

The 30 September 2009 “Padang” Earthquake

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6 October 2009

Earthquake Summary from USGS

The 2009 Padang earthquake occurred just off the western coast of Sumatra, Indonesia. The major shock hit at 17:16:10 local time on September 30, 2009 (10:16:10 UTC, September 30). It registered a moment magnitude (M_w) of 7.6, making it similar in size to the 1906 San Francisco earthquake, the 1935 Quetta earthquake, the 2001 Gujarat earthquake, and the 2005 Kashmir earthquake. The epicenter was 45 km west-northwest of Padang, Sumatra, 220 km southwest of Pekanbaru, Sumatra, and at a depth of 80 km. At least 1100 people were killed as a result, with “thousands” more trapped in collapsed buildings and some villages were buried by landslides.

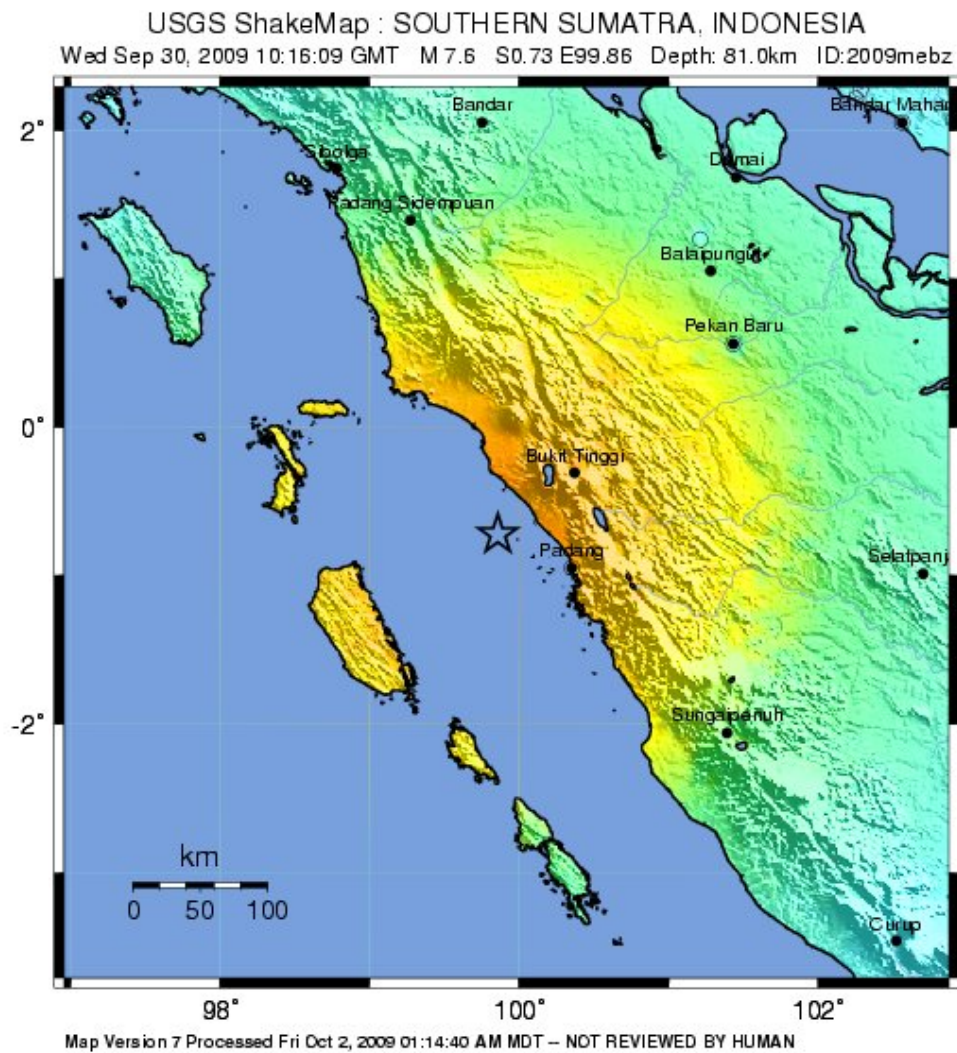
A second earthquake, which measured 6.6 M_w , struck the province of Jambi in central Sumatra, 08:52:29 local time on 1 October 2009 at a depth of 15 km, about 46 km south-east of Sungaipenuh. This earthquake appears to on or close to the trace of the Great Sumatran Fault, which is also a regular source of earthquakes. (Figure 2)

The Padang earthquake of September 30, 2009 occurred as a result of oblique-thrust faulting near the subduction interface plate boundary between the Australian and Sunda plates. At the location of this earthquake, the Australian Plate moves north-northeast with respect to the Sunda plate at a velocity of approximately 60 mm/yr.

On the basis of the currently available fault mechanism information and earthquake depth of 80 km, it is likely that this earthquake occurred within the subducting Australian Plate rather than on the plate interface itself. The recent earthquake was deeper than typical subduction thrust earthquakes that generally occur at depths less than 50 km.

The subduction zone surrounding the immediate region of this event has not witnessed a megathrust earthquake in the recent past, rupturing last in an earthquake of M 8.5 or larger in 1797. Approximately 350 km to the south, a 250 km section of the plate boundary slipped during an Mw 8.4 earthquake in September 2007, while approximately 300 km to the north, a 350 km section slipped during the Mw 8.7 earthquake of March 2005. In early 2008, the plate boundary up-dip of today’s earthquake was active in a sequence of Mw 5-6 earthquakes. It is not clear how today’s earthquake is related to the sequence of mega thrust subduction zone events on the shallower section of the plate boundary (Figure 2).

The Sumatra subduction zone has historically produced great thrust-fault earthquakes (mega thrusts). The component of relative plate motion that is parallel to the plate-boundary is substantially accommodated by strike-slip faulting on the Great Sumatra Fault (GSF), which is about 300 km inland of the Sunda trench. The part of the Sunda plate that lies to the west of the GSF and east of the principal plate boundary at the Sunda trench is sometimes called the “forearc sliver” of the Sunda plate, being distinguished from the rest of the Sunda plate because of its relative motion with respect to the plate's interior.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-18	18-31	31-60	60-118	>118
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 1. The USGS Shake Map shows the earthquake epicentre and gives a MM Intensity of 7 to 8 in Padang

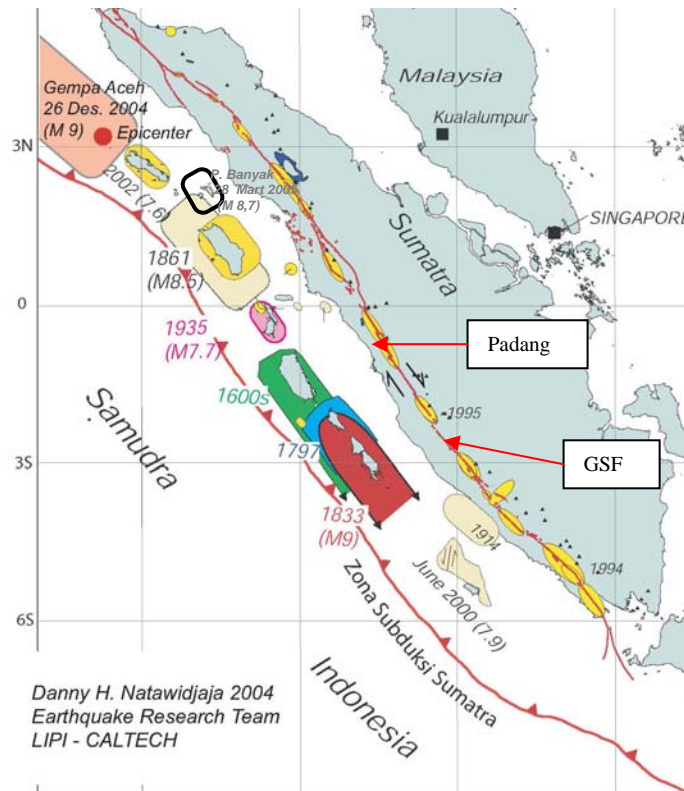


Figure 1. Map of tectonics and major earthquake sources of the Sumatran Plate Margin. The yellow ellips along the Sumatran Fault Zone are ruptures of the past earthquakes. The numbers indicate years of occurrences. Colored rectangles offshore the Sumatran west coast indicate major seismic sources beneath the ocean, on the subduction interface.

Figure 2. Source areas of earthquakes of the Sumatra region. The yellow zones along the Sumatran Fault are also historic earthquakes.

Both the subduction zone and the GSF earthquake activity and fault movement are a result of the northward movement of the Australian Plate at a rate of ~60mm per year relative to the Sunda Plate along the Sumatra Subduction zone plate boundary. As can be seen from the figures, there are regular great earthquakes of M8 to M9 on the subduction zone – on the Aceh segment in the north, the Nias segment in the centre and then the Padang segment to the south. For Nias and Padang segments, these great earthquakes seem to occur every 100 to 200 years, over which period, at a rate of 60mm per year, a total strain of some 6 to 12m will accumulate if the subduction interface is locked. A Magnitude 9 earthquake on the Padang segment of the subduction zone would be expected to cause MM8 to 9 intensity shaking in Padang and a significant tsunami. MM8 to 9 intensity shaking is significantly stronger and is likely to be more damaging in Padang than the present earthquake which caused ~MM7 to 8 intensity shaking in Padang, the main city of West Sumatra. Padang appears to be prepared for a tsunami and has tsunami evacuation boards in the city (see photo below).

Semilieu, Nias and the Mentawai islands are all “fore-arc” islands close to the deep sea trench where the (Indian –)Australian tectonic plate is subducting beneath the Sunda (Eurasia) plate. These islands are amongst the most seismically active places in the world in terms of the great earthquakes they have experienced, and all should all be in the most active seismic zone (zone 6) in Indonesia. It is clear that the GSF too has regular smaller earthquakes, typically in the range M6 to M7, and a strip area along this fault should also be included in Zone 6, the most active Indonesian seismic zone. The clear topographic surface lineament along the GSF is the geomorphic expression of

regular past fault activity all along the GSF. It has a striking geomorphic expression similar to the Alpine Fault in New Zealand.

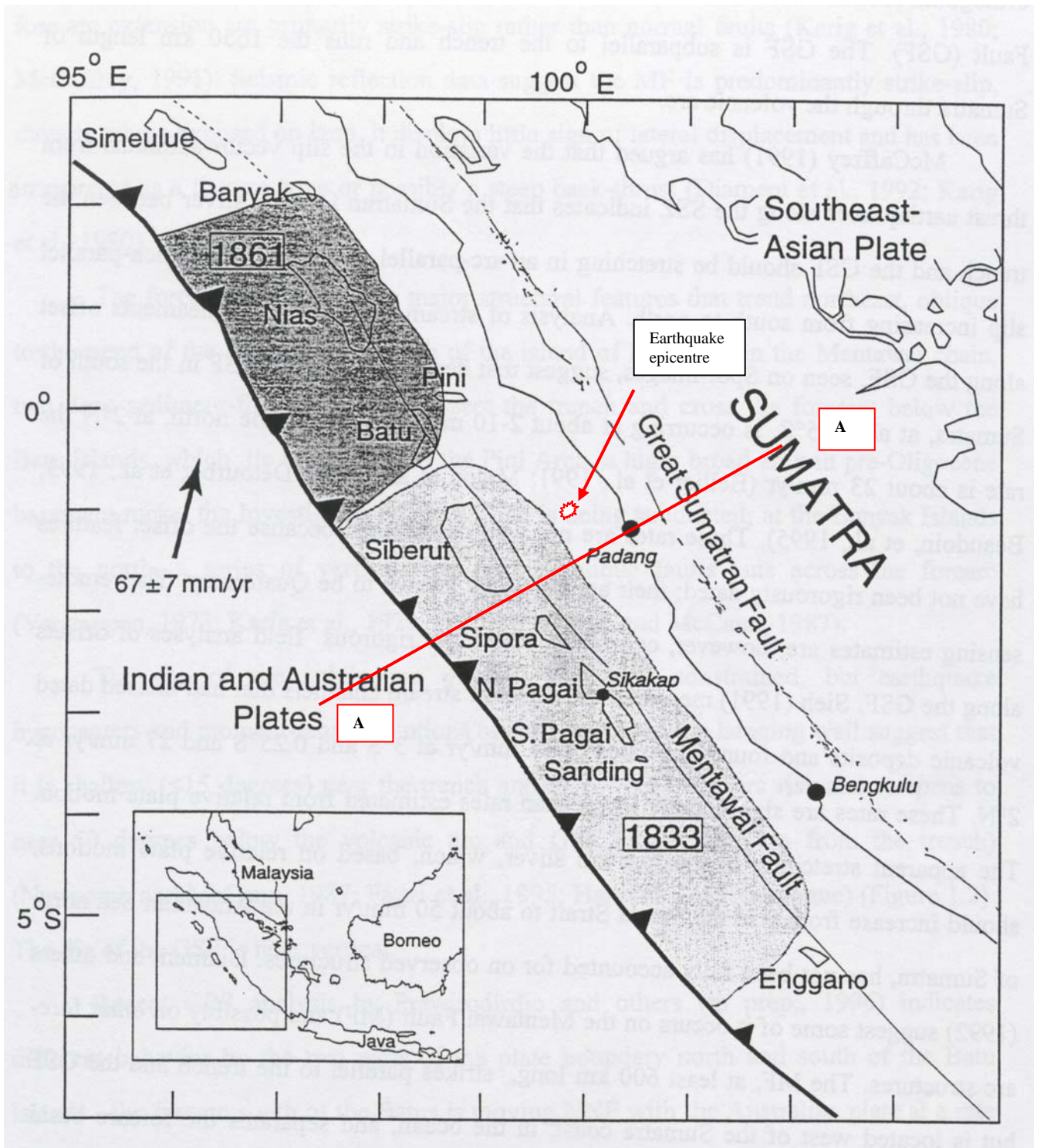


Figure 3. The previous Great earthquakes on the subduction zone were in 1866 under Nias on the Nias Segment and in 1833 under the Mentawai Islands on the Padang Segment. The Nias Segment has already ruptured again in the Great Nias Earthquake of 28 March 2005, and there is a high probability of a great earthquake on the Padang Segment in the coming (10's of) years as it is already ~180 years since the previous event and accumulated strain is about 11 m (from PhD thesis by Judy Zachariassen).

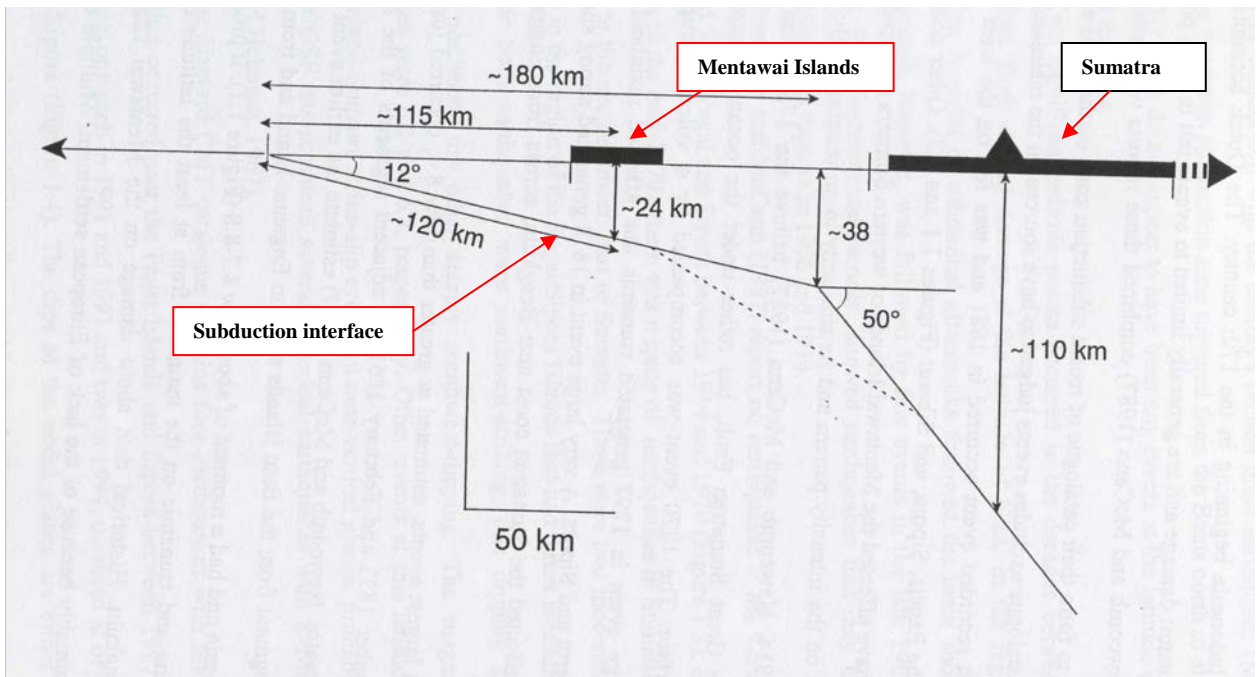


Figure 4. Section A – A. The Great Subduction Zone earthquakes occur on the subduction interface this is 20 to 24 km below Mentawai Islands. In the ~180 years between the 1833 and 2009, approximately 11m of strain has accumulated (60mm/yr over 180 yrs = ~11m) if the subduction interface is locked. This strain would be released by sudden rupture movement along the subduction interface, as was the case during the Great Nias Earthquake of 28 March 2005.

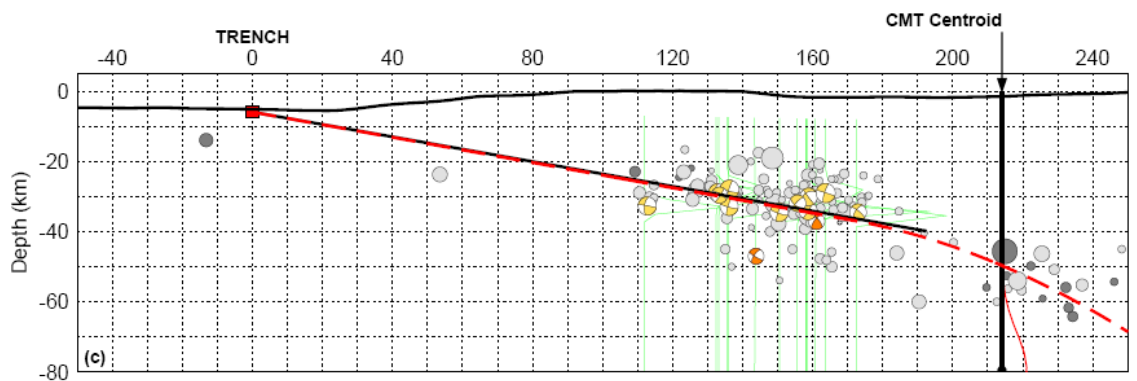


Figure 5. A cross-section by the USGS through the subduction zone at Padang, showing the subduction interface (dotted red line) and the focus, at 80km depth below the centroid of the Padang Earthquake. Compare this Figure with Figure 4.



Photo. A tsunami evacuation bill-board in Padang , near the provincial parliament (DPRD) buildings. Padang has experienced tsunami from local great subduction zone earthquakes in the past. The last great earthquake on the subduction zone was in 1833 and there is a high probability of another one in the coming 10's to 20's of years as these earthquake occur about every 200 years. Previous earthquakes were in 1833, 1797 and in the 1600's (Figure 5 below).

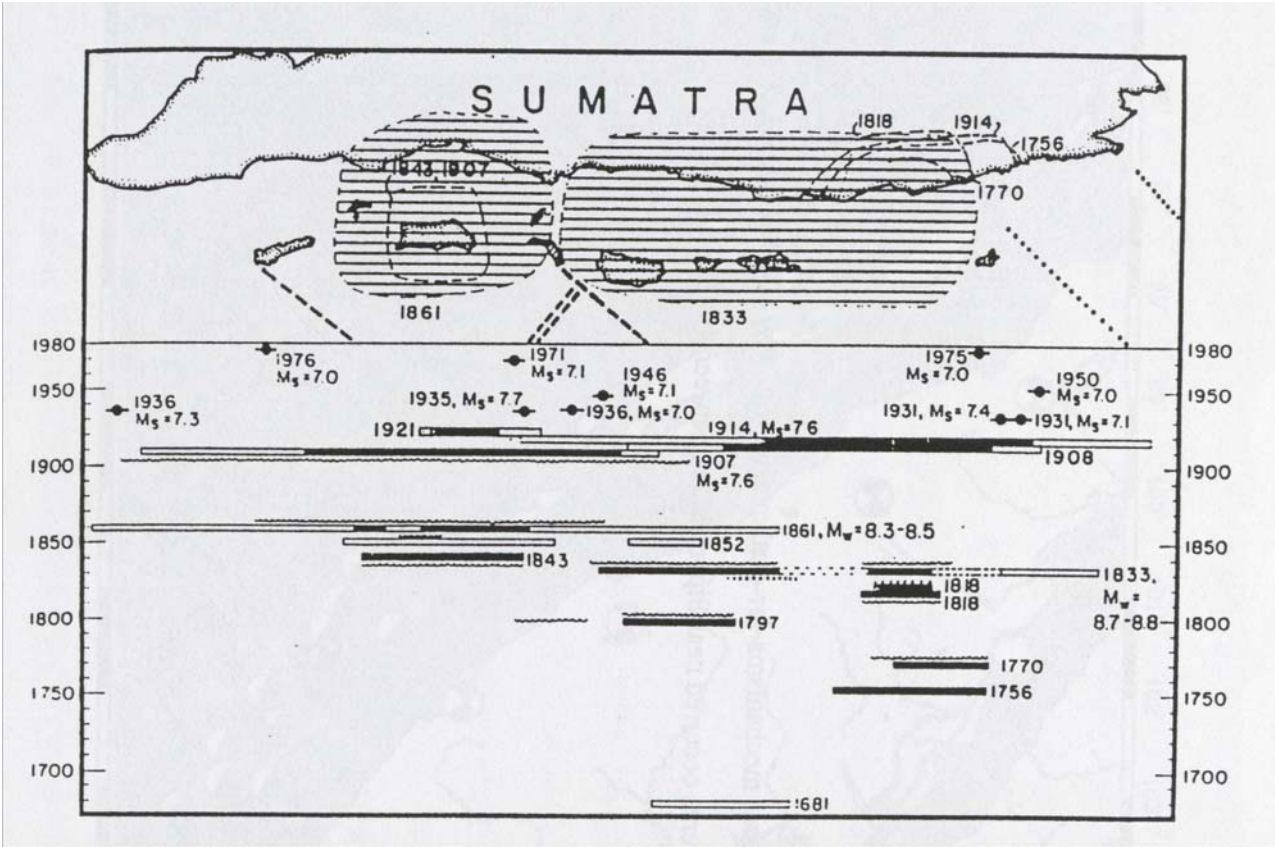


Figure 6. The known historic earthquakes in the Nias and Padang areas as shown by Judy Zacharisen. The dates, magnitudes and earthquakes which caused tsunami are shown on the diagram. The tsunami are the wavy lines. The 28 March 2005 Great Nias

Earthquake was caused by rupture of the subduction zone beneath Nias, essentially the same as the 1861 earthquake, as shown above.

A history of earthquakes and tsunami

In 1797 Padang was inundated by a tsunami with an estimated flow depth of 5–10 meters, following an earthquake, estimated to be 8.5–8.7 M_w , which occurred off the coast. The shaking caused considerable damage and the deaths of two people, while the tsunami resulted in several houses being washed away and several deaths at the village of Air Manis. The boats moored in the Arau river ended up on dry land, including a 200 ton sailing ship which was deposited about 1 kilometer upstream. In 1833 another tsunami inundated Padang with an estimated flow depth of 3–4 meters as a result of an earthquake, estimated to be 8.6–8.9 M_w , which occurred off Bengkulu. The shaking caused considerable damage in Padang, and due to the tsunami, the boats moored in the Arau river broke their anchors and were scattered.

At the time of independence in the 1940s the city had around 50,000 inhabitants. Today the population is close to 1 million and the city has spread along the coastal strip of low-lying land. This land is a geologically recent accumulation of mainly fine grained sediments.

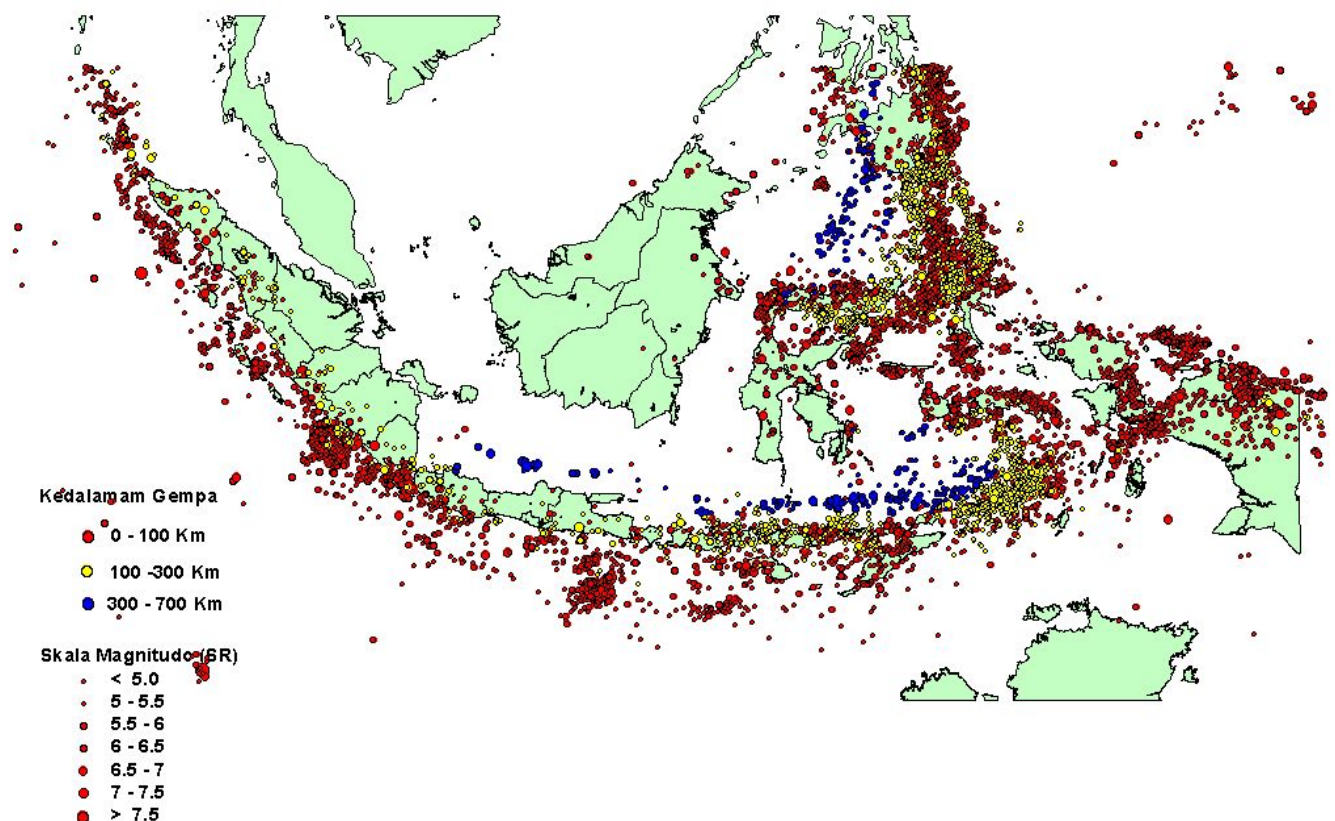


Figure 7. A sample of Indonesian seismicity – with colours showing depth. Red dots are shallower earthquakes (0 to 100 km deep) and blue are the deepest (300 to 700 km deep), outlining the subducting Australian Plate as it descends beneath the Sunda Plate – which in this location is the Indonesian and Malaysian land masses seen above.

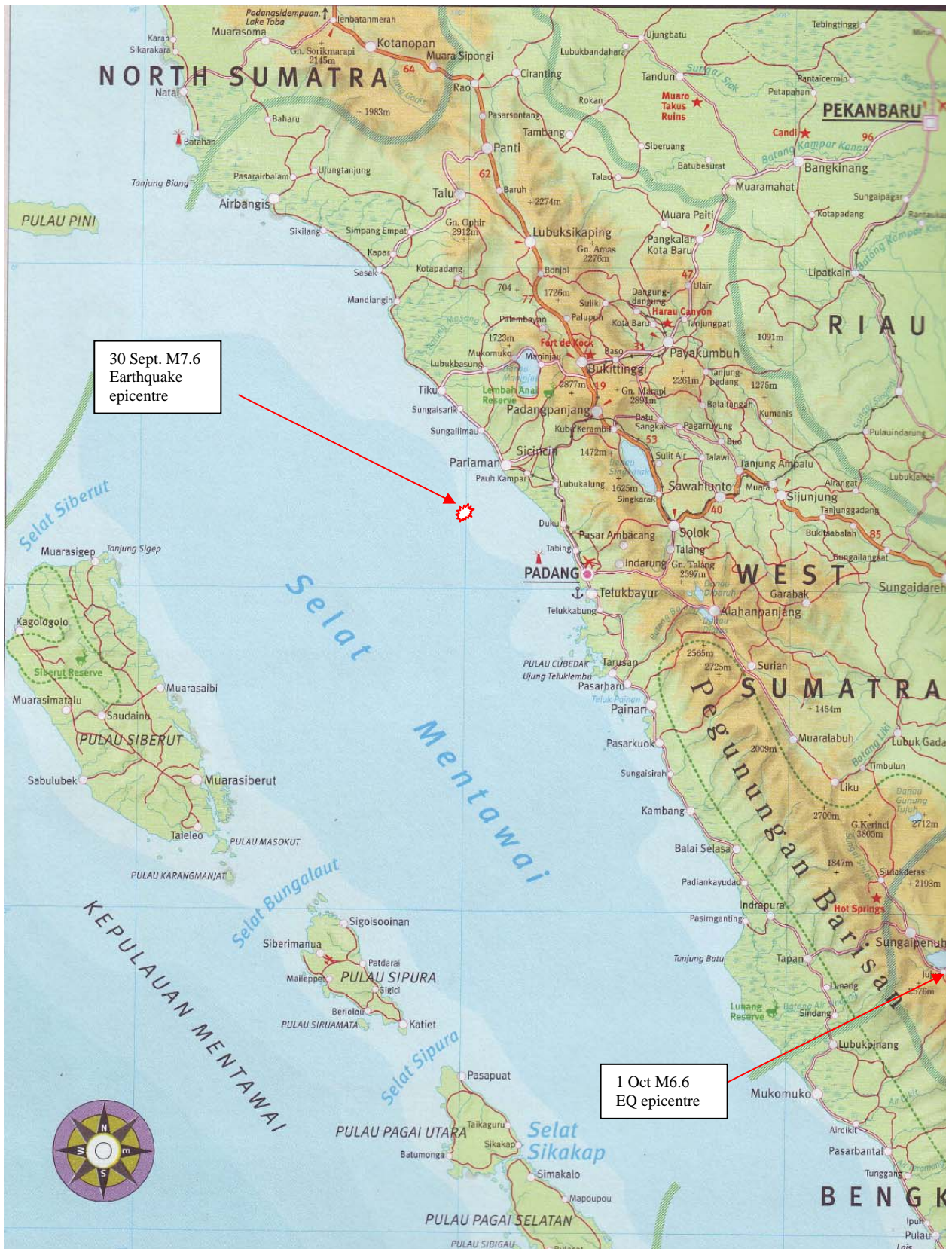


Figure 8. Relief map of the earthquake area. The lineament of the Great Sumatran Fault can be followed from Sungaipenuh in the south, through Liku, Muaralabuh, Surian, Solok, Lake Singkarak, Padangpanjang, Bukittinggi, Lubuksikaping, Panti.

Preliminary Earthquake Damage Assessment

Padang is located on a coastal strip of geologically sediments which have been deposited by rivers with their source in the volcanic mountains to the east (Figure 8). These rivers meander across the low-lying coastal strip, depositing fine-grained sediments and in places forming swampy ground, over which the city of Padang has now spread. The accumulated deep soils of the swampy coastal strip are likely to be classed as D (deep or soft soil sites) and E (very soft soil sites) in terms of NZS 1170.5 2004. News reports from Padang after the earthquake suggest that there may have been both liquefaction and ground amplification of the seismic waves - which were particularly damaging to taller buildings, with a longer natural period? Eye witnesses are describing visible ground waves from the earthquake.

Padang is the main city of West Sumatra Province and has a population of almost a million people. It has a big port in a natural bay surrounded by hills 6km to the south of the city. It also has a modern airport on the coastal strip to the north of the city. The airport is in use post earthquake. The provincial roading is relatively good (of similar standard to NZ) and is well maintained. The USGS give an earthquake intensity of MM7 to 8 in Padang (Figure 1), an intensity where in NZ we would expect damage to buildings to be relatively minor. It would be interesting to compare the earthquake damage in Padang with Bukittinggi, the next biggest town in West Sumatra, some distance inland, where the USGS also give an MM7 to 8 intensity. Bukittinggi is located on hilly volcanic deposits – stiff ground.

Many damaging and destructive landslides induced by the earthquake have been reported (it is the wet season). This confirms at least an MM7 intensity (maybe bigger?). There was a common appearance of wide cracks in the ground and reports of surface water in Padang after the EQ, (so much that people apparently thought a small tsunami may have come ashore). However, there was no tsunami and the appearance of surface water was attributed to broken water supply pipes. However, it is most likely, because Padang is on a low-lying coastal strip of weak soils where there is a high ground water table, that liquefaction of the weak ground has occurred, expelling water and sand to the surface and forming cracks through lateral spreading. Liquefaction such as this with expulsion of water from the ground on is commonly observed after earthquakes where the intensity of shaking has reached MM7 or more. The liquefaction and ground movements may have caused breakages of water pipes.

Many of the buildings in Padang (and other parts of Indonesia) would be rated in Building Classes 1, 2 and 3 described in the NZ MM Intensity scale below.

APPENDIX A — MODIFIED MERCALLI (MM) SCALE OF EARTHQUAKE INTENSITY

(developed for New Zealand conditions by Dowrick, 1996)

MM1

People: Not felt except by a very few people under exceptionally favourable circumstances.

MM2

People: Felt by persons at rest, on upper floors or favourably placed.

MM3

People: Felt indoors; hanging objects may swing, vibrations may be similar to passing of light trucks, duration may be estimated, may not be recognised as an earthquake.

MM4

People: Generally noticed indoors but not outside. Light sleepers may be awakened. Vibration may likened to the passing of heavy traffic, or to the jolt of a heavy object falling or striking the building.

Fittings: Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock.

Structures: Walls and frame of building are heard to creak, and partitions and suspended ceilings in commercial buildings may be heard to creak.

MM5

People: Generally felt outside, and by almost everyone indoors. Most sleepers awakened. A few people alarmed.

Fittings: Small unstable objects are displaced or upset. Some glassware and crockery may be broken. Hanging pictures knock against the wall. Open doors may swing. Cupboard doors secured by magnetic catches may open. Pendulum clocks stop, start, or change rate.

Structures: Some windows Type I cracked. A few earthenware toilet fixtures cracked.

MM6

People: Felt by all. People and animals alarmed. Many run outside. Difficulty experienced in walking steadily.

Fittings: Objects fall from shelves. Pictures fall from walls. Some furniture moved on smooth floors, some unsecured free-standing fireplaces moved. Glassware and crockery broken. Very unstable furniture overturned. Small church and school bells ring. Appliances move on bench or table tops. Filing cabinets or "easy glide" drawers may open (or shut).

Structures: Slight damage to Buildings Type I. Some stucco or cement plaster falls. Windows Type I broken. Damage to a few weak domestic chimneys, some may fall.

Environment: Trees and bushes shake, or are heard to rustle. Loose material may be dislodged from sloping ground, e.g. existing slides, talus slopes, shingle slides.

MM7

People: General alarm. Difficulty experienced in standing. Noticed by drivers of motorcars who may stop.

Fittings: Large bells ring. Furniture moves on smooth floors, may move on carpeted floors. Substantial damage to fragile contents of buildings.

Structures: Unreinforced stone and brick walls cracked. Buildings Type I cracked with some minor masonry falls. A few instances of damage to Buildings Type II. Unbraced parapets, unbraced brick gables, and architectural ornaments fall. Roofing tiles, especially ridge tiles, may be dislodged. Many unreinforced chimneys damaged, often falling from roof-line. Water tanks Type I burst. A few instances of damage to brick veneers and plaster or cement-based linings. Unrestrained water cylinders (Water Tanks Type II) may move and leak. Some windows Type II cracked. Suspended ceilings damaged.

Environment: Water made turbid by stirred up mud. Small slides such as falls of sand and gravel banks, and small rock-falls from steep slopes and cuttings. Instances of settlement of unconsolidated or wet, or weak soils. Some fine cracks appear in sloping ground. A few instances of liquefaction (i.e. small water and sand ejections).

MM8

People: Alarm may approach panic. Steering of motor cars greatly affected.

Structures: Buildings Type I, heavily damaged, some collapse. Buildings Type II damaged, some with partial collapse. Buildings Type III damaged in some cases. A few instances of damage to Structures Type IV. Monuments and pre-1976 elevated tanks and factory stacks twisted or brought down. Some pre-1965 infill masonry panels damaged. A few post-1980 brick veneers damaged. Decayed timber piles of houses damaged. Houses not secured to foundation may move. Most unreinforced domestic chimneys damaged, some below roof-line, many brought down.

Environment: Cracks appear on steep slopes and in wet ground. Small to moderate slides in roadside cuttings and unsupported excavations. Small water and sand ejections and localised lateral spreading adjacent to streams, canals, lakes, etc.

MM9

Structures: Many buildings Type I destroyed. Buildings Type II heavily damaged, some collapse. Buildings Type III damaged, some with partial collapse. Structures Type IV damaged in some cases, some with flexible frames seriously damaged. Damage or permanent distortion to some Structures Type V. Houses not secured to foundations shifted off. Brick veneers fall and expose frames.

Environment: Cracking of the ground conspicuous. Landsliding general on steep slopes. Liquefaction effects intensified and more widespread, with large lateral spreading and flow sliding adjacent to streams, canals, lakes, etc.

MM10

Structures: Most Buildings Type I destroyed. Many Buildings Type II destroyed. Buildings Type III heavily damaged, some collapse. Structures Type IV damaged, some with partial collapse. Structures Type V moderately damaged, but few partial collapses. A few instances of damage to Structures Type VI. Some well-built timber buildings moderately damaged (excluding damage from falling chimneys). Dams, dykes, and embankments seriously damaged. Railway lines slightly bent. Cement and asphalt roads and pavements badly cracked or thrown into waves.

Environment: Landsliding very widespread in susceptible terrain, with very large rock masses displaced on steep slopes. Landslide dams may be formed. Liquefaction effects widespread and severe.

MM11

Structures: Most Buildings Type II destroyed. Many Buildings Type III destroyed. Structures Type IV heavily damaged, some collapse. Structures Type V damaged, some with partial collapse. Structures Type VI suffer minor damage, a few moderately damaged.

MM12

Structures: Most Buildings Type III destroyed. Many Structures Type IV destroyed. Structures Type V heavily damaged, some with partial collapse. Structures Type VI moderately damaged.

Construction types

Buildings Type I: Buildings with low standard of workmanship, poor mortar, or constructed of weak materials like mud brick or rammed earth. Soft storey structures (e.g. shops) made of masonry, weak reinforced concrete, or composite materials (e.g. some walls timber, some brick) not well tied together. Masonry buildings otherwise conforming to Buildings Type I–III, but also having heavy unreinforced masonry towers. (Buildings constructed entirely of timber must be of extremely low quality to be Type I).

Buildings Type II: Buildings of ordinary workmanship, with mortar of average quality. No extreme weakness, such as inadequate bonding of the corners, but neither designed nor reinforced to resist lateral forces. Such buildings not having heavy unreinforced masonry towers.

Buildings Type III: Reinforced masonry or concrete buildings of good workmanship and with sound mortar, but not formally designed in detail to resist earthquake forces.

Structures Type IV: Buildings and bridges designed and built to resist earthquakes to normal use standards, i.e. no special collapse or damage limiting measures taken (mid 1930s to c. 1970 for concrete and to c. 1980 for other materials).

Structures Type V: Buildings and bridges designed and built to resist earthquakes to normal use standards, i.e. no special damage limiting measures taken, other than code requirements, dating from since c. 1970 for concrete and c. 1980 for other materials.

Structures Type VI: Structures dating from c. 1980 with well defined foundation behaviour, which have been especially designed for minimal damage, e.g. seismically isolated emergency facilities, some structures with dangerous or high (value) contents, or new generation low damage structures.

Windows

Type I – Large display windows, especially shop windows.

Type II – Ordinary sash or casement windows.

Water tanks

Type I – External, stand mounted, corrugated iron water tanks.

Type II – Domestic hot-water cylinders unrestrained except by supply and delivery pipes.