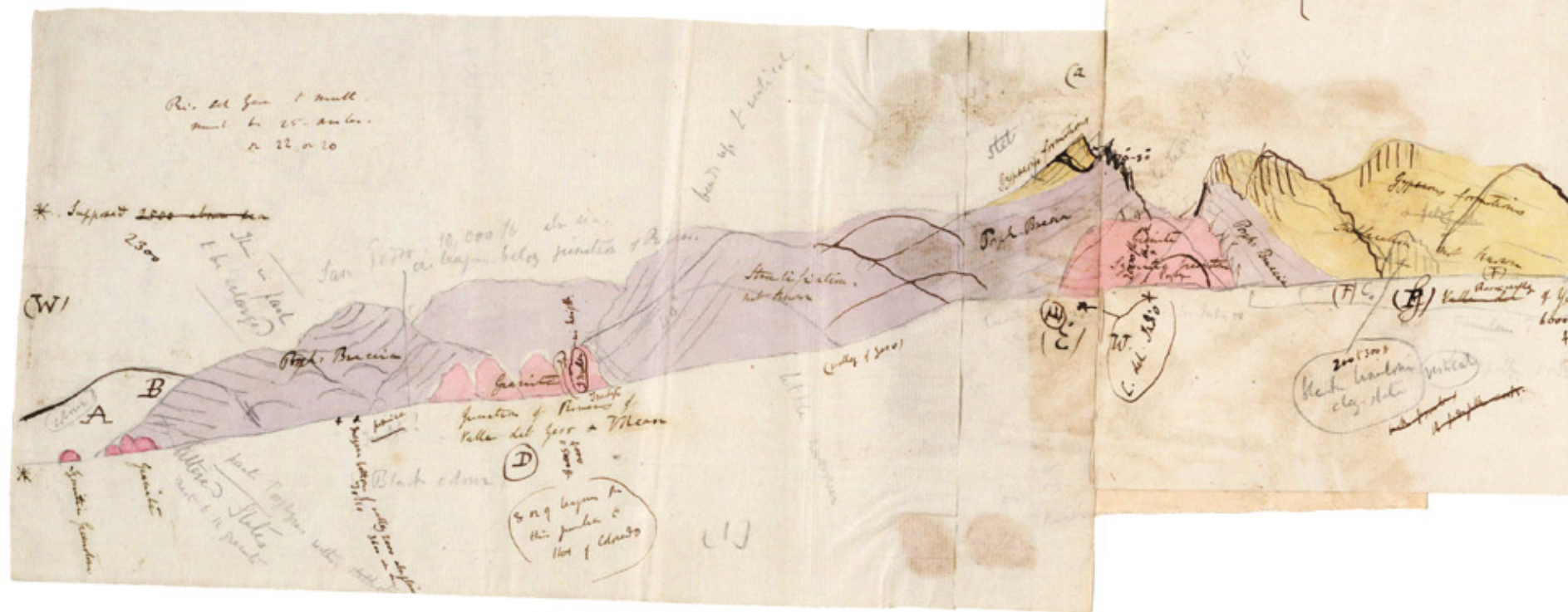




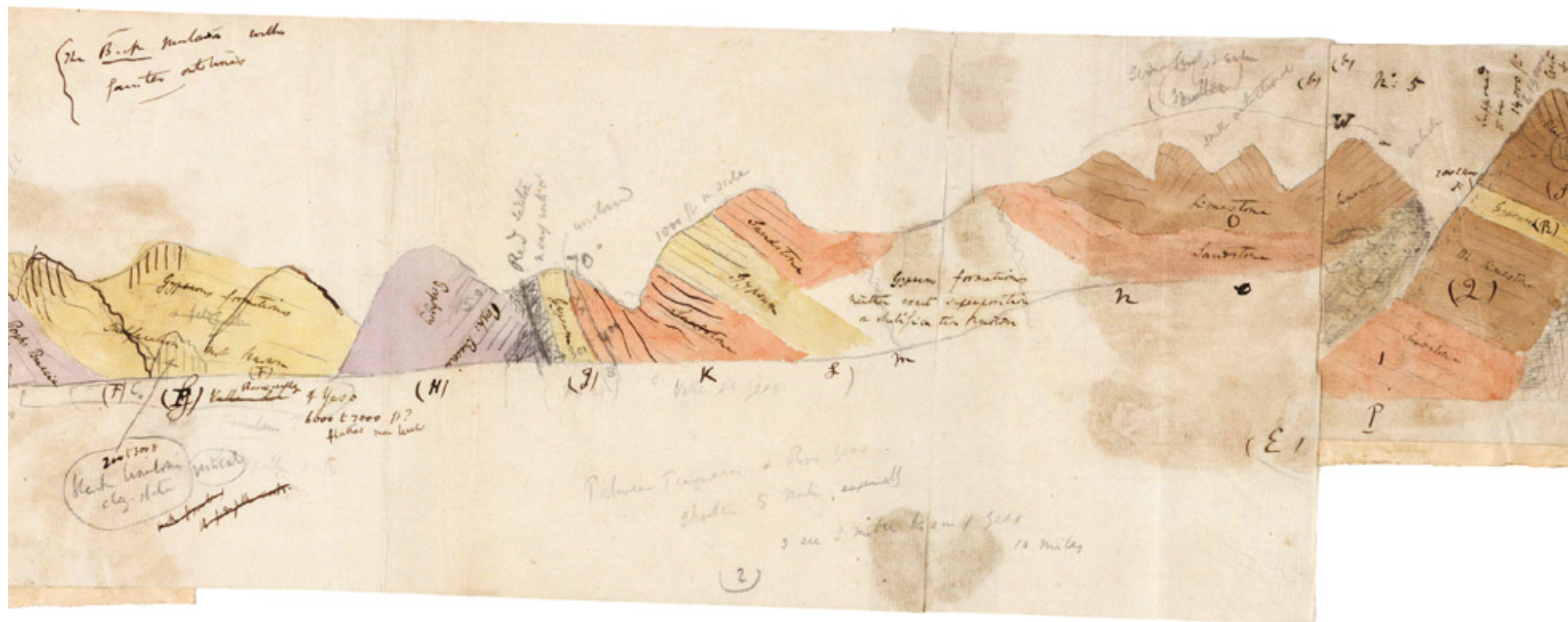
*: "I returned a week ago from my excursion across the Andes to Mendoza. Since leaving England I have never made so successful a journey...how deeply I have enjoyed it; it was something more than enjoyment; I cannot express the delight which I felt at such a famous winding-up of all my geology in South America. I literally could hardly sleep at nights for thinking over my day's work. The scenery was so new, and so majestic; everything at an elevation of 12,000 feet bears so different an aspect from that in the lower country...to a geologist, also, there are such manifest proofs of excessive violence; the strata of the highest pinnacles are tossed about like the crust of a broken pie...; after staying a day in the stupid town of Mendoza I began my return by Uspallata"*

Letter to his sister from Valparaíso, 23rd. of April of 1835

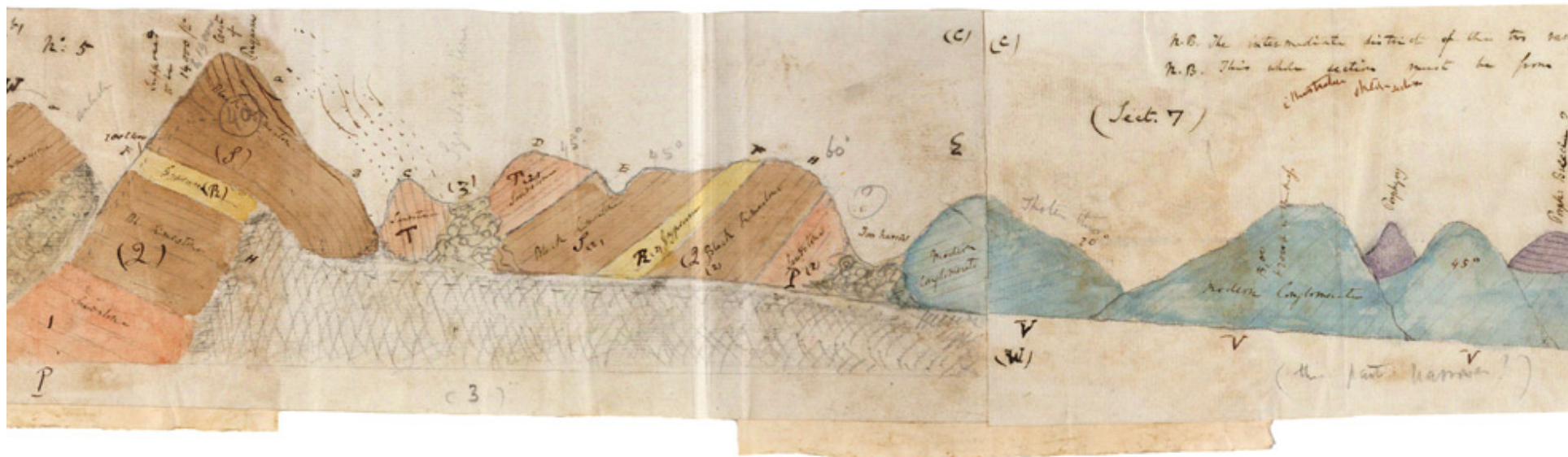




















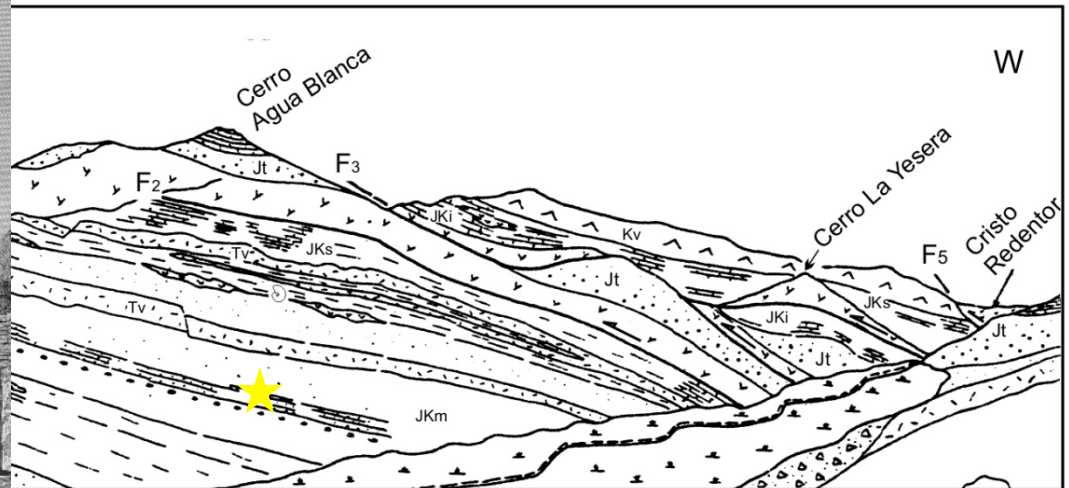
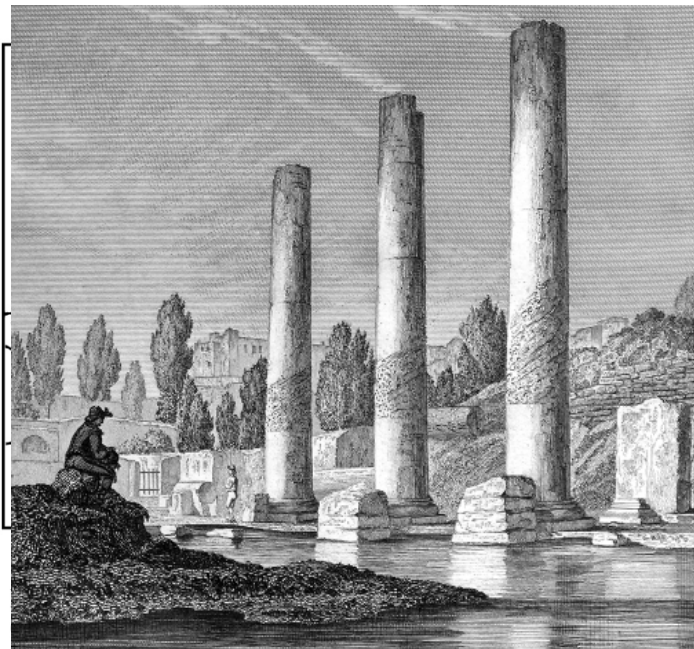




**"Shelters of Darwin"**



# STRATIGRAPHIC SECTION OF THE INCA'S BRIDGE



present structural interpretation. Crt: Alto Tupungato Formation (Carboniferous), Trch: Choiyoi Tordillo Formation (Late Jurassic), JK<sub>i</sub>: Early Titho-Neocomian deposits, JK<sub>m</sub>: Middle Neocomian deposits, JK<sub>s</sub>: Late Neocomian deposits, Ic: Santa Maria Conglomerates (Miocene), Tv: Puente del Inca Trachyte (Miocene).

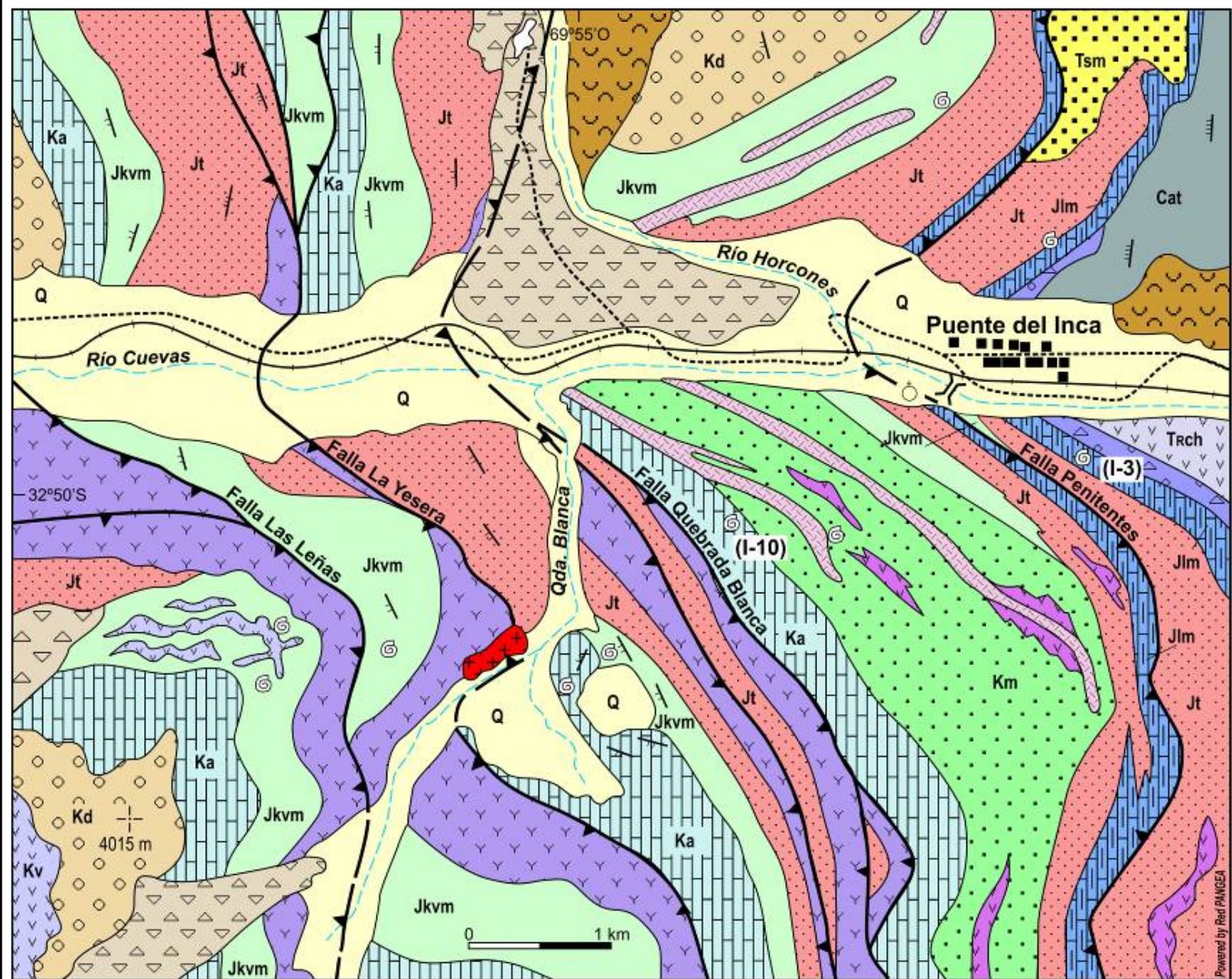


## Darwin at the Inca's Bridge



- He found marine fossils at more than 3,000 meters above sea level.
- He identified shallow marine levels separated by hundred of meters, and postulated for the first time the subsidence of the sea bottom during sedimentation.
- Recognized different timing of uplift between the Main and Frontal Cordilleras.





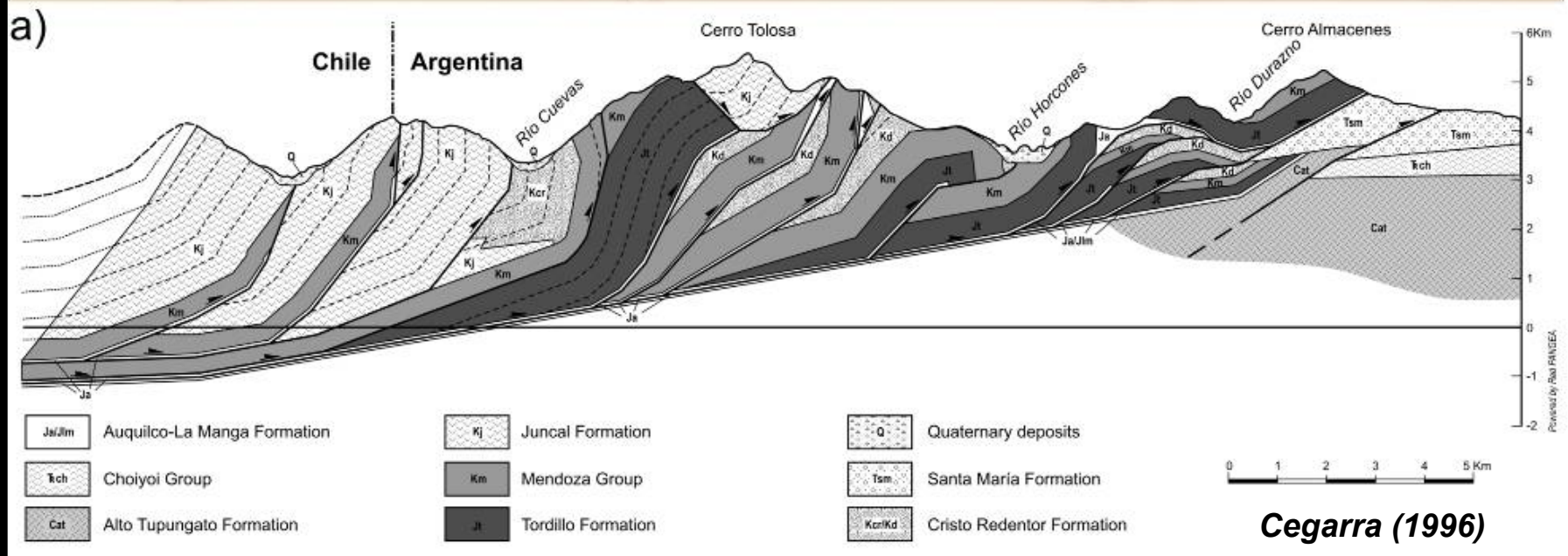
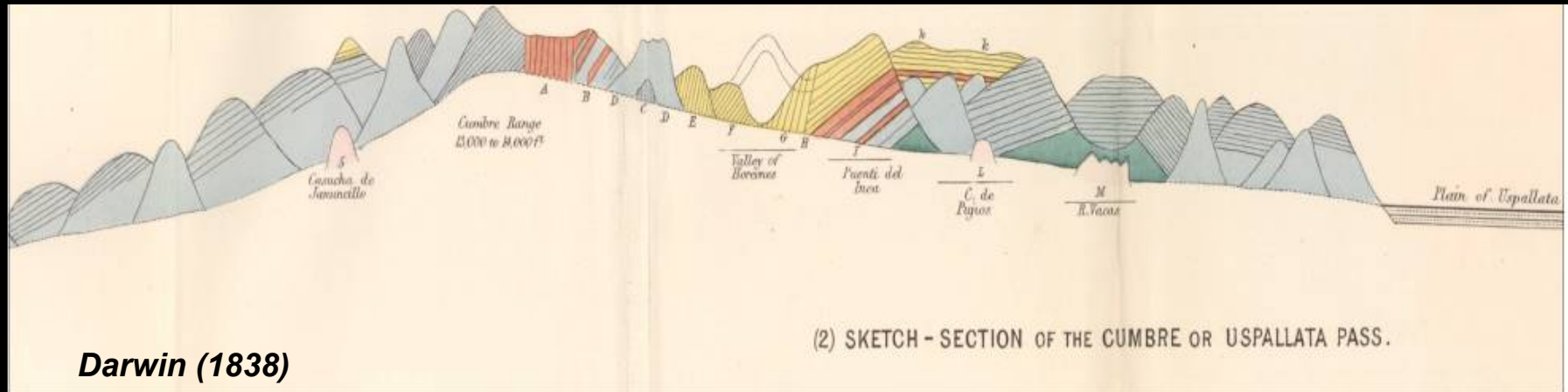


# STRUCTURAL SECTIONS NEAR THE INCA'S BRIDGE



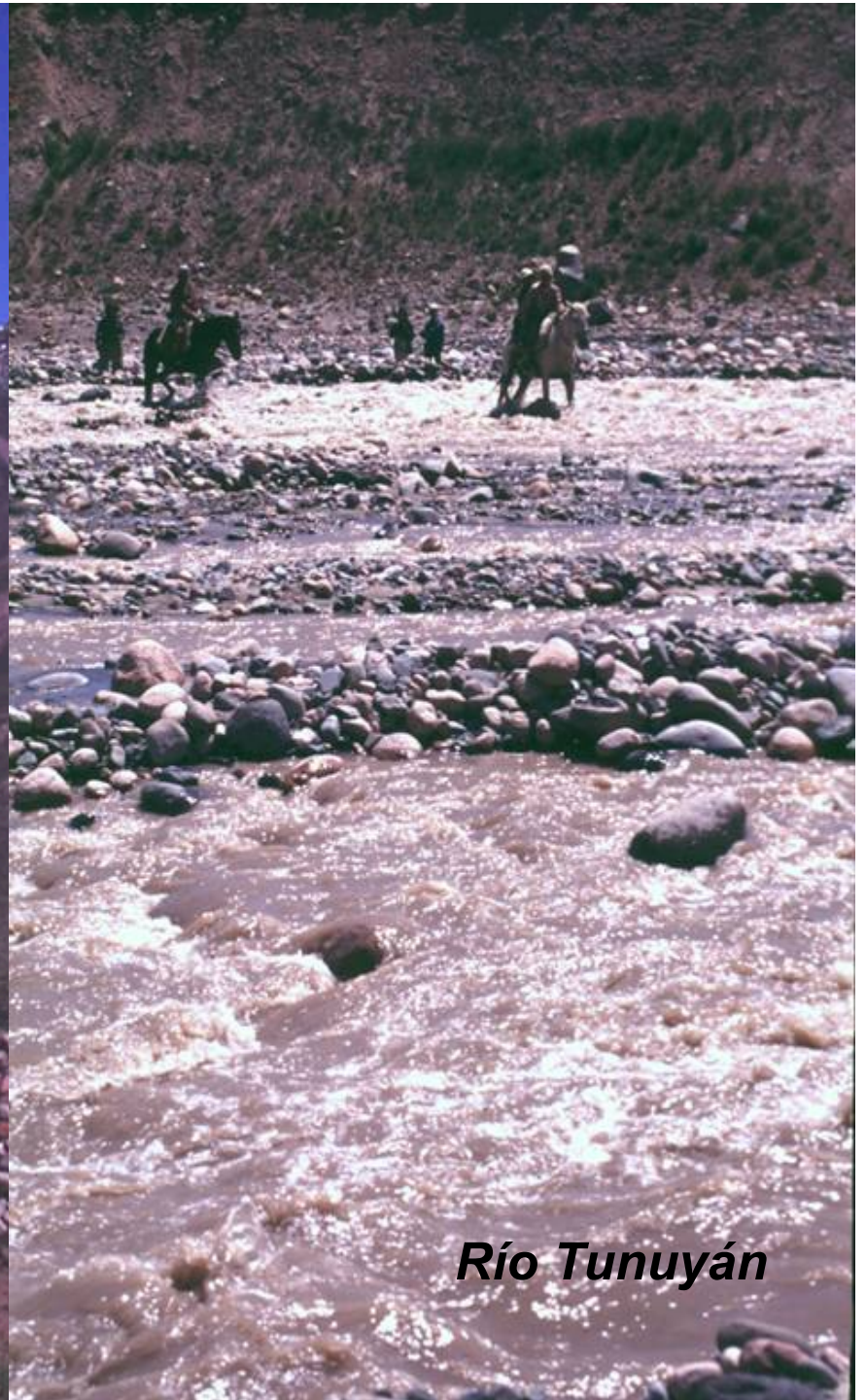
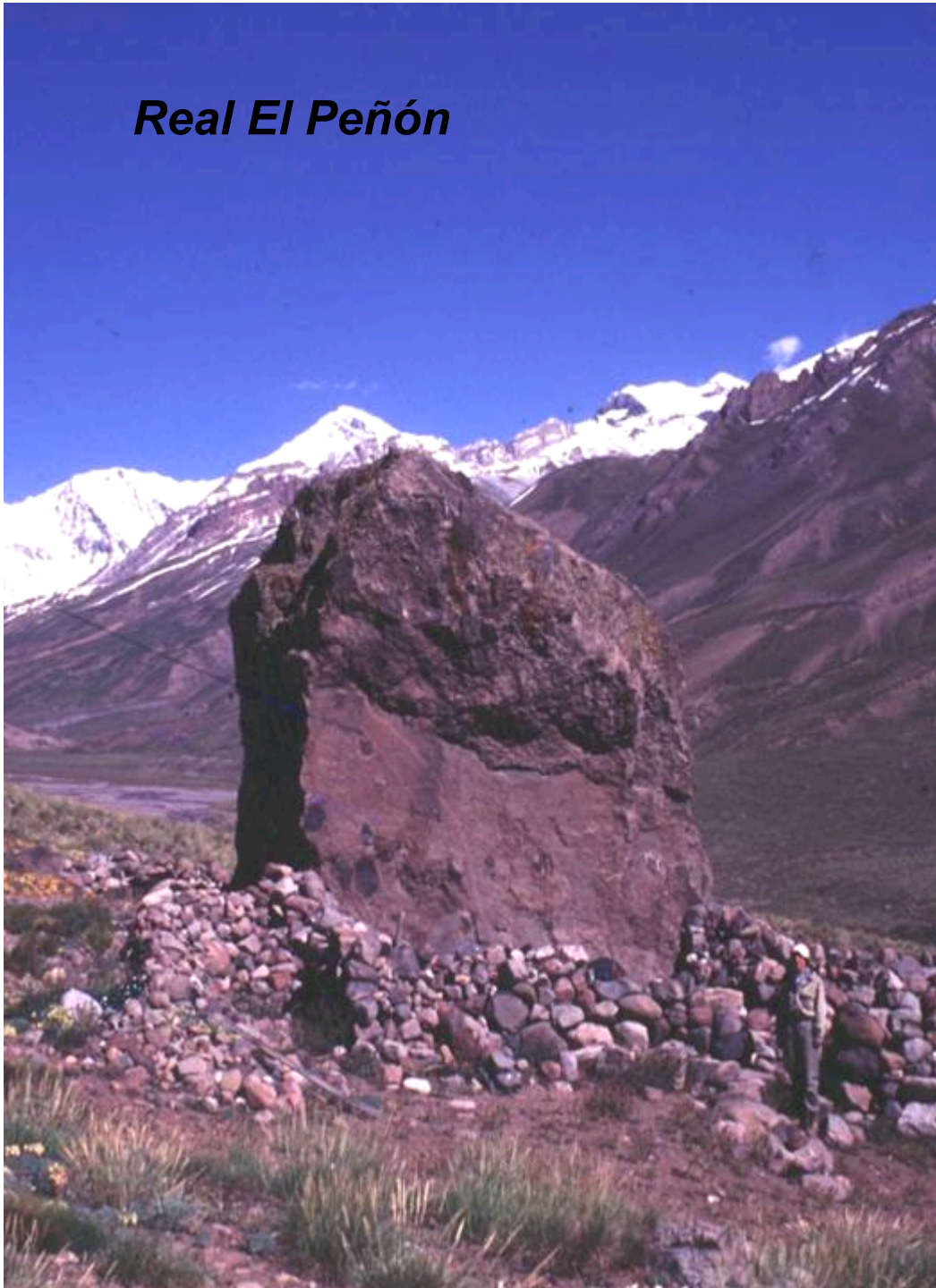


# STRUCTURAL SECTION NEAR THE INCA'S BRIDGE





*Real El Peñón*



*Río Tunuyán*



**Synorogenic deposits**

***Río Palomares***





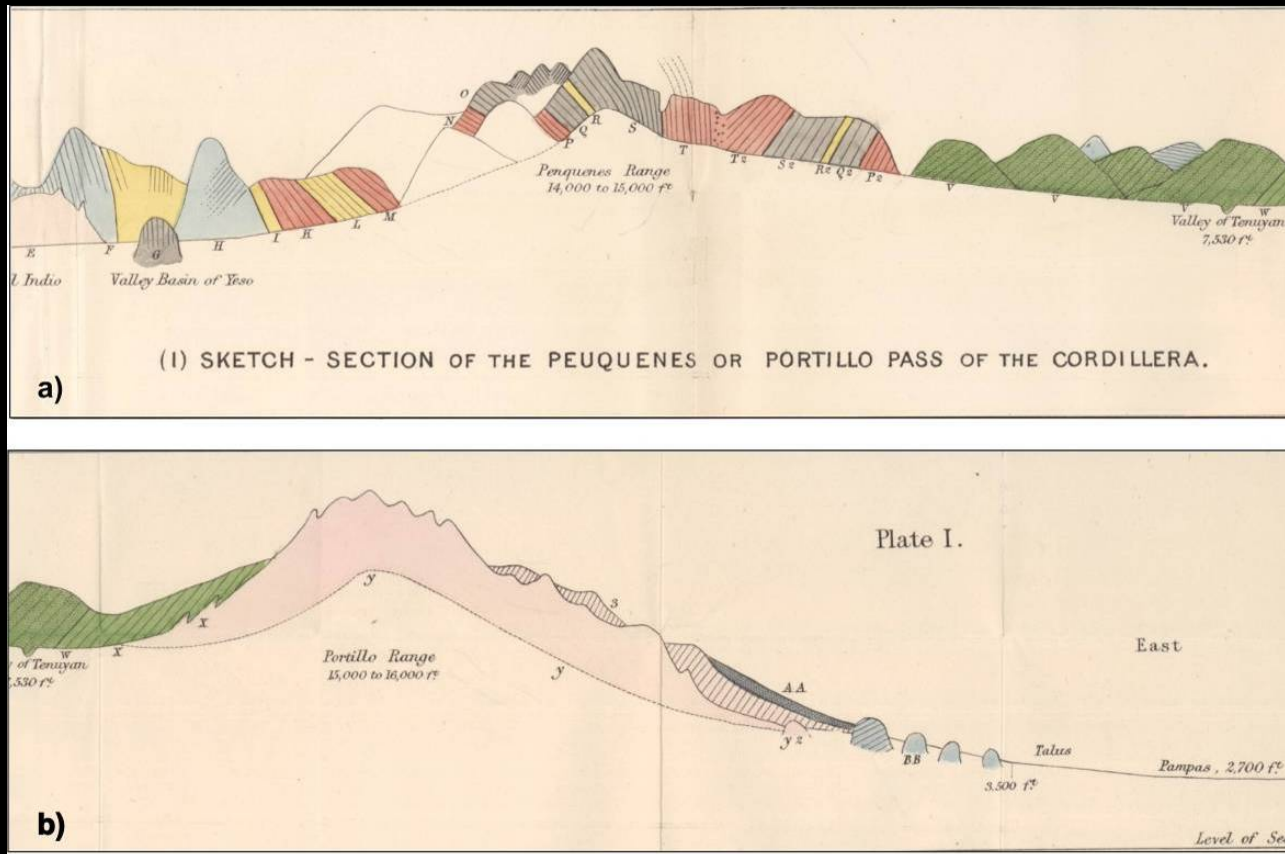
# **MAIN CONTRIBUTIONS OF DARWIN TO THE ANDES**

- **Evidence of uplift: > than 3,000 meters!!!**
- **Evidence of subsidence (hundred of meters)**
- **Association with volcanic eruptions**
- **Association with earthquakes**
- **Evidence of lateral growth in the mountain uplift**

***The Andes are an active Mountain Chain (Darwin, 1838)***



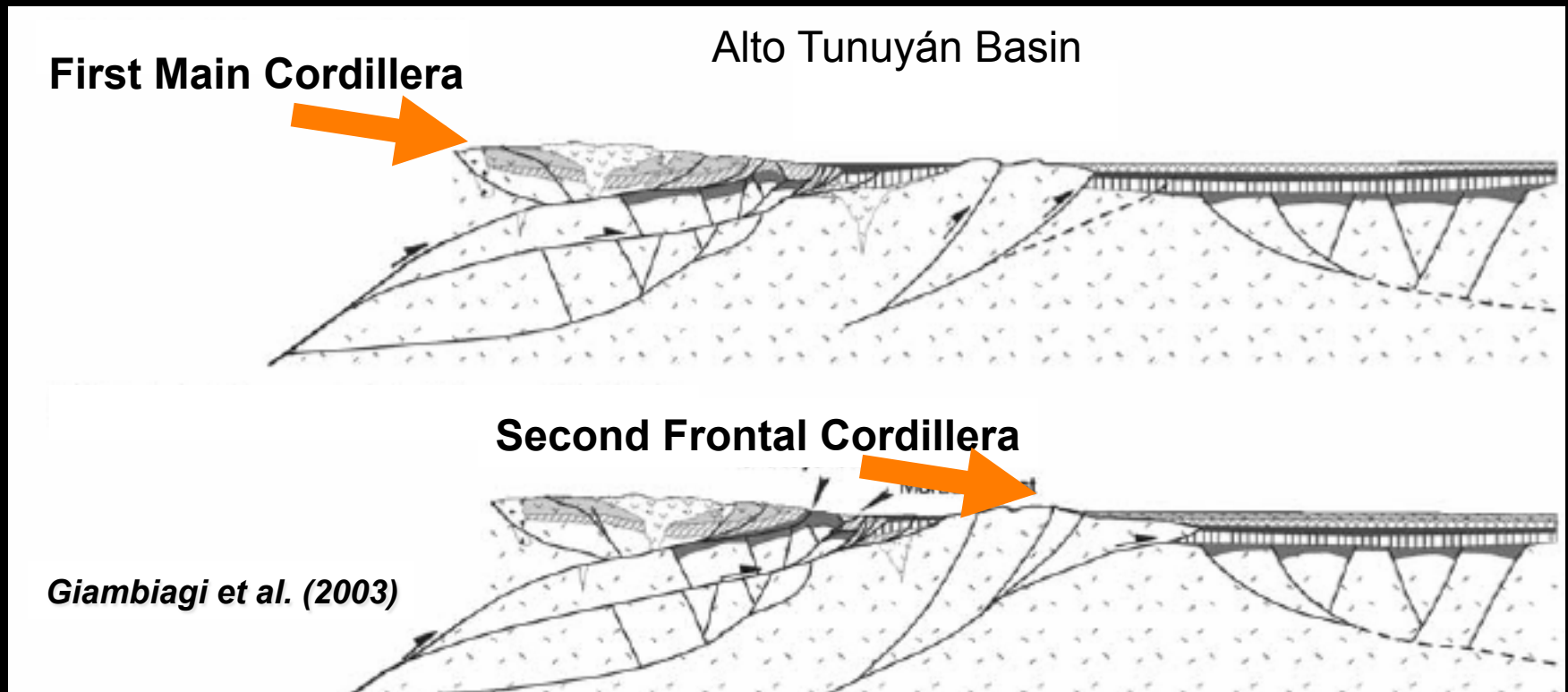
# STRUCTURAL SECTION OF ALTO TUNUYÁN



- Recognized limestone fragments with fossils at the base and metamorphic rocks in the younger sequences derived from the Frontal Cordillera.
- Later all the Tertiary sequence is uplifted interbedded with volcanic rocks. The uplift is of episodic nature.



# STRUCTURAL SECTION OF THE ALTO TUNUYÁN

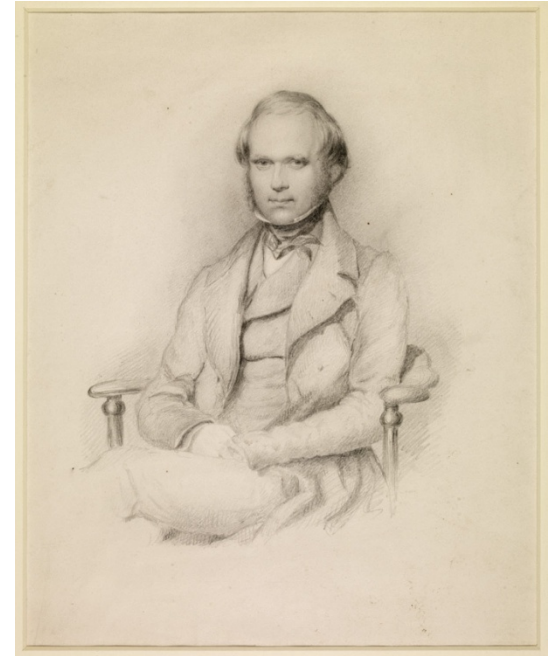


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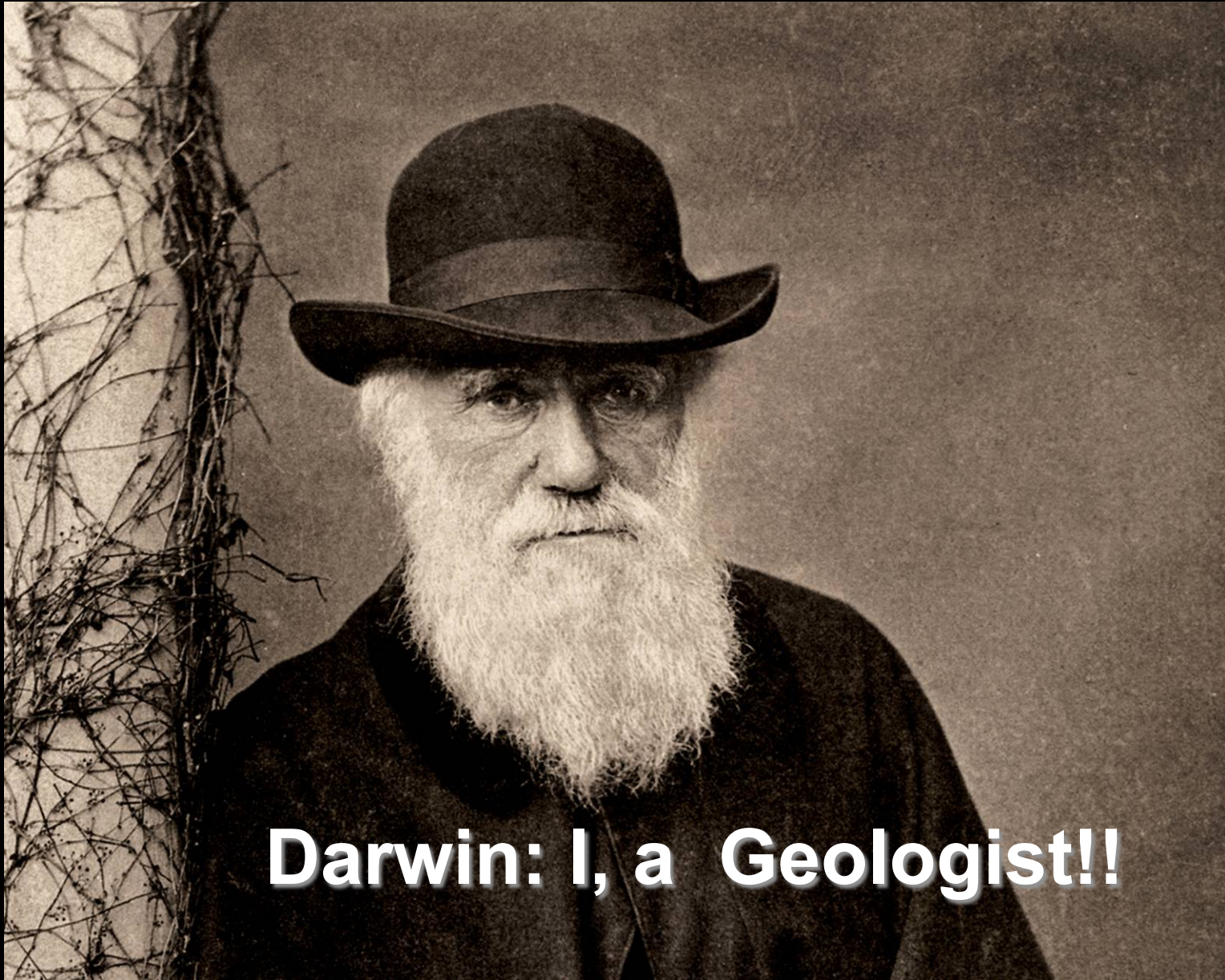
# **Darwin and the Andean uplift:**

**Darwin's legacy to the geologic knowledge of his time:**



***He was the first to recognize that the Andes are an active mountain chain, which was uplifted thousand of meters through earthquakes associated with an active volcanism, in an episodic way, and with evidence of lateral growth . . .***

***. . . but what it is more important:***

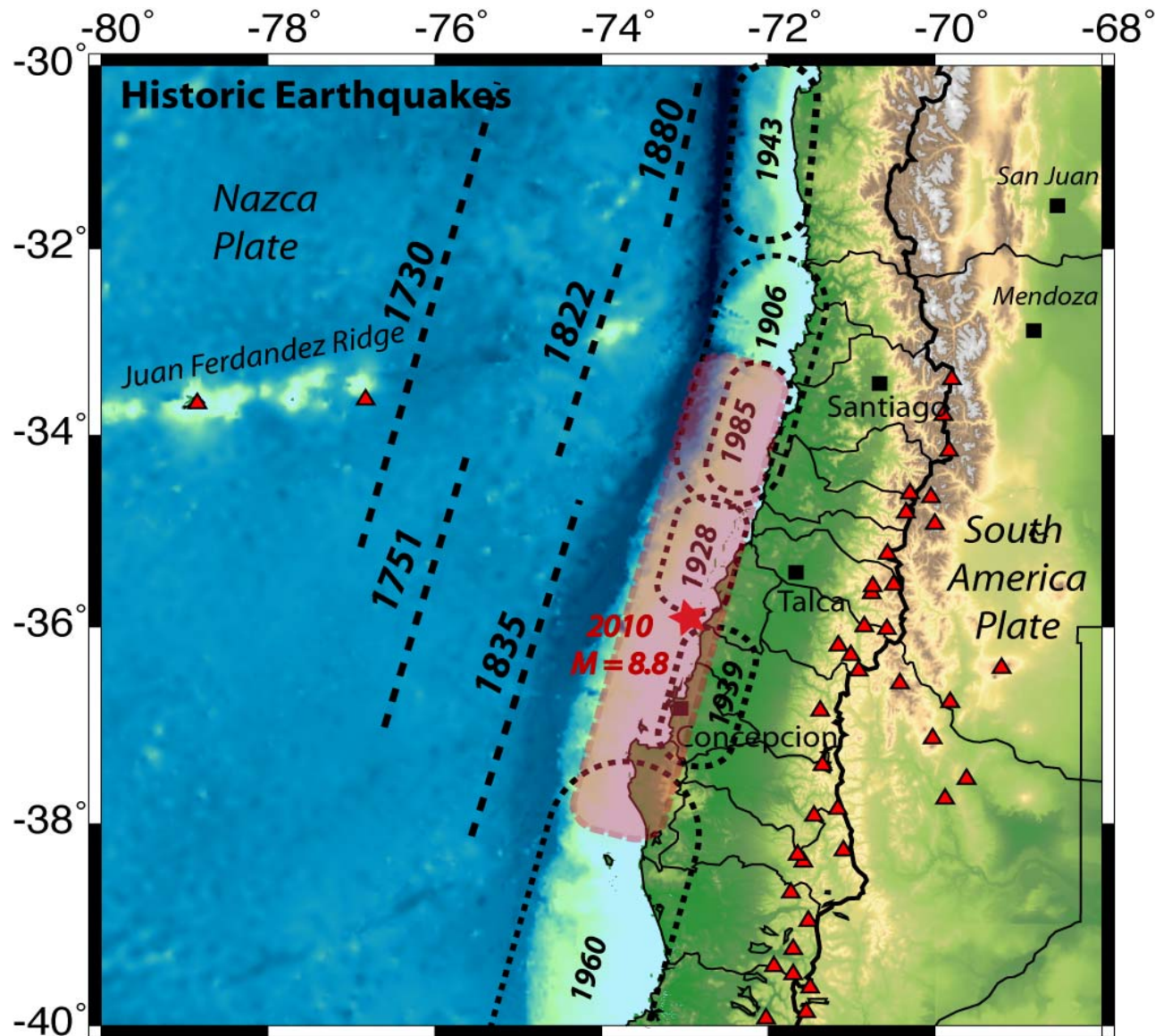


**Darwin: I, a Geologist!!**

*He concluded that the 'Geology of whole world will turn out simple'.*

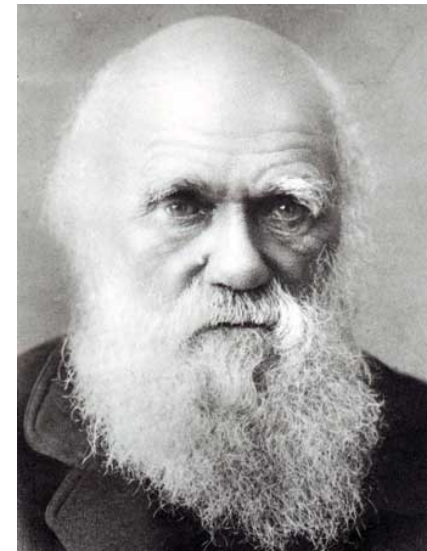


# Can we predict the earthquakes?



Based on Beck et al., 1998

Darwin described the last earthquake (1835) in this segment of the continental margin.



1835



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### Interseismic strain accumulation measured by GPS in the seismic gap between Constitución and Concepción in Chile

J.C. Ruegg<sup>a,\*</sup>, A. Rudloff<sup>b</sup>, C. Vigny<sup>b</sup>, R. Madariaga<sup>b</sup>, J.B. de Chabalier<sup>a</sup>, J. Campos<sup>c</sup>, E. Kausel<sup>c</sup>, S. Barrientos<sup>c</sup>, D. Dimitrov<sup>d</sup>

<sup>a</sup> *Institut de Physique du Globe (IPGP), Paris, France*

<sup>b</sup> *Laboratoire de Géologie, Ecole Normale Supérieure (ENS), CNRS, Paris, France*

<sup>c</sup> *Departamento de Geofísica (DGF), Universidad de Chile, Santiago, Chile*

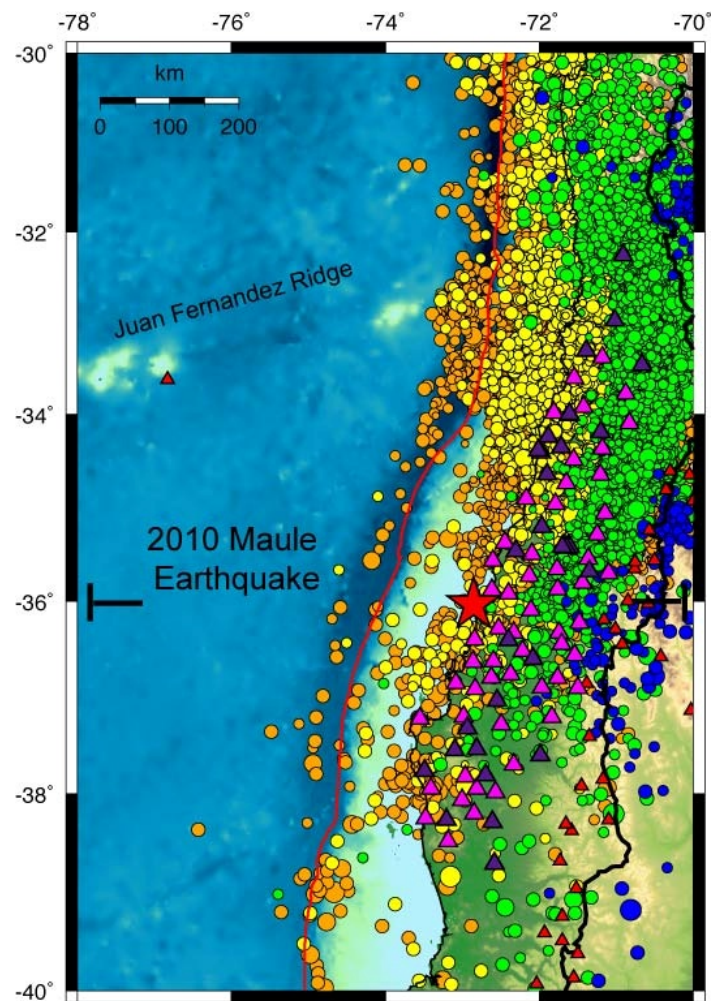
<sup>d</sup> *Bulgarian Academy of Sciences, Sofia, Bulgaria*

Nov. 2009 (3 months prior to the Maule megathrust earthquake).

the northern area of our network the fit is improved locally by using a lower dip around 13°. Finally a convergence motion of about 68 mm/year represents more than 10 m of displacement accumulated since the last big interplate subduction event in this area over 170 years ago (1835 earthquake described by Darwin). Therefore, in a worst case scenario, the area already has a potential for an earthquake of magnitude as large as 8–8.5, should it happen in the near future.

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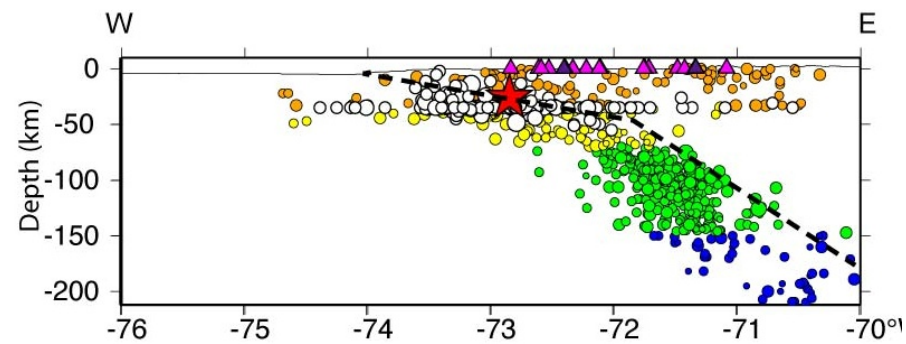
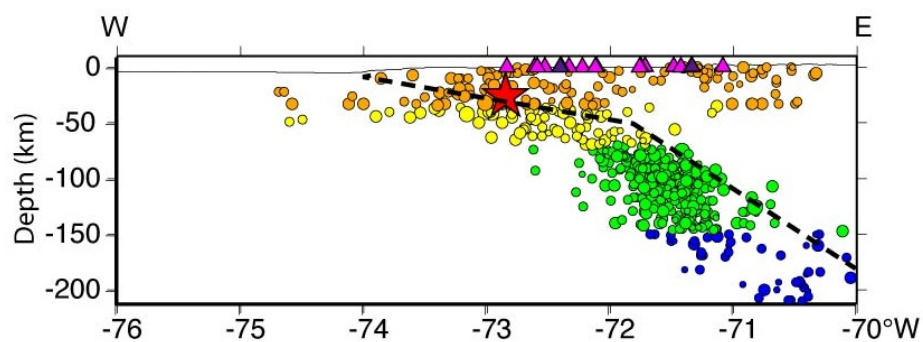
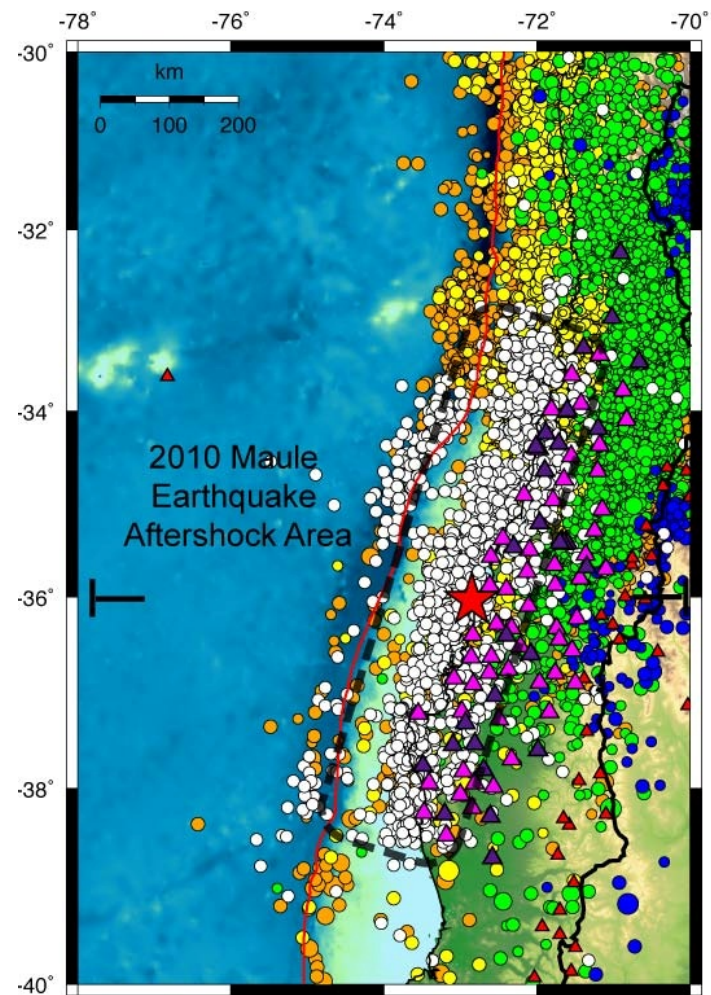


*IRIS, EEUU*

- ▲ Volcanoes
- ▲ IRIS broadband seismic stations
- ▲ French/Caltech & Chile broadband seismic stations

Earthquake depth (from NEIC)  
 orange 0-35 km  
 yellow 36-60 km  
 green 61-150 km  
 blue >150 km

--- Estimate of top of the slab



## **Predicting the unpredictable; evidence of pre-seismic anticipatory behaviour in the common toad**

R. A. Grant<sup>1</sup> & T. Halliday<sup>2</sup>

<sup>1</sup> Department of Life Sciences, The Open University, Milton Keynes, UK

<sup>2</sup> Oxford, UK

### **Keywords**

common toad; earthquakes; seismicity; behaviour; reproduction; spawning; ionospheric perturbations; VLF sounding.

### **Correspondence**

Rachel A. Grant, Department of Life Sciences, The Open University, Milton Keynes MK7 6AA, UK.

### **Abstract**

The widespread belief that animals can anticipate earthquakes (EQs) is poorly supported by evidence, most of which consists of anecdotal *post hoc* recollections and relates to a very short period immediately before such events. In this study, a population of reproductively active common toads *Bufo bufo* were monitored over a period of 29 days, before, during and after the EQ (on day 10) at L'Aquila, Italy, in April 2009. Although our study site is 74 km from L'Aquila, toads showed a dramatic change in behaviour 5 days before the EQ, abandoning spawning and not



# USGS ShakeMap : CENTRAL ITALY

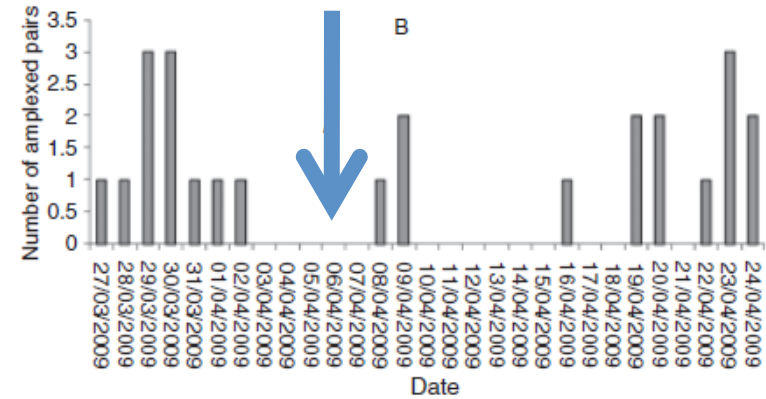
Mon Apr 6, 2009 01:32:42 GMT M 6.3 N42. 42 E13.39 Depth: 10.0km ID:2009fcaf



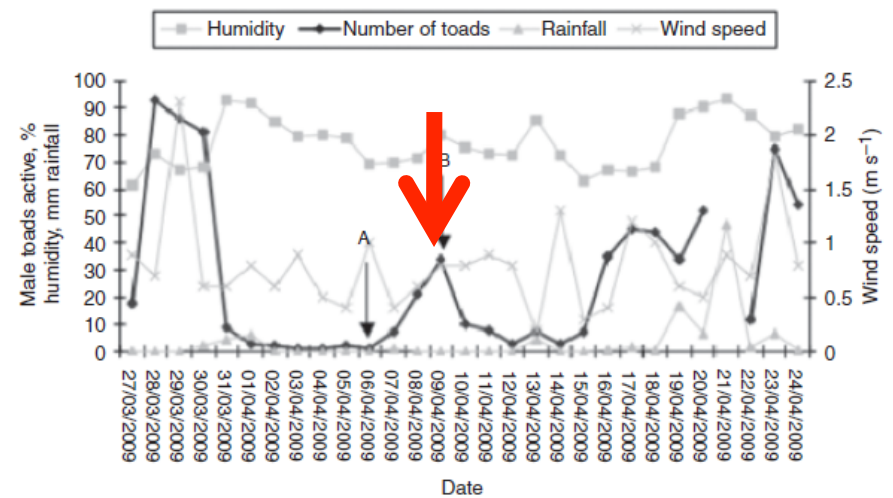
➡ Aquila Earthquake

➡ Full Moon

Grant & Halliday (2010)



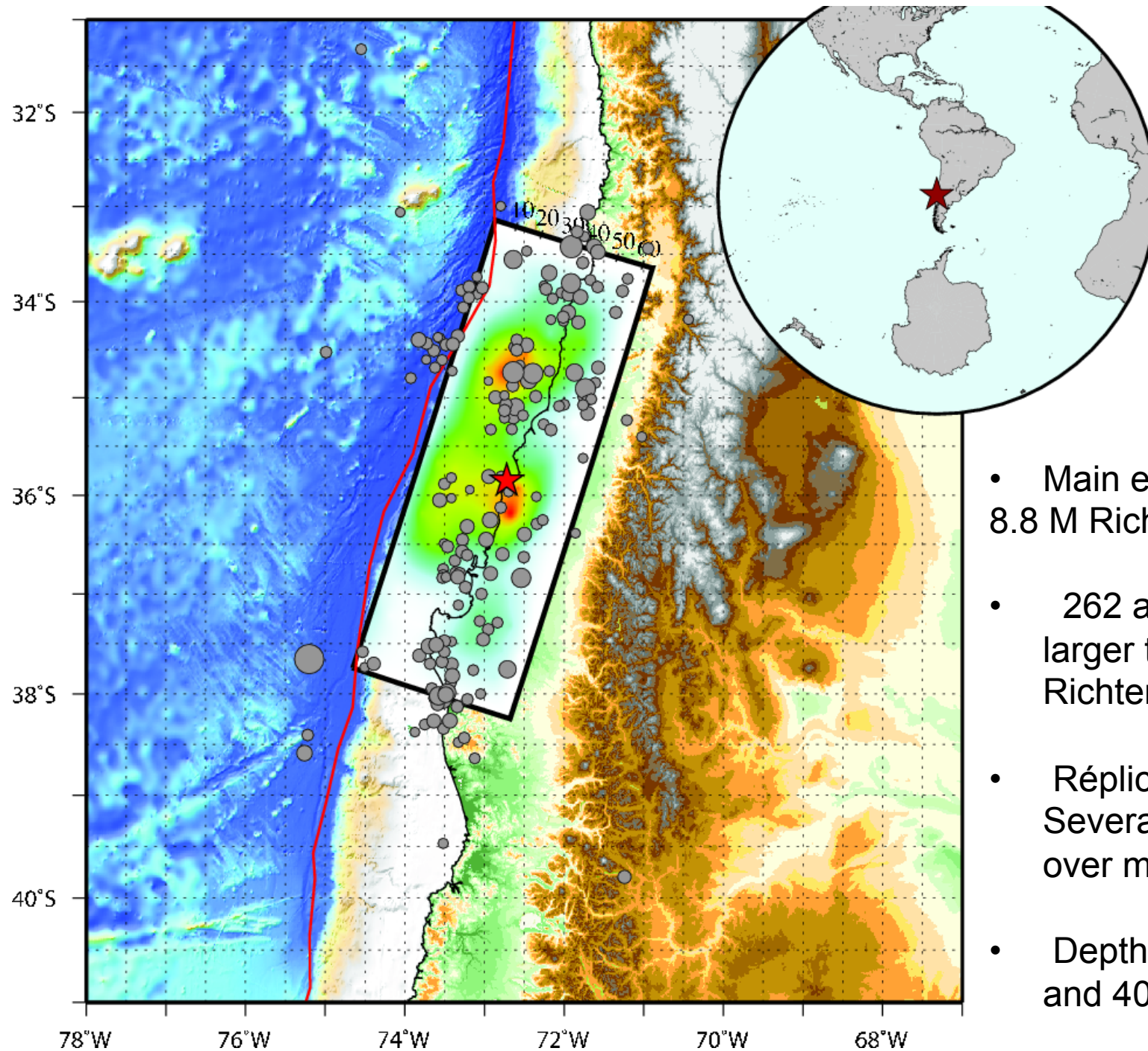
number of mating pairs of toads *Bufo bufo*





Ancient  
Chinese  
seismograph





- Main earthquake of 8.8 M Richter.
- 262 aftershocks larger than 5 Richter scale.
- Réplicas de hast  
Several aftershocks over magnitude 7.
- Depths between 35 and 40 km.





**Uplift of the Península de Arauco**





**Uplift of the Península de Arauco**

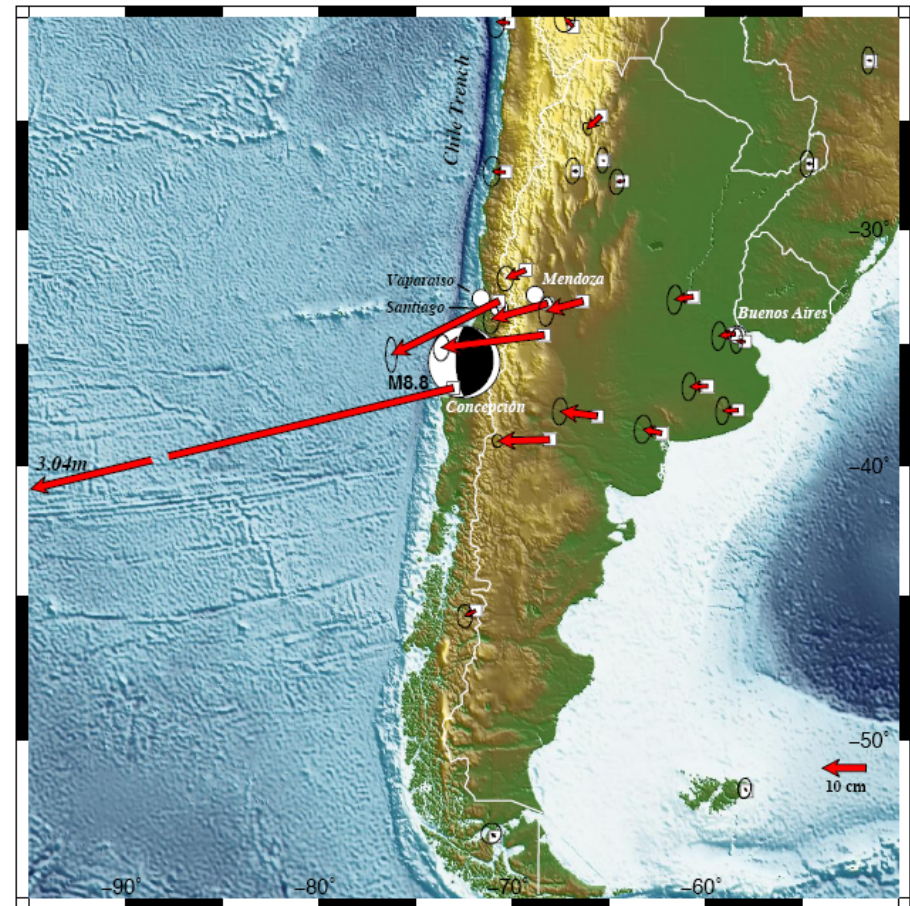
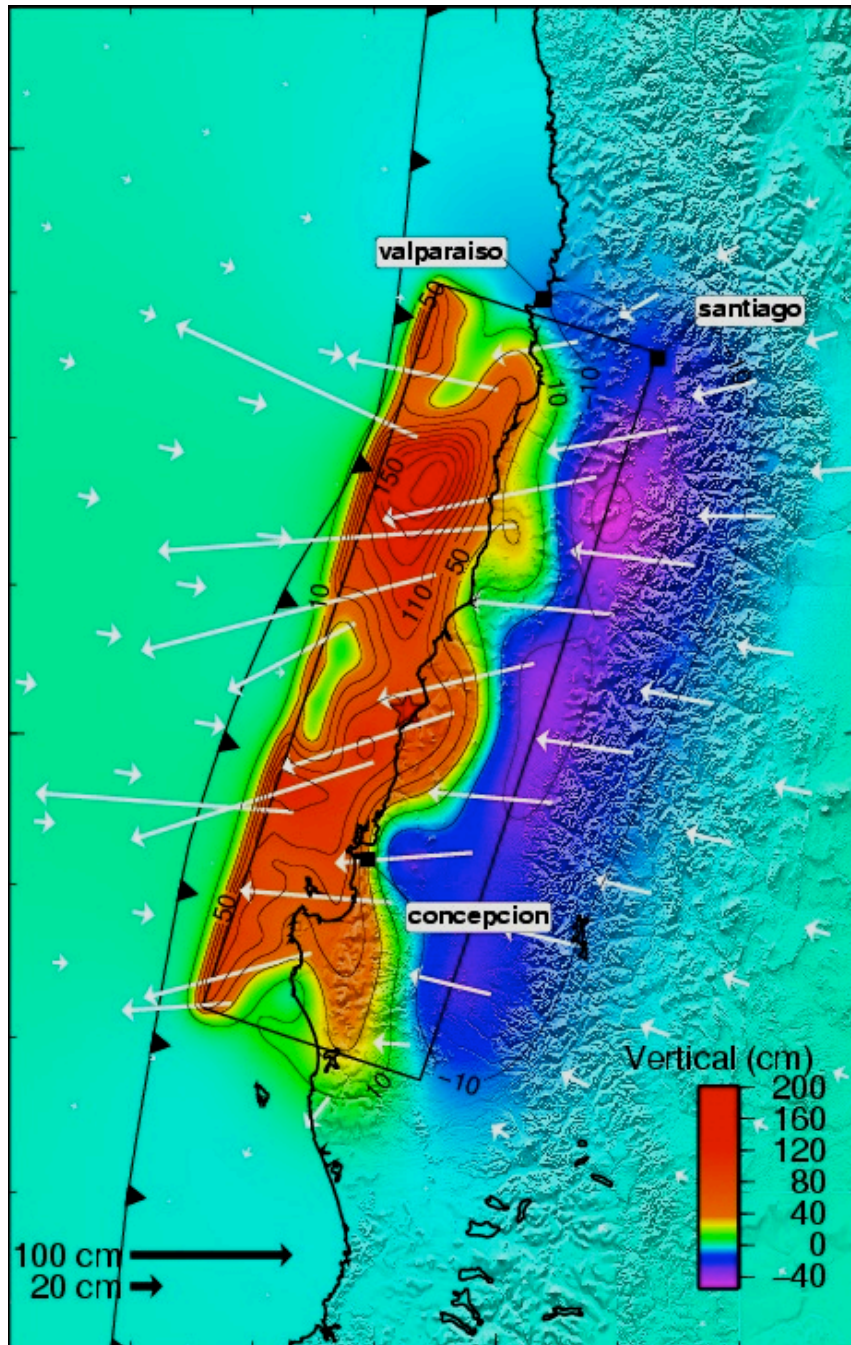


**Lebú**



# GPS COSEISMIC DISPLACEMENTS

3, 05 meters in Concepción!



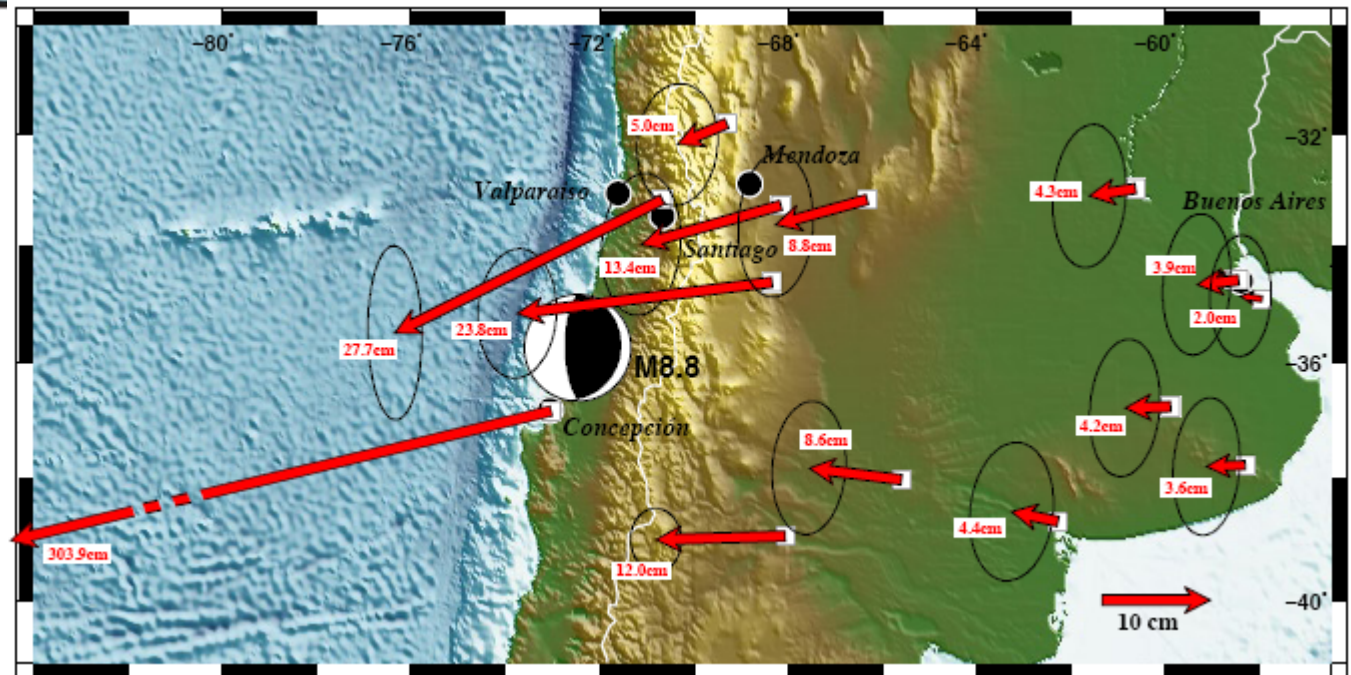
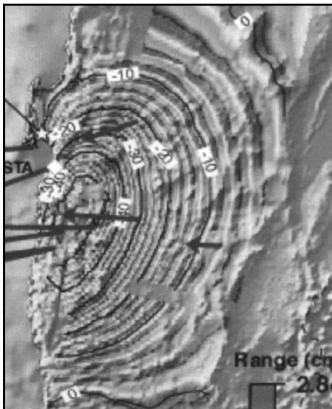


# COSEISMIC DISPLACEMENT IN ARGENTINA AND CHILE

Buenos Aires: 3.9 cm  
Mendoza: 8.8 cm  
Rosario: 4.3 cm  
Bahía Blanca: 4.4 cm  
San Rafael: 23.8 cm

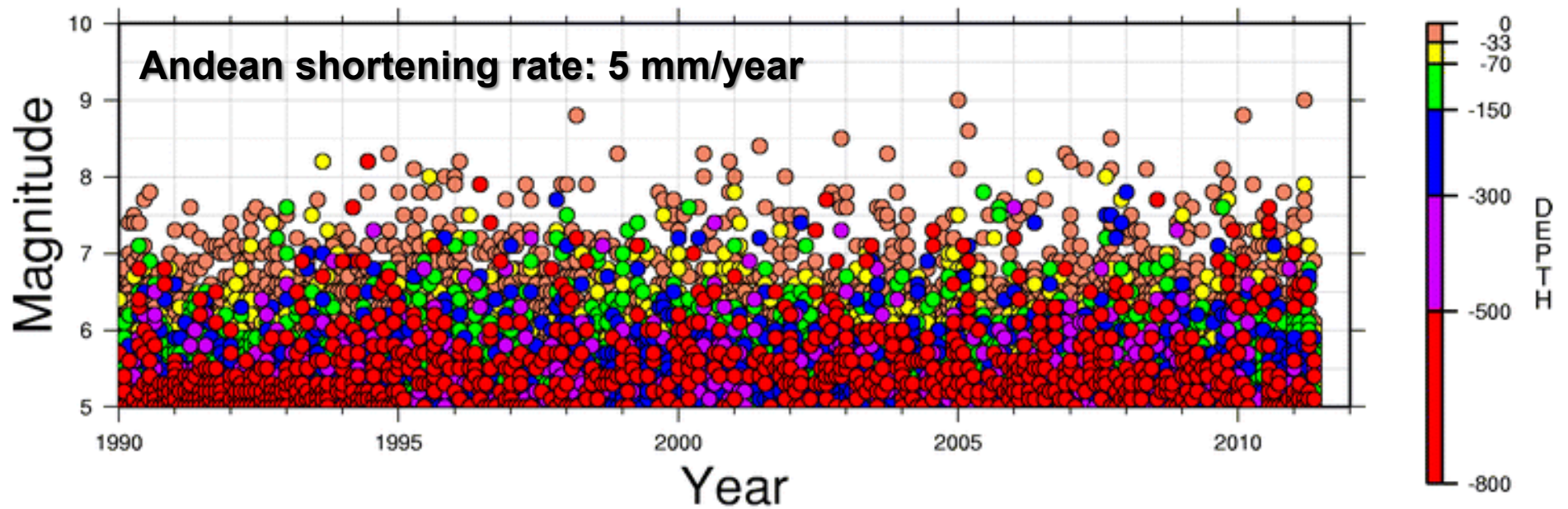


Santiago: 27.7 cm  
Concepción: 303.9 cm



# Earthquakes Located by the NEIC

## Magnitude 5 and Greater

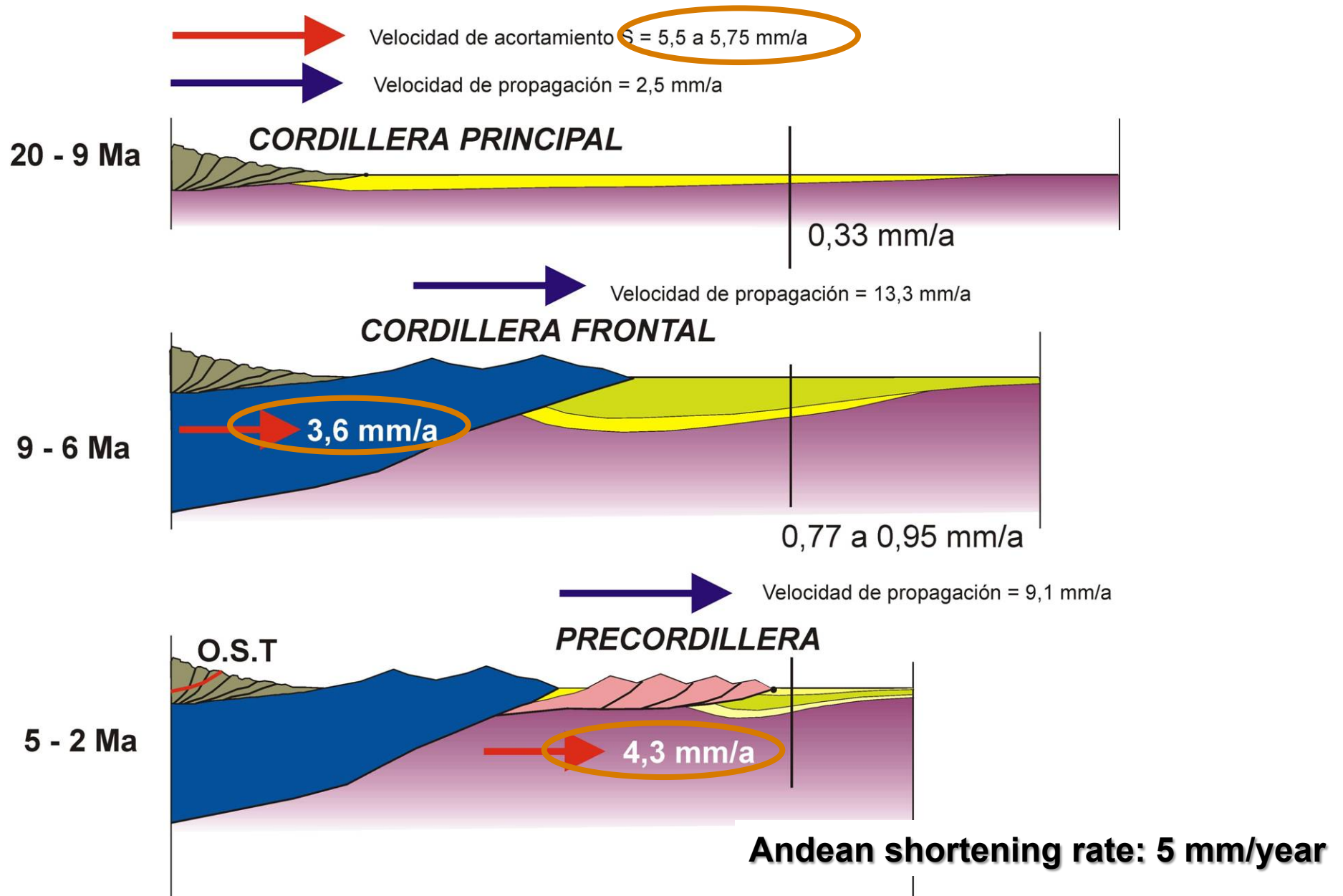


Magnitud	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
8.0 to 9.9	1	1	0	1	2	1	2	4	0	1	1	1
7.0 to 7.9	14	15	13	14	14	10	9	14	12	16	21	8
6.0 to 6.9	146	121	127	140	141	140	142	178	168	144	151	115
5.0 to 5.9	1344	1224	1201	1203	1515	1693	1712	2074	1768	1896	1943	1167
4.0 to 4.9	8008	7991	8541	8462	10888	13917	12838	12078	12291	6805	10406	5266

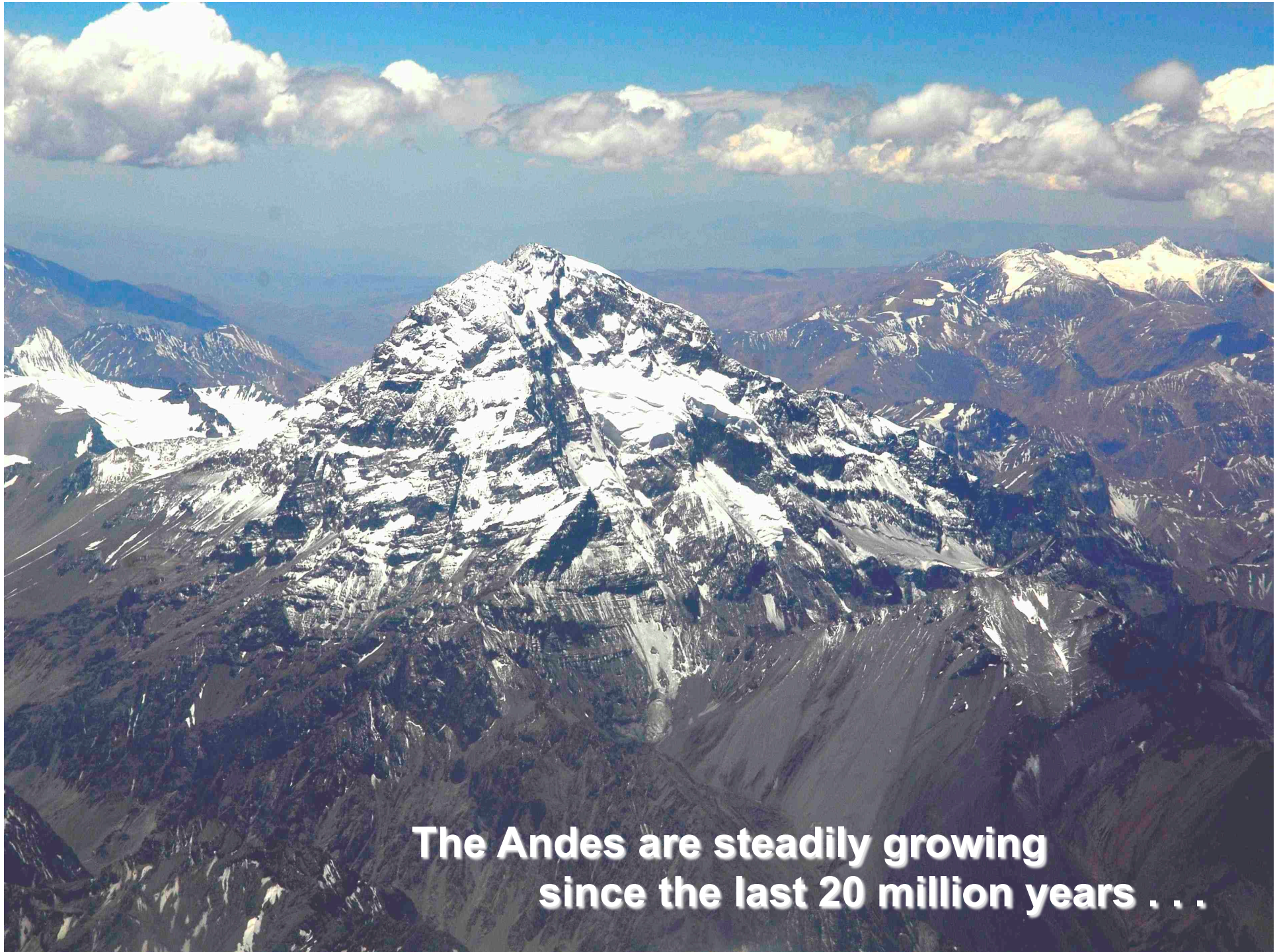
U.S.G.S. (2011)



# DEFORMATION RATES OF THE LAST 20 Ma IN THE ANDES







**The Andes are steadily growing  
since the last 20 million years . . .**