НАЦИОНАЛНА КОНФЕРЕНЦИЯ ПО ГЕОФИЗИКА
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The great subduction earthquakes – Chile (Mw8.8, 2010) and Sumatra (Mw9.1, 2004) sources of the continental plate movements

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Силните субдукционни земетресения – Чили(Mw8.8, 2010) и Суматра (Mw9.1, 2004), източници на премествания на континентални плочи
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Направен е сравнителен анализ между двете най-силни земетресения регистрирани напоследък на Земята и разположени в близост до субдукционни зони. В светлината на съвременната геодинамика, положението на епицентрите и хипоцентрите им, процесите на разкъсване на земната кора и други данни е потърсено обяснение на относително бързите движения на континенталните плочи или части от тях. Първото грандиозно земетресение (Mw9.1, 2004) генерира огромни вълни цунами, явявайки се по този начин едно от най-катастрофалните събития сполетели човечеството през цялата му история. Второто гигантско земетресения (Mw8.8, 2010) разположено в близост до Чилийското крайбрежие, генерира относително малки вълни цунами (явление абсолютно необичайно за подобни по сила земетресения), но предизвика тежки разрушения и повече от 1000 жертви в крайбрежните селища. Огромни площи и обеми от континенталната разрушена земна кора са очертани от поредица силни следтрусове, които помагат за определянето на размерите им. Съвременни сателитни GPS измервания, показват размерите на преместванията, регистрирани в околностите на тези силни земетресения.

Introduction

The seismogenic potential of the subduction zones is the largest one according the planet's geodynamics. Almost all great earthquakes (especially with the moment magnitude larger then 8.5) are closely related to the subduction zones. The plate movements in these zones are most active, constant temporal displacements reaching 6-7 cm/y and thus they are responsible about the stress accumulation and the following giant earthquakes.

The seismicity of the subduction zones is studied in the relation of the two very strong earthquakes – the Sumatra one (on 26th December 2004, My~9.1) and the Chile one (February 27th 2010, Mw~8.8) and their tsunamigenic potential. The first dangerous event (a couple of earthquake and tsunami) had heavy consequences and more than 200 000 fatalities. The second one – with relatively small tsunamis with no victims, produced about 1 000 deaths as a consequence mainly due to the earthquake effects to the buildings of the Chile coastal area.

Both events were related with the stress release and movements of the plates in the subduction zones – Nazca plate subducting South American continental plate (for the Chilean quake) and Sunda trench collision zone (for the Sumatra seismic event). Due to this collision the stress field in the whole contact zone between the two plates increased and generated huge seismic events which can produce the large displacement, especially measured on the upper plate. This process is accompanied by the temperature increase, volcanic activity in deeper parts, crust and astenosphere deformations, orogenic effects and deep trench creation – fig.1. The rebound effect expressed frequently like megathrust seismic events, almost always generate tsunami waves.

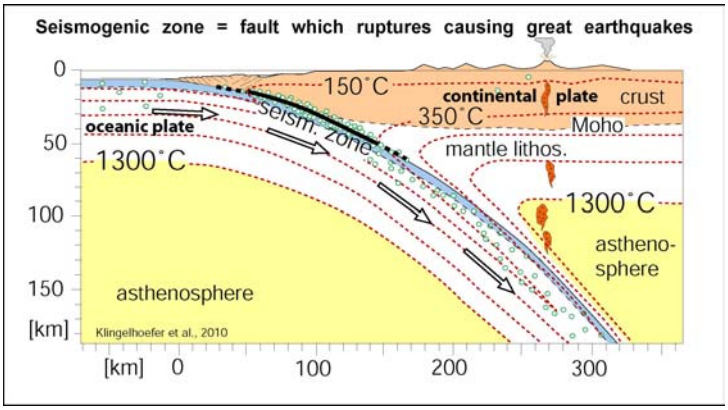


Fig.1. Schematic view of a subduction zone

Tectonic setting

The region where the great earthquake occurred on 26 December 2004, marks the seismic boundary formed by the movement of the Indo-Australian plate as it collides with the Burma subplate, which is part of the Eurasian plate. However, the Indo-Australian tectonic plate may not be as coherent as previously believed. According to recent studies it appears that the two plates have separated many million years ago and that the Australian plate is rotating in a counterclockwise direction, putting stress in the southern segment of the India plate. For millions of years the India tectonic plate has drifted and moved in a north/northeast direction, colliding with the Eurasian tectonic plate and forming the Himalayan Mountains. As a result of such migration and collision with both the Eurasian and the Australian tectonic plates, the Indian plate's eastern boundary is a diffuse zone of active seismicity and deformation, characterized by extensive faulting and numerous large earthquakes.
The epicenter of the 26 December 2004 earthquake was near the triple point junction of three tectonic plates where major earthquakes and tsunamis have occurred in the past. Previous major earthquakes have occurred further north, in the Andaman Sea and further South along the Sumatra, Java and Sunda sections of one of the earth's greatest fault zones, a subduction zone known as the Sunda Trench. The great Sunda trench extends for about 3,400 miles (5,500 km) from Myanmar (Burma) south past Sumatra and Java and east toward Australia and the Lesser Sunda Islands, ending up near Timor. Slippage and plate subduction make this region highly seismic. The Burma plate encompasses the northwest portion of the island of Sumatra as well as the Andaman and the Nicobar Islands, which separate the Andaman Sea from the Indian Ocean. Further to the east, a divergent boundary separates the Burma plate from the Sunda plate.
More specifically, in the region off the west coast of northern Sumatra, the India plate is moving in a northeastward direction at about 5 to 5.5 cm per year relative to the Burma plate. These data have been inferred by the GPS measurements and observations. (http://walrus.wr.usgs.gov/news/reports.html)

The Chile 27 January 2010 great seismic event is located over the edge of the subduction zone of Nazca plate subducted under the South America continental plate at the approximately mid location of the Chile Ands. The subduction in the area started several million years ago and the low destruction of the oceanic crust succeed to subduct in more then 3-400 km inland reaching one of the known most deep parts of the mantle. The deepest earthquakes of this plate are expressed down to 600-700 km. thus producing great events like Bolivian one of 9th June, 1994 year (Mw~8.0) felt from Antarctica to New York. The GPS measured horizontal velocities of the South American plate move to the west are measured of about 6-7 cm. (It is better to say that the subducted Nazca plate has such velocity of east movement). The Peru-Chile trench is the frontal boundary of the subduction and it is confirmed by the hypocenters location of the earthquakes in the area. (http://earthquake.usgs.gov)

Data about the earthquakes

The 26th Boxing Day 2004 earthquake occurred with a starting point of the hypocenter located at 3,316°N; 95,854°E. The reported mechanism by the Harvard tensor moment solution was thrust type. Then the ruptured process has extended to the North for about 10 minutes and according different models the area of the surface dislocations covered more than 337 500 sq. kilometers. The depth reached 33 km. The initial aftershock‘s behavior confirmed this direction of dislocation. Almost two-three months after the main event, all aftershocks covered the north part of affected area – fig.2. The thrust type mechanism, the great magnitude, large area of surface deformations, the activation of the underwater deposits slides and the displaced water volume are the main factors leaded to the giant tsunami spread across the Indian Ocean and brought so much victims and destructions.
The earthquake of February 27, 2010 (M~8.8, depth down to 30 km.), was probably triggered by the dynamic stress load caused by collision of South America and Nazca plates. The January 27th earthquake occurred - as a result of thrust faulting - on the boundary of the Nazca and South America plates (fig.2.). It was caused by the release of stresses when the Nasca plate subducted beneath the overriding South America plate. This interaction results in convergence at the Chile Trench and involves local movement, with a total area of displacement of about 0.5 km^2. The shock was located to the North of the ruptured area of the strongest recently recorded seismic event of 1964 with the largest magnitude of Mw~9.5 – fig. 3. (http://earthquake.usgs.gov)

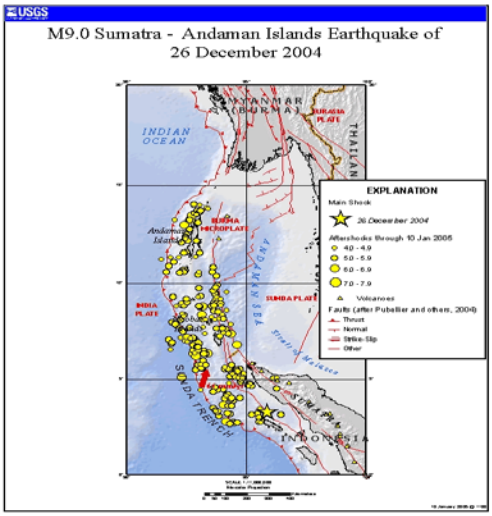


Fig.2. The location of the epicenters due to the 26th Dec.2004 seismic event. Ruptured zone is outlined by the yellow circles of aftershocks according their tectonic positions

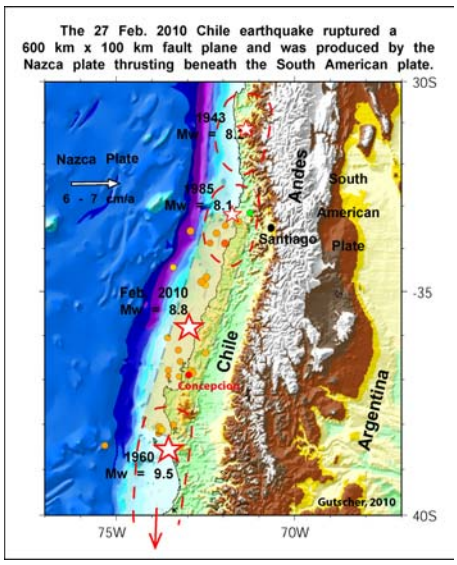


Fig.3. The strongest subduction earthquakes near Chile coast

A comparative analysis

Triple junction points of tectonic plates, particularly in areas of active subduction, are some of the most seismic areas of the world - capable of causing great earthquakes and tsunamis. The 1960 Great Chilean Earthquake and Tsunami originated near such a triple point tectonic junction as 2010 Chilean earthquake.

The same is valid about 26th Boxing Day 2004 great Sumatra earthquake and 27th February Chilean event. Usually, when a great earthquake occurs, most of the stress is relieved and another great earthquake may not occur for many years in the same region. However, this is not always the case, as dynamic stress loading can accelerate the occurrence of another major earthquake along an adjacent seismic zone. Sometimes the opposite occurs and the release of energy on one segment, may also release stress on an adjacent seismic fault. In this case it looks like that the stress release process was accelerated rather than delayed.

The summary of all investigated parameters have been presented at Table 1. Both seismic events have very similar characteristics (magnitude, depth, mechanism type). The differences are connected mainly to the ruptured areas (length, width, vertical displacements), average water depth, the supposed underwater slides and the tsunami parameters – maximum observed run ups and the displaced water volumes. It is visible that the maximum run ups Hmax are of one order difference and the displaced water volumes have the same differences. So, the reasonable explanation is connected with the presented model and due probably to the displaced water volumes. These numbers depends mainly on the average water depth in the areas of bottom displacements and their sizes. The energies released are 1/3 to ¼ and depend on the magnitudes. The energy released for both shocks are 3.35×10^{18} [J] for the first shock and 1.21×10^{18} [J] for the second one.

Table 1. Main characteristics of both earthquakes occurred on 26th December 2004 and 27th February 2010

Date	Mw	H [km]	Earthquake mechanism	Location	Rupture length [km]	Rupture width [km]
26.XII.2004	9,1	30	Thrust type	3,316°N; 95,854°E	1200-1300	270
27.II.2010	8,8	30	Thrust type	35.89 S ; 73.04 W	600-650	100

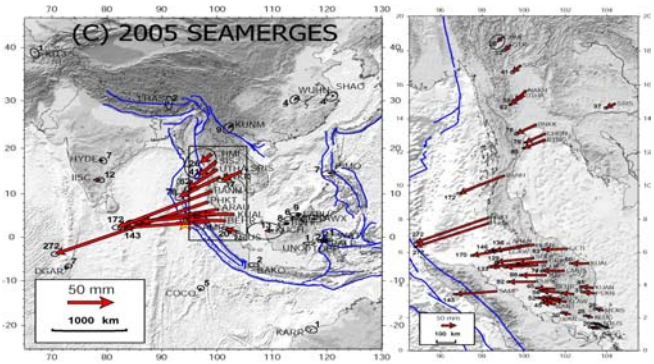


Fig.4. GPS displacements due to the great Sumatra seismic event.

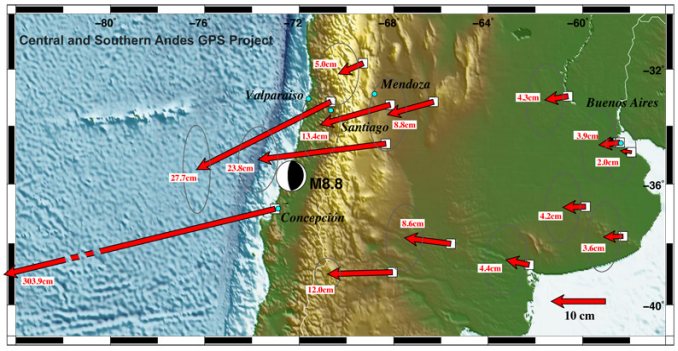


Fig.5. Coseismic displacements Mw8.8 earthquake, Chile, Feb 27, 2010.

Due to the release of both seismic events the coseismic displacements are observed (fig.4. and Fig.5.) and measured by satellite GPS network. The displacements show clear nonlinear behavior, which is their important characteristic.

Conclusions

The subduction zones have high seismic potential due to the stress accumulation and sudden stress release. The relatively fast movement of the plates, the intrusion of the down plate under the upper one and the stress accumulation and release, are those most important factors due to which the strongest seismic events can occur there. Both investigated strong seismic events confirmed this assessment.

It is visible and really clear that the recent geodesy and GPS measurements are the only performed observations, which can provide reliable and fast information about the sudden plate movements.

The results obtained discover that during the recent years the satellite GPS measurements can help to detect the whole (or the part) continental plate displacements due to the very large earthquakes located in subduction zones. After the discovery of the free oscillations of the Earth, the observations of the effects of big parts of the plates' displacements are the second very great discovery to confirm the plate movements due to the sudden disturbances. The decrease of the measured GPS horizontal displacements (for example clearly visible to the Chile earthquake), shows that it is rather difficult to explain and/or practically not to expect and consider plates (even in a big scale) like pure elastic bodies which have nonlinear behavior. The observed attenuation of the displacements observed on far field zones in South America shows that the movements far from the epicentral area are smaller thus proving the nonelastic behavior of the continents – fact not very frequently considered during the large scale models of the Earth crust and geodynamics.

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