LARGE EARTHQUAKES AND THE DEVELOPMENT OF SEISMOLOGY

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Lisbon earthquake was felt over the whole Iberian Peninsula and as far as Germany and Switzerland. It was followed by a large tsunami. Caused the destruction of Lisbon and damage in Cadiz, Huelva and Seville.
THERE WAS A DEBATE ON THE NATURAL OR SUPERNATURAL CHARACTER OF THE EARTHQUAKE
SOME OPINIONS IN SPAIN

supernatural or natural event

Miguel San José, Bishop of Guadix
“To deny or doubt that earthquakes are usually the effects of the wrath of God can be considered an error in the faith”.

Agustín Sánchez, Trinitarian theologian
“God uses creatures to infuse fear in sinners and move them to repentance”.

José de Cevallos, theologian, later Rector of the University of Seville.
“The earthquake has been entirely natural, caused by natural and proportioned second causes”

Antonio del Barco, a cleric and historian from Huelva,
Stated that “he studied, as a philosopher, the causes, duration, extension and effects of the earthquake”
Benito Feijoo presented in 1756 the original theory that earthquakes are caused by electrical discharges in the Earth’s interior, like lightening and thunders in the atmosphere.

The theory had been proposed before by William Stuckley and Giovanni Beccaria.
PROPAGATION OF SEISMIC WAVES

John Michell, proposed in 1760 that in earthquakes shaking propagates as elastic waves from the focus. For the first time the origin of the earthquake was separated from the waves it generates and are propagated to large distances (Essay on the causes of the phenomena of earthquakes).

Explosive source substituted the Aristotelian doctrine.
NAPLES EARTHQUAKE OF 1857

On 16 December at 21:15 local time produced large damage in the regions of Basilicata y Campania. Caused 19000 casualties and destroyed 6300 houses. Greatest damage at Montemurro and Saponara where half of the population died.
ROBERT MALLETT (1810-1881)

An Irish engineer in 1846 he published, "On the Dynamics of Earthquakes", which is considered to be one of the foundations of modern seismology applying mechanics to earthquakes. He is credited with coining the words: seismology, isoseismal map and epicenter.

He was the first to measure seismic velocities from explosions.
From February to April 1858, Mallet traveled to Italy to study the Naples earthquake.

In his report he joined the naturalistic description of phenomena with a rigorous physical–mathematical analysis, integrating geology, physics and mathematics in the study of an earthquake.

His report included 156 photographs.
Mallet determined the location of the focus from cracks directions. “The first approximation to the depth of the focus ever attempted for any earthquake”.
THE ANDALUCIAN EARTHQUAKE
25 DECEMBER 1884
DAMAGE AND CASUALTIES

The villages of Arenas del Rey, Alhama de Granada y Ventas de Zafarraya were completely destroyed.

Total dead were 745 and 1485 wounded

The topography added to the damage with many landslides and ground fractures. Most buildings were of very poor quality.
FIRST INTERNATIONAL SCIENTIFIC STUDY OF AN EARTHQUAKE

Three commissions were established for the study of the earthquake by Spain, France and Italy.

**Spanish**: Headed by *Manuel Fernandez de Castro*, mining engineer in charge of the geological map. It distributed 500 questionnaires. Published a report of 106 pp on 30 March 1885.

**French**: Headed by *Ferdinand Fouqué* (Académie de Sciences) with three other members and four assistants. Its report centered on geologic studies was published in 1890. It was translated into Spanish with commentaries in 1893.

**Italian**: Formed by *Giuseppe Mercalli* and *Torquato Taramelli* (Academia dei Lince). Its report includes a catalogue of earthquakes in southern Spain and one of the first isoseismal maps. They determined the depth of the focus at 12 km.
INTENSITY MAP BY MERCALLI WITH DIRECTIONS OF SHAKING AND EPICENTRAL DETERMINATION
(grades: disastroso, rovinoso, fortissimo)
Ferdinand Fouquet and French geologists took advantage of this earthquake to propagate the new ideas that earthquakes are caused by fracture in faults and tectonic processes, proposed by Charles Lyell, Eduard Suess and others.

In Spain these ideas were presented by José Macpherson after the earthquake.
The earthquake caused catastrophic damage in San Francisco with more than 3000 casualties. About 300,000 of the 400,000 inhabitants lost their houses. The earthquake was followed by a fire which contributed to the destruction of the city. Damage was distributed along the coast.
The shock broke the San Andreas fault and it could be followed along the surface for 430 km. The horizontal displacements across the two sides of the fault were up to 6 meters with the Pacific side moving northwest with respect to the east side.
After the earthquake in 1910, Francis Reid proposed the elastic rebound theory. Earthquakes take place by fracture of a fault with the release of the elastic strain accumulated in it by tectonic processes. The earthquake process is formed by slow strain accumulation and sudden release by breaking.
CHILE EARTHQUAKE OF 22 MAY 1960
Mw = 9.5
The oceanic crust underthrusted along 800 km with displacements of up to 25 m. Heavy damage from Concepcion to Valdivia. Up to 3000 dead. In Valdivia 40% of houses destroyed. Produced a large tsunami.
Although the free oscillations of the earth were first observed in the large earthquakes of Kamchatka 1954 and Mongolia 1957, the best observations came from the Chile 1960 earthquake.

Results were published in 1961 by Leonard Alsop, Maurice Ewing, Hugo Benioff and Frank Press.

They observed both spheroidal and toroidal modes.
The frequency analysis of the displacements produced by the earthquake shows the presence of the different modes. The longest period corresponds to the spheroidal mode $0S_2$, with 53.9 minutes. The longest toroidal mode is $0T_2$ with 44 minutes. The rotation of the Earth produces splitting of the eigenfrequencies which were also observed.
On 11 March a large earthquake of Mw 9 stroke off-shore Japan and produced a large tsunami.

The magnitude of shaking and size of the tsunami were beyond any expectations.

It has caused the revision of seismic risk assessment ideas. Inadequacy of present probabilistic methods.
Shaking: ground acceleration 3g at 75 km. Tsunami: waves up to 30 m. Casualties 1600 dead, 3000 missing. Damage 10000 millions dollar.
FUKUSHIMA NUCLEAR PLANT

Four of the six reactors were damaged, three with full meltdown. Largest nuclear disaster since Chernobyl. Nuclear plants security is questioned.

Growing concern about the future of nuclear energy.
SUMMARY

New developments in the science of seismology are sometimes produced after the occurrence of large earthquakes.

Lisbon, 1755: earthquakes as natural events, elastic waves.
Andalucia, 1884: intensity maps, displacements in faults.
San Francisco, 1906: elastic rebound theory.
Chile, 1960: free oscillations of the earth.