

TSUNAMI AND CATAclySMIC FLOODS

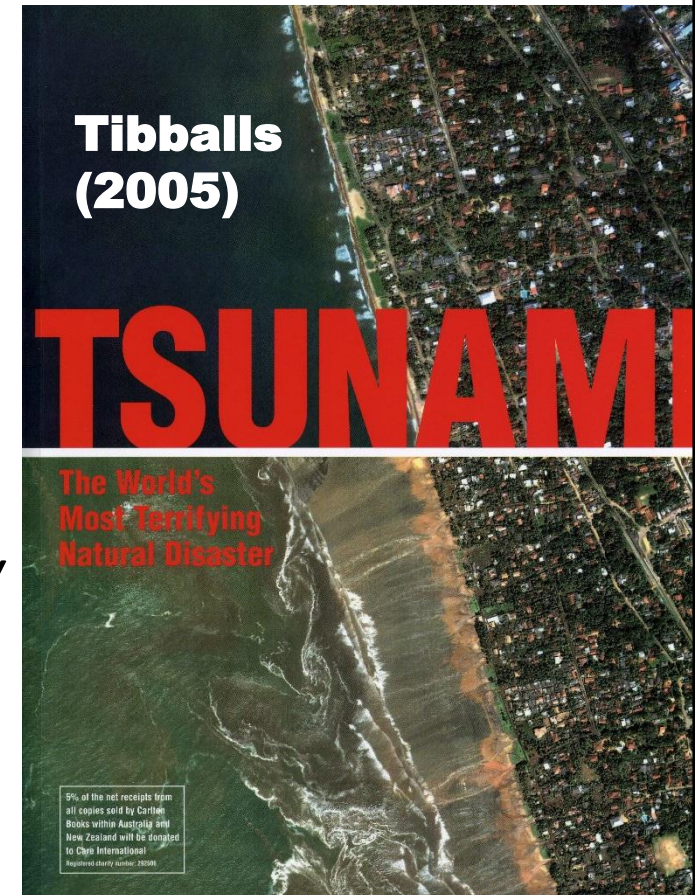
ENV101 Earth Systems

Professor Wayne Erskine

Adjunct Professor in RIEL, CHARLES DARWIN UNIVERSITY

SCHOOL OF ENVIRONMENT, CHARLES DARWIN UNIVERSITY

15 October 2015



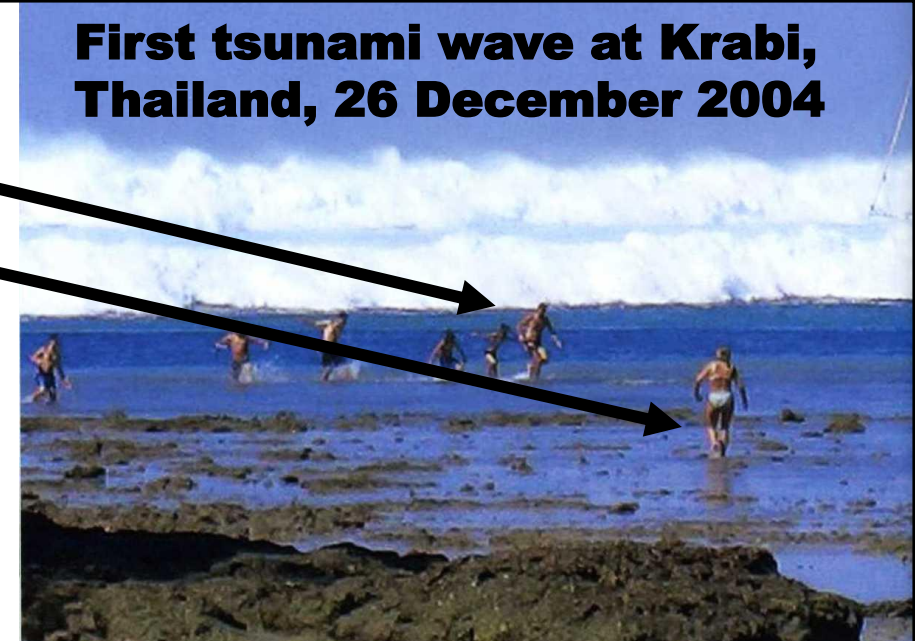
This lady and her family survived

**First tsunami wave at Krabi,
Thailand, 26 December 2004**

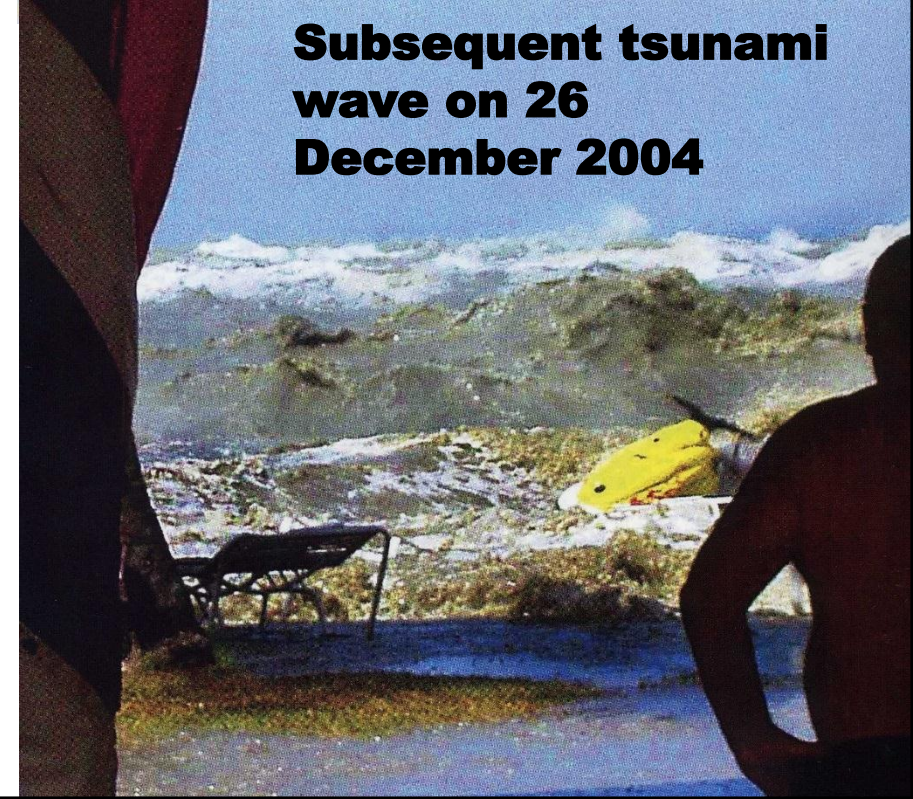
OUTLINE:

1. WHAT IS A TSUNAMI?
2. TSUNAMI GENERATION AND BEHAVIOUR
3. SOME MAJOR TSUNAMIS
4. IMPACTS ON HUMANS
5. ECOLOGICAL EFFECTS
6. CATAclySMIC: BIGGER THAN LARGE!
7. FLOOD GENERATION MECHANISMS
8. PALAEOFLOOD HYDROLOGY

The aim of this lecture is to introduce you to two large-scale physical disturbances that significantly impact on humans.



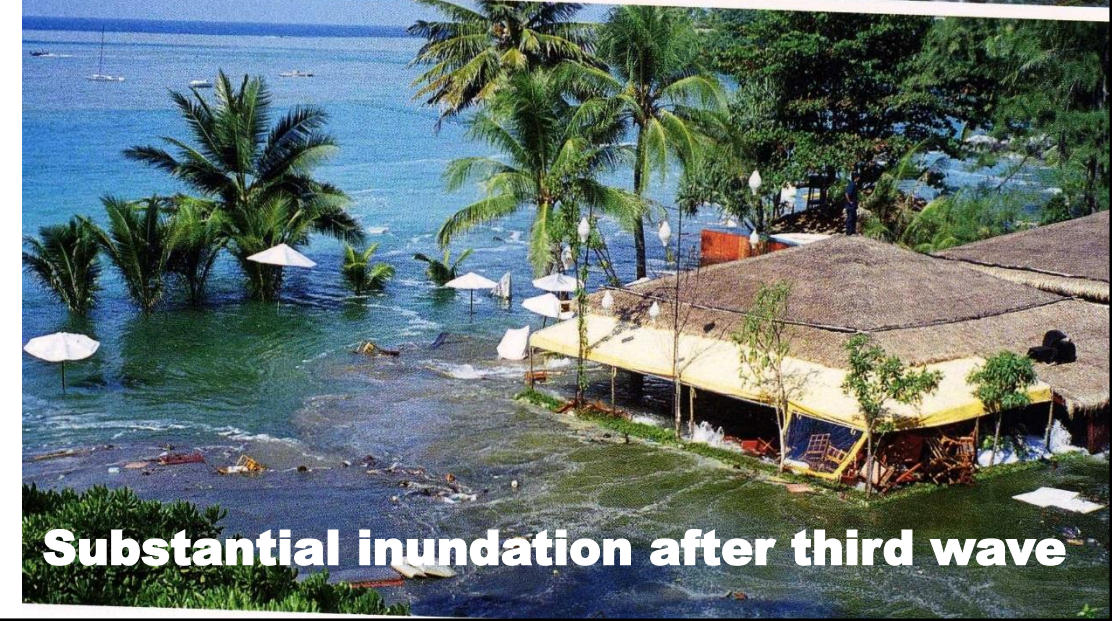
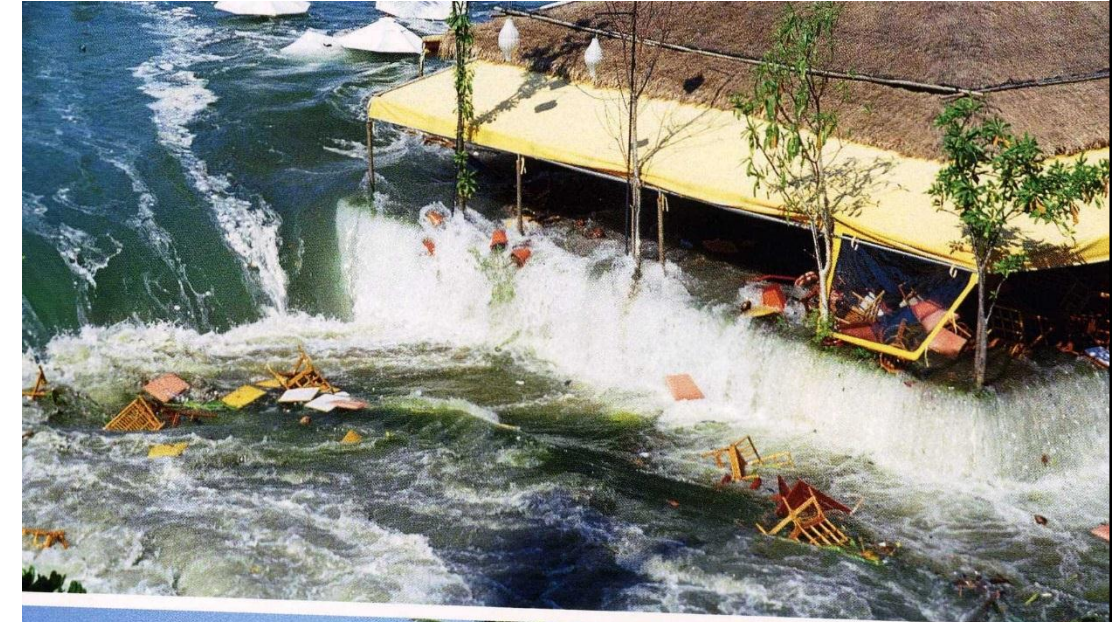
**Subsequent tsunami
wave on 26
December 2004**



WHAT IS A TSUNAMI?

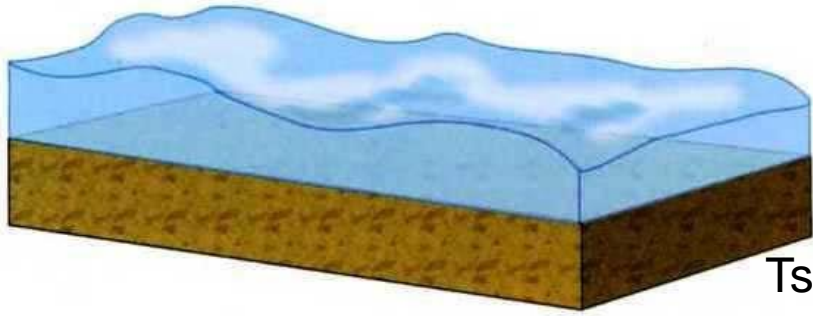
- A ***tsunami*** (pronounced 'soo-nar-me') is Japanese and literally means harbour (*tsu*) wave (*nami*). Singular and plural are the same in Japanese and I will follow this convention in the lecture. One or more waves can be generated per event. The wave train has a low height in the ocean but can reach up to at least 30 m in height at the coast.
- With tsunami, the entire ocean from the surface to sea floor is moving due to displacement of billions of tonnes of seawater. Velocity of tsunami is controlled by water depth.
- Tidal wave is a misnomer for tsunami because the wave(s) has/have absolutely nothing to do with tides! Do not call tsunami, tidal waves! Other causes of tsunami include meteorite impact, subaerial and subaqueous landslides, etc. Therefore tsunami are not restricted to oceans but have occurred in lakes also. *We discussed earthquakes in my first lecture so as to help you understand tsunami.*
- Sea can retreat some distance before tsunami reaches the coast. Seek high ground immediately if you experience an earthquake and observe the sea retreating. Tsunami can just cause inundation also.

First swell reaches the lawn



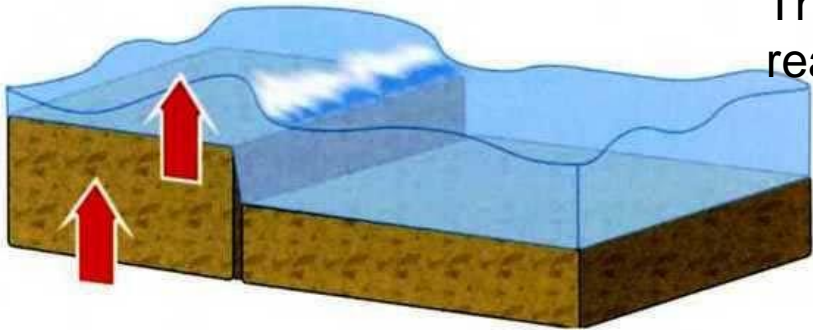
Substantial inundation after third wave

From: Tibballs (2005: pp. 23 & 24)



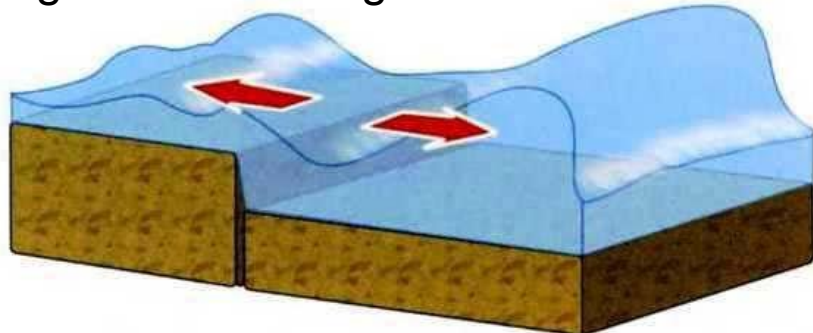
The tsunami in December 2004 was triggered by an earthquake deep in the Indian Ocean between the Australian and Eurasian plates.

Tsunami are not very high in the open ocean as shown in the top figure opposite. They must reach shallow water before the real wave height is expressed.

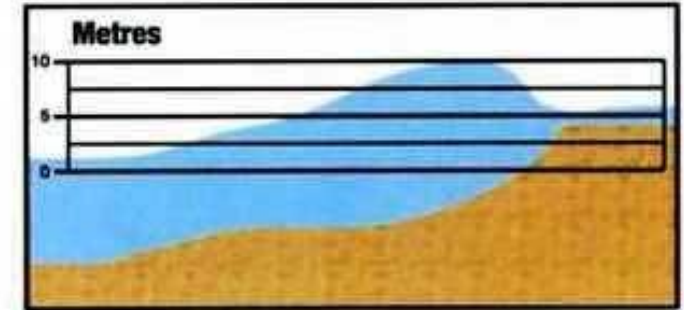
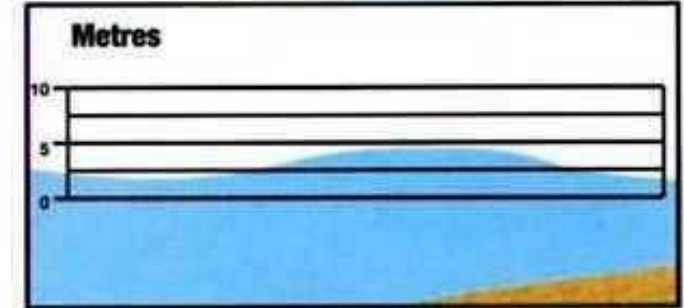
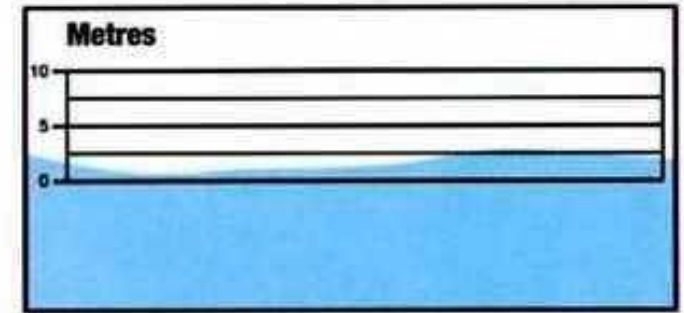


The energy from the earthquake vertically jolted the seabed by several metres, displacing hundreds of cubic kilometres of water.

Please note that this tsunami is grossly exaggerated in magnitude in the figure below.



Giant waves began moving away from the earthquake's epicentre and the journey of the deadliest tsunami in history was underway.



The tsunami moved at up to 800km/h (500mph) in deeper water. Shallow water acts as a brake on the front of the wave, but the back continues at full speed to form a wall of water.

TSUNAMI GENERATION AND BEHAVIOUR

Tsunami often reach the shore without breaking and hence do not lose much energy as they approach the coast because they are very long with unusual shaped crests. Most tsunami travel in wave trains containing several large waves that in deep water are < 0.4 m high. The wave period (time it takes for a pair of wave crests to pass the same point) is long (1.6 to 33 minutes) and is referred to as the tsunami window. The wavelength (distance between successive wave crests) is also very large, typically 10 to 500 km. Travel velocity of 600-900 km/h in the deepest part of the ocean. About 60% of the increase in wave height of a tsunami occurs within the last 20 m depth of water.

**From:
Cummins
(2005: p.
18).**

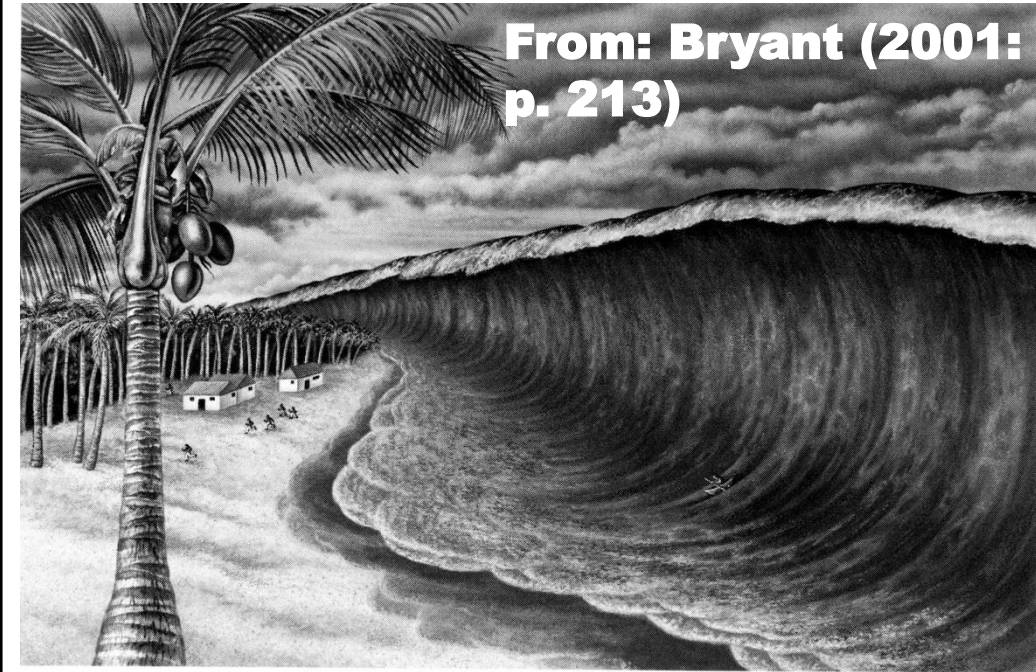


Figure 2. Calculated maximum amplitude of the tsunami caused by 1833 Sumatra earthquake. Most tsunami energy was directed into the open Indian Ocean, away from the Bay of Bengal. (Numerical modelling performed by David Burbidge of Geoscience Australia.)



Sea floor rose near the plate boundary and subsided 100-200 km landward of the plate boundary on 26 December 2004. The wave travelling to the east had a receding leading edge which caused the sea to withdraw while to the west, the leading edge inundated the coast. So Sumatra and Thailand experienced a sudden withdrawal of the sea whereas Sri Lanka and India experienced inundation without any warning (Cummins 2005).

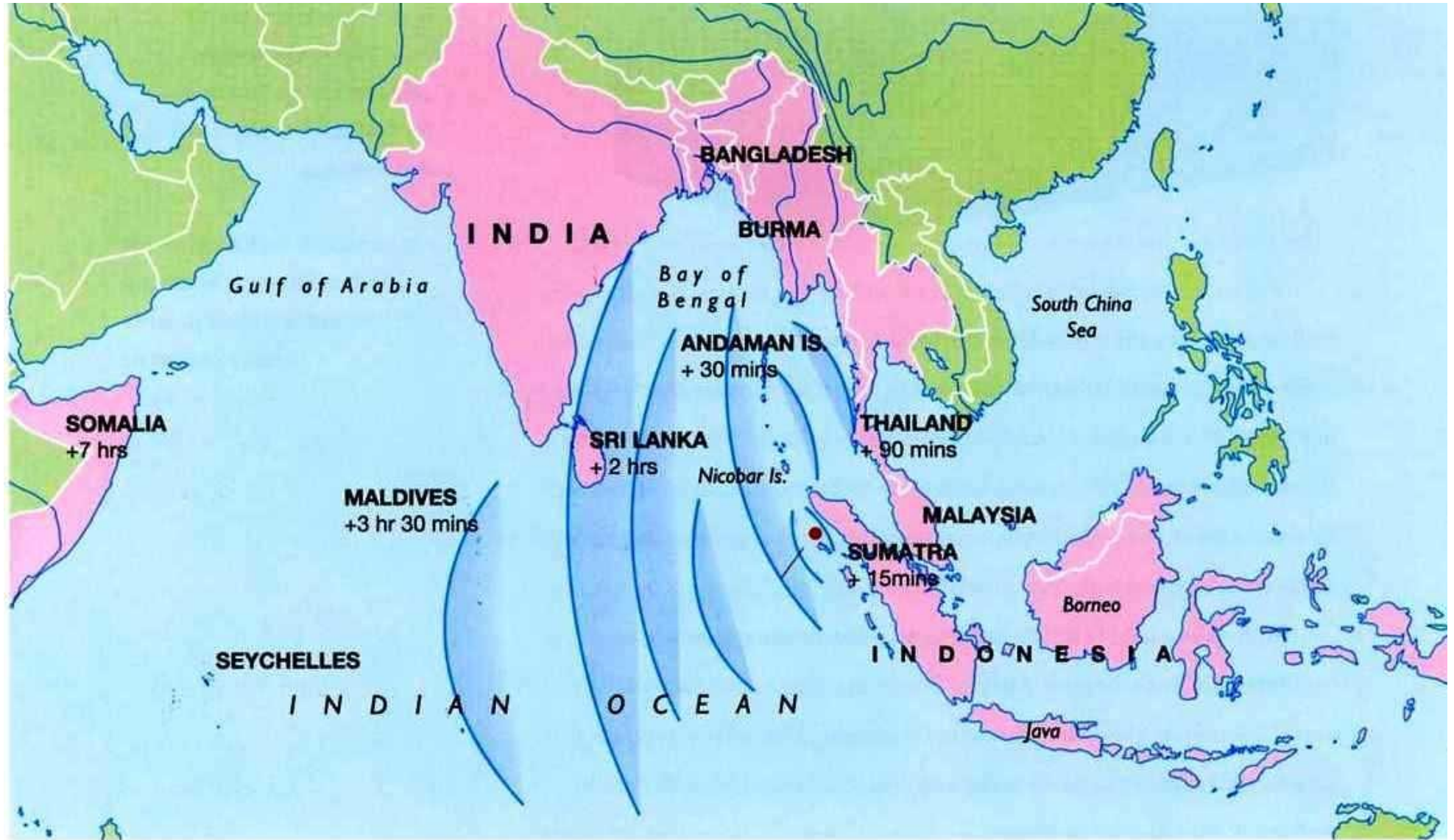
**From: Bryant (2001:
p. 213)**



7.1 An artist's impression of the tsunami from the third explosion of Krakatau hitting the coast of Anjer Lor at about 10:30 A.M. on 27 August 1883. ©Lynette Cook



**Tsunami 26 December
2004 at Krabi Beach, Thailand
Photo from Museum of New
Zealand Te Papa Tongarewa**



The tsunami on 26 December 2004 wrecked everything in it's path over a seven-hour period.

From: Tibballs (2005: p. 24)

Existing tide gauges at Vishakapatnam, India and Cocos Islands are insufficient to give adequate warning time of a tsunami generated in the Sunda trench. This is because it takes about 2.5 hours for the tsunami to reach these gauges. Therefore, no warnings can be issued until the tsunami has already impacted on the worst affected areas. Then there would need to be an effective warning system in place that can quickly communicate the warning to the potential impact area. Furthermore, the potentially affected people would have to have confidence in the warning and respond immediately, using designated paths to well-known safety areas. None of this currently exists. The Indian Ocean is not perceived as important as the Pacific Ocean. The Australian Tsunami Alert System is currently in operation but is being replaced by the Australian Tsunami Warning System. This system will integrate with the Indian Ocean Tsunami Warning System and the

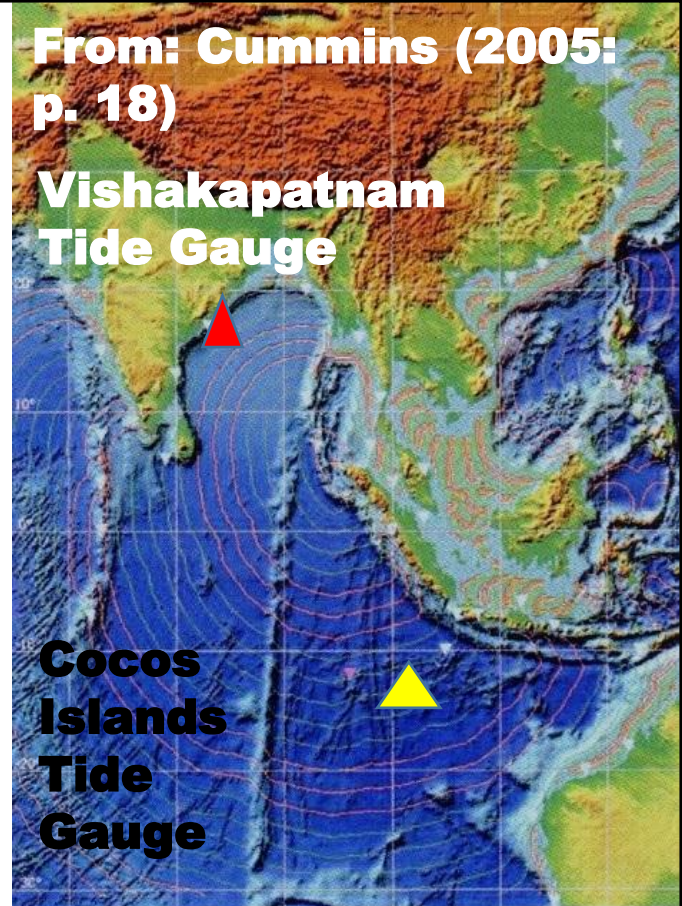


Figure 3. Travel-time contours for the Boxing Day tsunami. The source zone is roughly constrained by the tsunami arrival times at the Vishakapatnam and Cocos Islands tide gauges (the latter is indicated by the inverted magenta triangle south-west of Indonesia). Contours are at 15 minute intervals, and alternate colour every hour.

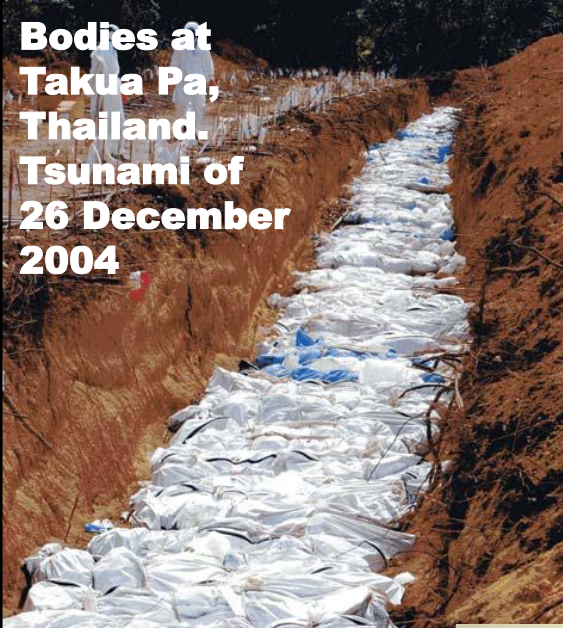
Figure generated using software provided with the Integrated Tsunami Database for the Pacific, by Slava Gusiakov.

MAJOR TSUNAMI

Some of the worst tsunami recorded include the following:

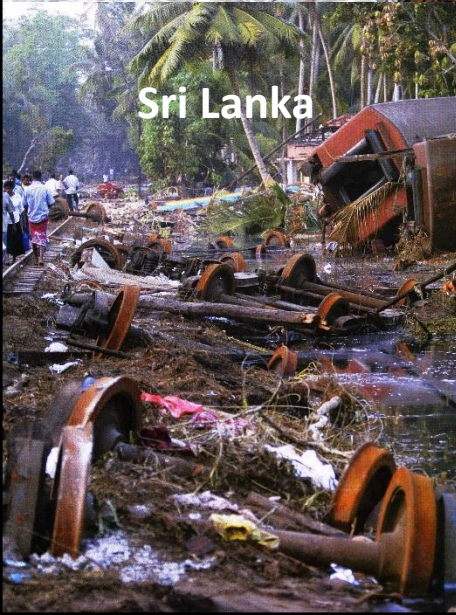
1. **Sunda Trench** - 26 December 2004 - 9.3 (Richter Scale) earthquake caused the tsunami - 0.6 m high wave in deep ocean – 5-10 m high waves in Thailand and Sri Lanka - 200k to 310k people killed (never know real death toll).
2. **Krakatau** - 27 August 1883 – 15 m high wave – 36417 fatalities
3. **Aitape Coast, Papua New Guinea** – 17 July 1998 – 10-15 m high tsunami – 2202 people died, 1000 injured and 10000 homeless
4. **Lisbon** – 1 August 1755 – 15 m high tsunami – earthquake generated – 70000 fatalities

**Bodies at
Takua Pa,
Thailand.
Tsunami of
26 December
2004**



Banda Aceh

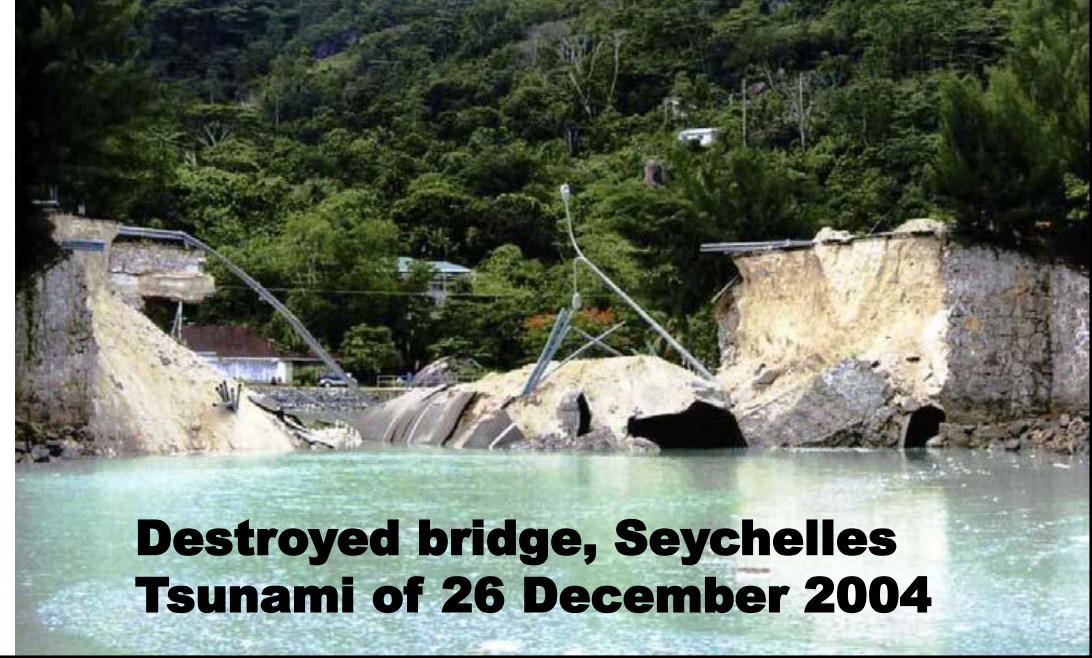
**Nagappatinam, India after
Tsunami of 26 December 2004**



Sri Lanka



Sri Lanka



**Destroyed bridge, Seychelles
Tsunami of 26 December 2004**

Extinction of the dinosaurs – comet impacted the Earth at Chicxulub in Mexico at the Cretaceous-Tertiary boundary. **K/T Extinction event.** There are 160 impact craters on the surface of the Earth (Bryant 2001)



8.1 An artist's impression of the Chicxulub impact tsunami as it crossed the coastal plain of the United States. The impact event was responsible for the extinction of the dinosaurs, 65 million years ago. The figure appeared originally in Alvarez (1997). ©Princeton University Press 1997 and reprinted by permission.

ECOLOGICAL EFFECTS

Tsunami can play important roles in both primary and secondary succession.

Primary succession refers to vegetation development on raw parent material rather than a developed or modified soil (Attiwill & Wilson 2004: p. 197). This is a clumsy way of saying that a new landform is formed by erosion and/or deposition that is subsequently colonised by vegetation. Tsunami can extensively erode bedrock and sediments, such as barriers, beaches, deltas and rock platforms, and can deposit large amounts of sediment to form new depositional landforms, such as beach ridges. A pioneer plant community establishes that changes greatly over time until a subsequent, usually different disturbance, initiates secondary succession.

Secondary succession refers to the replacement of pre-existing vegetation following a disturbance that disrupts the vegetation (Attiwill & Wilson 2004: p. 197). This refers to the destruction of the pre-existing vegetation and the initiation of a new phase of vegetation colonisation on the same soils. Therefore, erosion and deposition are much less than is the case for primary succession. As you will see in subsequent slides, tsunami are very effective at completely removing vegetation from barrier and beach ridge systems behind beaches. Major tsunami, such as 26 December 2004, are responsible for many types of primary succession.



Gleebruk village, Sri Lanka on 12 April 2004 (left) and immediately after the 26th December 2004 tsunami (right). Note the erosion of the flood tide delta at the mouth of the estuary, the destruction of the aquaculture ponds in the estuary, the destruction of the bridge, wholesale loss of vegetation and the large-scale beach erosion. Unless you observe such large-scale geomorphological (landform) changes first hand, it is difficult to believe that they can occur.

CATAclysmic FLOODS

Cataclysmic floods are very large floods that are much greater than more frequently recorded floods. Their peak discharge is much greater than the usually recorded floods. Floods are characterised by their peak instantaneous discharge and cataclysmic floods have peak discharges that are much greater than the mean annual flood. In NSW, rainfall-generated, large floods often have peak discharges between 10 and 45 times greater than the mean. Cataclysmic floods are those at the upper end of this range and much larger. They have been called short-lived super floods and have been difficult to accept by ecologists and earth scientists who incorrectly thought that such events have not occurred.

THEY DO OCCUR!

FLOOD GENERATION MECHANISMS

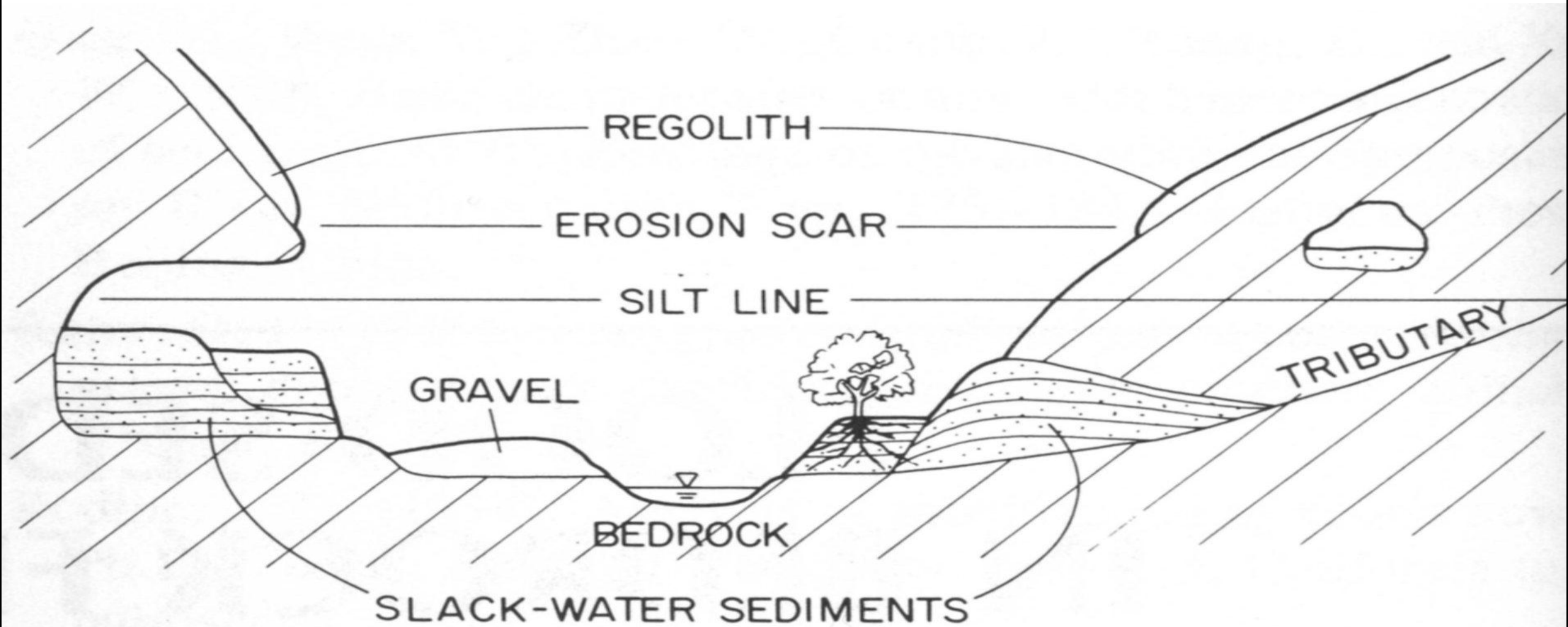
1. **JOKULHLAUPS** – these are glacial outburst floods where a considerable volume of glacial melt water is released over a short time period. They are caused by subglacial volcanic activity that melts overlying ice producing significant amounts of meltwater and by complete failure of ice-dammed lakes and breached moraine-dammed lakes. One occurred in January 2002 at Kverkfjoll, Iceland.
2. **GLACIAL OUTBURST FLOODS DURING DEGLACIATION** – outbursts from gigantic ice-dammed lakes. Yes these are jokulhlaups but I am separating them because they have generated the world's two largest floods! These were outbursts from glacial Lake Missoula which eroded the Channeled Scabland region of north America (No. 2) and Altay Mountains of Siberia (No. 1). The ice dams held $>1000 \text{ km}^3$ of water and failed cataclysmically! Victor Baker has investigated both events and has published some superb research.
3. **RAIN STORMS** – high intensity and/or long duration rain storms. These do occur in Australia and are important landforming agents for fluvial environments.

World's two largest floods were glacial outburst floods:

GLACIAL LAKE MISSOULA	ALTAY MOUNTAINS SIBERIA
No. 2 on the all time list of cataclysmic floods	No. 1 on the all time list of cataclysmic floods
$17 \times 10^6 \text{ m}^3/\text{s}$ peak discharge	$18 \times 10^6 \text{ m}^3/\text{s}$ peak discharge
100 m deep flows 18 m/s mean flow velocity	400-500 m deep flows 20-40 m/s flow velocities
1800 N/m ² bed shear stress	5000 to 50000 N/m ² bed shear stress
$3.2 \times 10^4 \text{ W/m}^2$ specific stream power	10^5 to 10^6 W/m^2 specific stream power

The floods produced coarse-grained channel deposits and finer-grained slackwater deposits.

Slackwater deposits are fine-grained sediments that accumulate in low velocity or low energy regions marginal to the main flood flow. Locations of slackwater deposition are shown in the figure below and are used to determine the peak stage/height of the formative flood.



Bars formed of coarse-grained sediments and are up to 200 m high. Giant current ripples are well developed, as shown in the adjacent photographs for the Altay Mountains, Siberia.

Source: Rudoy & Baker (1993)

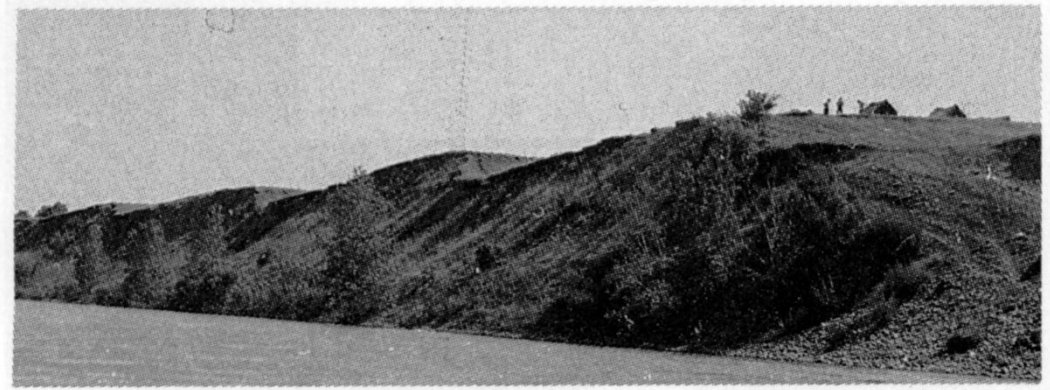


Fig. 9. Giant current ripples at Platovo along the Katun River (foreground). Note the human figures and tents on the nearest ripple crest.



Fig. 10. Giant current ripples south of Kuray Village and east of Tome River (Fig. 3).

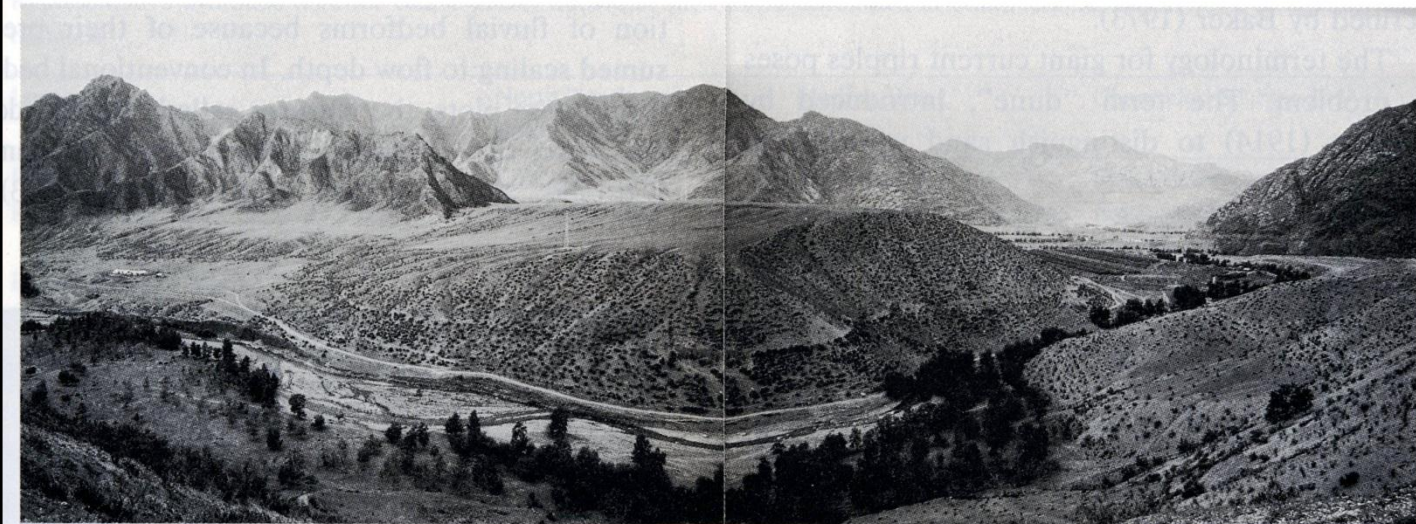
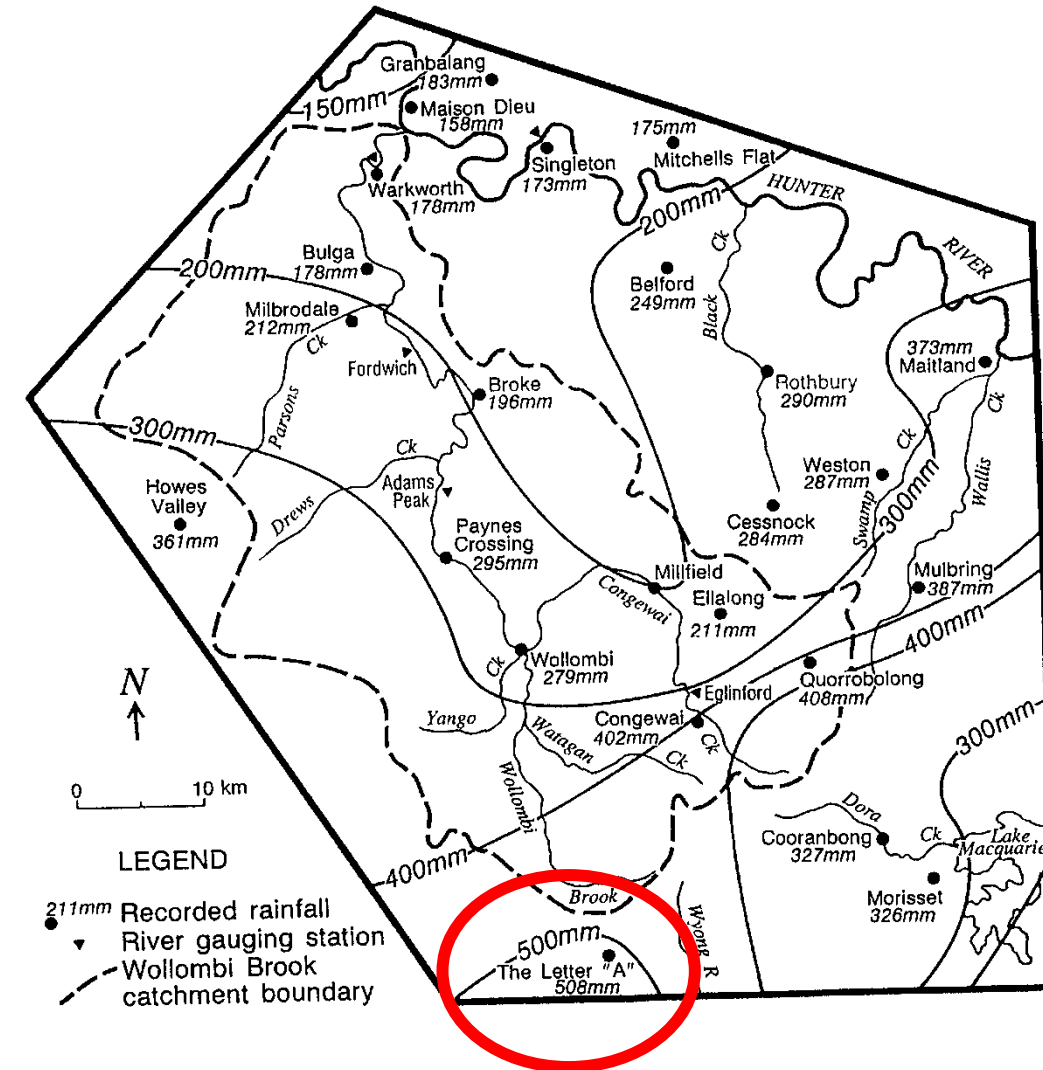
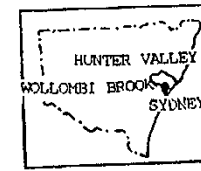


Fig. 7. Giant bar (*L* in Fig. 3) at the mouth of Little Jaloman River (foreground). Main Katun River Valley is to the right. Slackwater deposit exposures (*S* in Fig. 3) occur at the far left, inset against the bar.

AUSTRALIAN RAIN STORMS

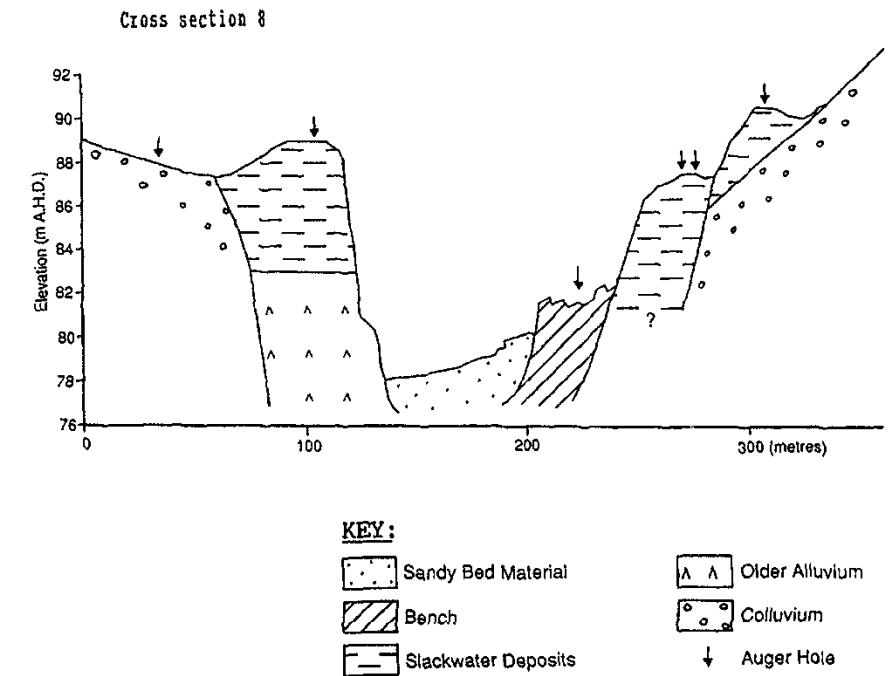
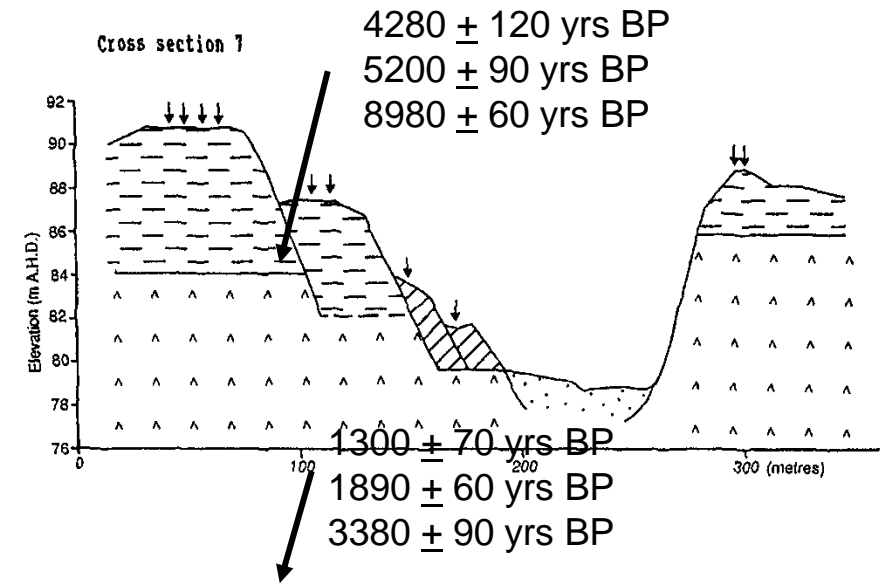
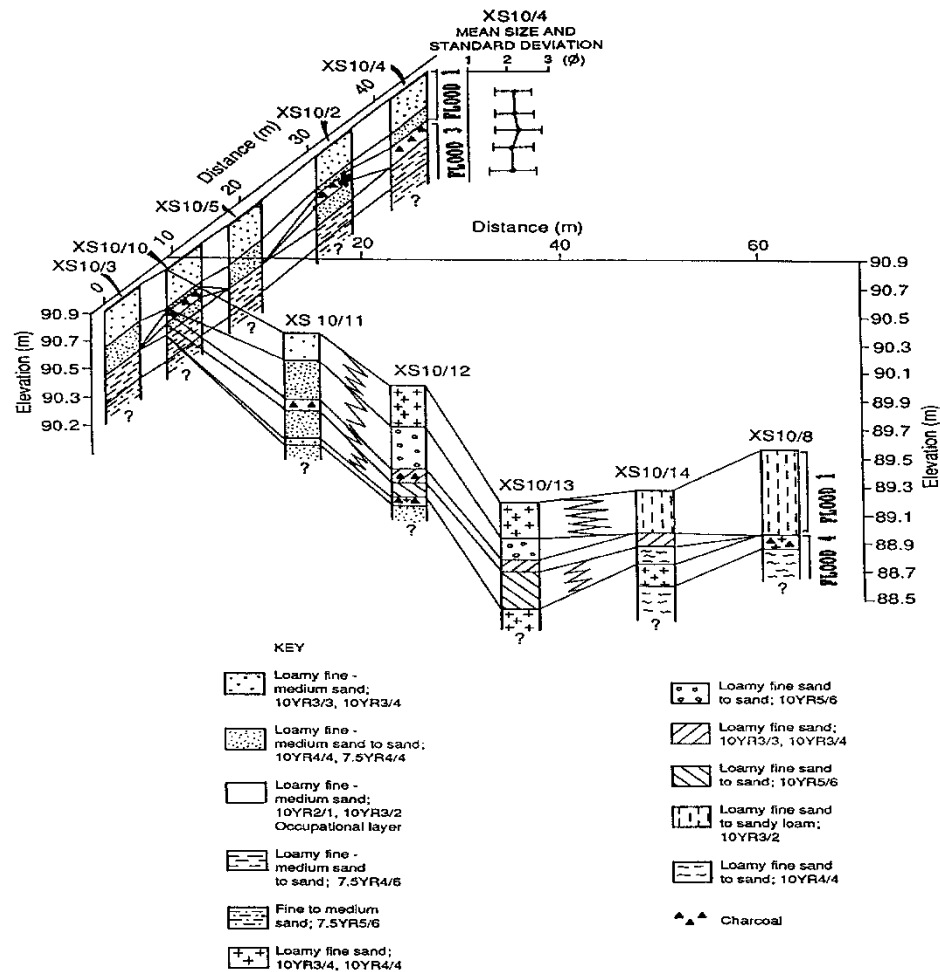
Rainfall for 17-18 June 1949 over the Wollombi Brook catchment, NSW. Maximum rainfall was 508 mm at 'The Letter A'. Rainfall decreased to north but still substantial. Largest daily rainfall recorded in temperate Australia was 820 mm at Wongawilli near Wollongong in February 1984. Dorrigo also produces large floods. See Erskine & Saynor (2012) for large flood at Ranger Mine at Jabiru.



1949 FLOOD ON WOLLOMBI BROOK

Paynes Crossing Erskine & Peacock (2002)	Warkworth Erskine (1996) & Erskine & Chalmers (2009)
11.4 m peak height	12.38 m peak height
4400 m ³ /s peak discharge	4360 m ³ /s peak discharge
22 times greater than mean annual flood	26.85 times greater than mean annual flood
Larger palaeofloods	

Slackwater deposit stratigraphy at cross section 10. Source: Erskine & Peacock (2002)



PALAEOFLOOD HYDROLOGY

- Developed by Victor Baker and students and colleagues
- Application of earth science and hydraulics to flood determination before European settlement
- Use of sedimentology to identify individual flood deposits
- Use of stratigraphy to correlate flood deposits between sites
- Use of dating to age flood deposits
- Use of hydraulics to estimate peak discharge and velocity
- Now widely practised