Maritime Natural Hazards in the Indian Ocean Region

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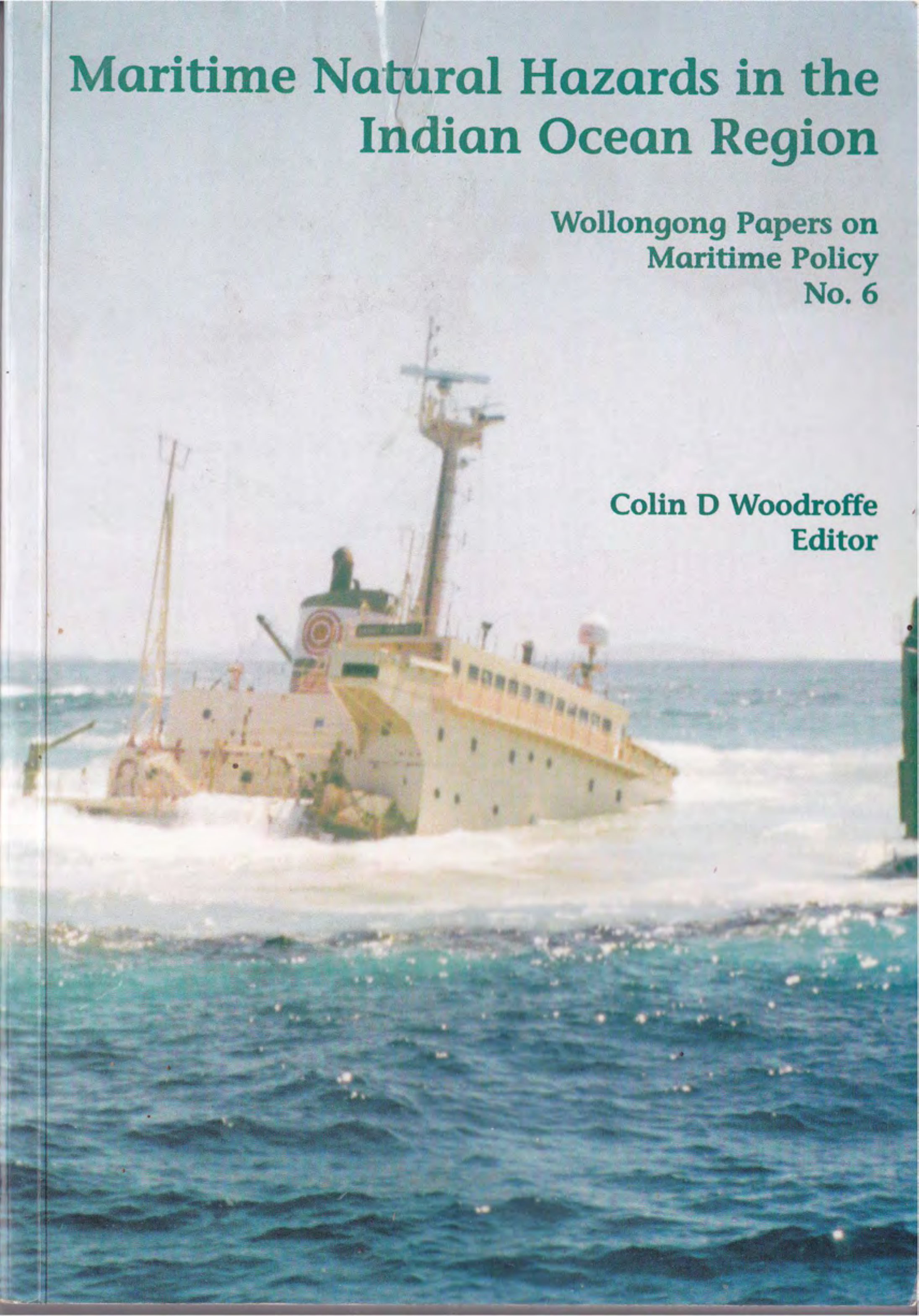

TSUNAMI OBSERVATIONS IN WESTERN AUSTRALIA

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INTRODUCTION

Several tsunamis (seismic sea waves) have been observed and recorded on tidal gauges on the Australian coast. None have caused significant damage. The most significant waves were along the Western Australian coast following the Krakatoa volcanic explosion in 1883 (Bureau of Meteorology, 1929), and Indonesian earthquakes on 17 August 1977 (Gregson & others, 1979) and 3 June 1994 (WST).

Shallow ocean depths around New Zealand, Fiji, New Caledonia and Lord Howe ridge protect the eastern coast of Australia from tsunamis. Tsunamis from the south and west of Australia are unlikely as the earthquakes are associated with transcurrent faulting and therefore do not have the vertical earth movement needed to generate sea waves.

The section of the coast most likely to experience tsunamis is the north-west coast of Western Australia from earthquakes that occur in the Indonesian Sunda Arc. Much of the coast has a very wide continental shelf, up to 200 km wide at the 200 m bathometric contour, which absorbs the waves, preventing them from reaching large heights. However, there are parts of the coast where the shelf narrows, particularly near the North-West Cape where the shelf is only about 10 km wide. Although infrequent, tsunamis have the potential of causing the loss of life and significant damage. With the offshore development in the north-west the significance is increasing.

PRE-HISTORICAL OBSERVATIONS

Two events have occurred at the Abrolhos Islands, 70 km west of Geraldton that may or may not be of significance with respect to the occurrence of tsunamis.

Many of the low islands are composed of coral rubble storm ridges with elevations of less than 2m above sea level. During a sedimentological study of the islands by Curtin University (Collins & others, 1993), radiocarbon dating has indicated an erosional episode between 4000 and 2000 14C years before present. Although further work is needed to determine the origin of this destructive event, tsunamis or cyclonic storms are considered the most likely.

Recent studies in the Sandy desert area inland from Broome show evidence of massive tsunami effects in the last 1000 years which override 60 m high hills lying 2 km from the coast and in some locations appear to have penetrated inland a distance of 30 km.

An unsubstantiated report oindicates a number of Chinese workers drowned at the Abrolhos Islands about 1900. A search of earthquake catalogues could not identify an earthquake that could have been responsible for this occurrence.

OBSERVATIONS

Four significant tsunamis have been observed along the northwest coast of Western Australia in the last 120 years. Detailed descriptions are given in the appendix and shown in Figure 1.

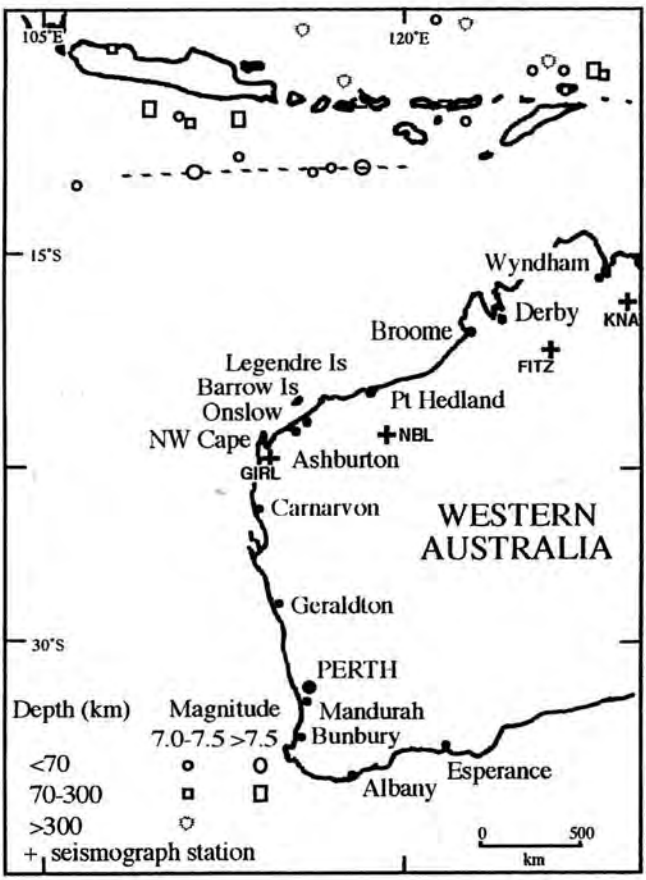

Figure 1: Tsunami observations along the Western Australian coast showing location of seismic events and recording stations

1883, August 17
A tsunami followed the massive volcanic explosion at Krakatoa (6.07°S, 105.24°E). Large waves and irregular tides were observed for several days on the Western Australia coast between Geraldton and Derby. An estimated 36,000 people were killed in Indonesia as a result of the eruption.

1885, January 5
Geraldton experienced a subsidence of the sea of one metre at 10.25 p.m. (WST) following an earthquake. The Australian earthquake catalogue lists an earthquake of magnitude Ms 6.5 at 29°S and 114°E at 1220 UT on 5 January.

1977, August 19
Seismic sea waves were observed and recorded on tide gauges between Derby and Geraldton over several hours with unusual tides over the next day. The tsunami followed a magnitude Ms 7.9 earthquakes located at 11.09°S and 118.46° which occurred at 1408 WST.

1994, June 3
At 0220 (WST) a magnitude Ms 7.2 earthquake located at 10.477°S and 112.835°E resulted in a tsunami which was observed between North West Cape and Onslow. The recordings were also obtained on tide gauges along the coast. The tide was low at the time the tsunami arrived along the coast.

These events are listed in the data base of tsunamis observed along the Australian coast (McCue & others, 1994).

Details of the effects in Indonesia of the latter two events are given in reports prepared by the International Tsunami Information Centre (1977, 1994).

INSTRUMENTAL RECORDINGS

The tsunami on 3 June 1994 was recorded on tide gauge recorders operated by either the Western Australian Department of Transport or various port authorities. Details of tide gauges that are operated are given in Table 1.

The tsunami of 19 August 1977 was recorded on tide gauges at Dampier and Broome and a wave rider buoy at Legendre Island (Wallace, 1994).

The tsunami of 3 June 1994 recorded on tide gauges from Broome to Geraldton. Despite the comparatively coarse sampling rate, clear evidence of the tsunami was recorded at several locations. The Department of Transport filtered the data to remove the astronomical and long period components. The resulting grams are reproduced in Figure 2 (courtesy D Wallace, Department of Transport). Significant tsunami signals were recorded at Dampier, Barrow Is and Onslow. The onset at Onslow is just before 6.00 am which is not inconsistent with reported observation. No fluctuations were recorded at Wyndham which is not surprising as the gauge is approximately 70 km from the ocean in the narrow Cambridge Gulf. The tsunami is probably evident at Carnarvon but partially obscured by wind driven seiches of 25 minute period. Waves were observed on the tide gauge recorder on Cocos Island with a peak of 14 cm and a period of 30 minutes at about 5.25 WST.

Table 1: Tide gauge records

Location	Remarks	Sample Rate	Arrival Time (WST)	Wave Action
Tsunami 19 August 1979				
Wyndham				None
Broome	In Roebuck Bay		1742	2.5 cm, 12 min intervals
Pt Hedland	Not operating			None
Dampier (tug jetty)			1730	40 cm, 15-34 min intervals Unusual wave activity for 21 hrs
Carnarvon	Not operating			
Geraldton			2120	20 cm maximum, periods 22-38 min
Legendre Is	Wave Rider Buoy 34km N Dampier		1659	1.2 m, period 30 sec Two more waves in 12 mins
Fremantle				None
Albany				None
Esperance				None
Tsunami 3 June 1994				
Wyndham	Digital*	15 min		None
Pt Hedland				?
Broome	Digital*	15 min	700	1-2 cm
Dampier (King Bay)	Digital*	15 min	535	45 cm
Barrow Is	Digital*	15 min	545	20 cm
Onslow	Digital*	15 min	545	22 cm
Carnarvon	Digital*	5 min	650	Masked by 25 min seiches
Geraldton	Digital*	5 min	900	Few cms

* Stilling well/float actuated digital loggers

The 15 minute sampling rate is not suitable to give a true record of the effects of tsunamis as the period of wave action is in the order of 10 to 15 minutes as observed by various observers.

Tide gauge recordings for the period following the five earthquakes since 1900 with magnitudes of 7.5 or more in the Sunda Arc are being examined by the Department of Transport for any unusual wave action, although depending on the type of instrumentation it is doubtful whether the events will be evident.

TSUNAMI TRAVEL TIMES

The travel time from the earthquake source to various locations varied considerably and is a function of both distance and water depth between the source and point of observation. Water depth can have a significant effect on the travel time locations and similar distances. This is clearly evident in Table 2.

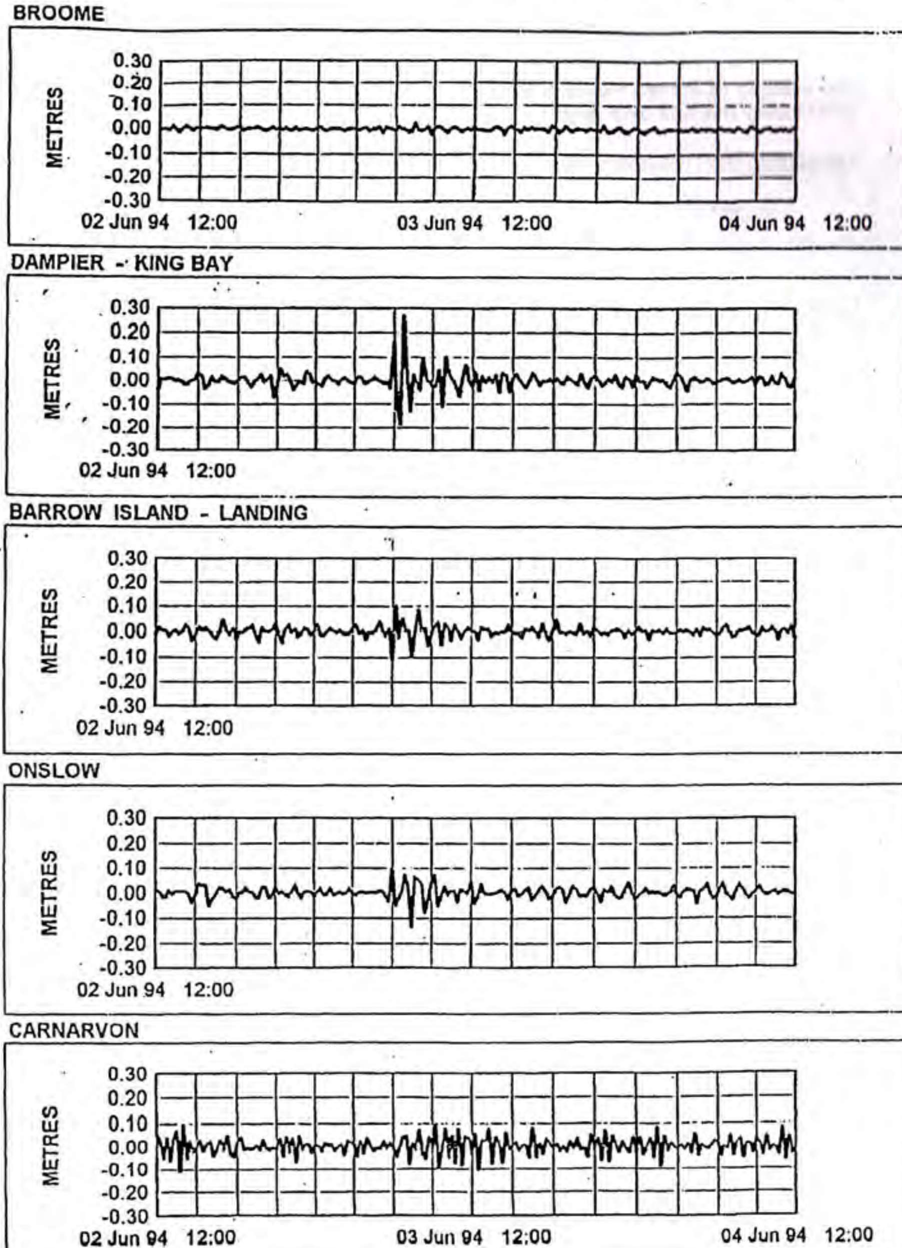

Figure 2: Tide gauge recordings on 3 June 1994 (15 min tidal data has been high pass filtered). (Courtesy of D Wallace, Department of Transport, WA)

The velocity of the sea waves is related to the depth of water, with velocities of up to 1000 km/hr reached over deep ocean.

Tanahashi (1963) estimates the velocity of a tsunami wave using the formula:

$v = (gh)^{1/2}$ where v = velocity km/hr
h = depth of water in meters
g = acceleration due to gravity 9.8 m/sec^2

Using barometric maps the average velocity was calculated between contours of water depth and the approximate travel time between contours would be determined. Hence the total travel between the origin of the earthquake on 3 June 1994 and arrival at different locations along the coast could be calculated. Figure 3 graphically shows the changes in water depth and velocity of the sea wave between the earthquake epicentre and Onslow. There was good agreement, within 10 minutes between the theoretical (0602 WST) and the observed arrival time (0550 WST).

Table 2: Travel time to various locations

Location	Distance km	Arrival time	Travel time	Location	Distance km	Arrival time	Travel time
19 August 1979 - 1408 WST				***3 June 1994 - 2120 WST***			
Cape Leveque	690	1750	3 42	Barrow Is	1300	545	3 35
Broome	765	1742	3 34	Dampier (King Bay)	1330	535	3 25
Pt Hedland	920	1800	3 52	Griffin Venture	1350	0440	2 20
Pt Samson	955	1745	3 37	No name Bay	1380	0630	
Legendre Is	955	1649	2 51	Onslow	1390	550	3 30
Dampier	990	1730	3 22	Onslow	1390	545	3 25
Dampier	990	1740	3 32	Northwest Cape	1390	0615	3 55
Barrow Is	1025	1800	3 52	Onslow	1390	0550	3 30
Geraldton	1825	2120	7 12	Broome	1420	700	4 40
				Exmouth	1420	0600	4 40
				Carnarvon	1710	650	3 25
				Geraldton	2150	900	6 40

At the *Griffin Venture* anchored approximately 60 km offshore with a water depth of 135 m the first effects were observed at 0440 WST. Using the same method as for Onslow, the theoretical arrival time of the tsunami was 0448 WST. There was reasonable agreement between the calculated arrival times and actual times of observations at the other locations. Table 2 shows the actual travel time from the earthquakes to points of observation. Although the travel time generally increases with distance it is also affected by the water depths over which the tsunami travels. This is evident in the case of Legendre Is and the Griffin Venture where travel time were 46 minutes and 65 minutes respectively, shorter than other locations at the same distance.

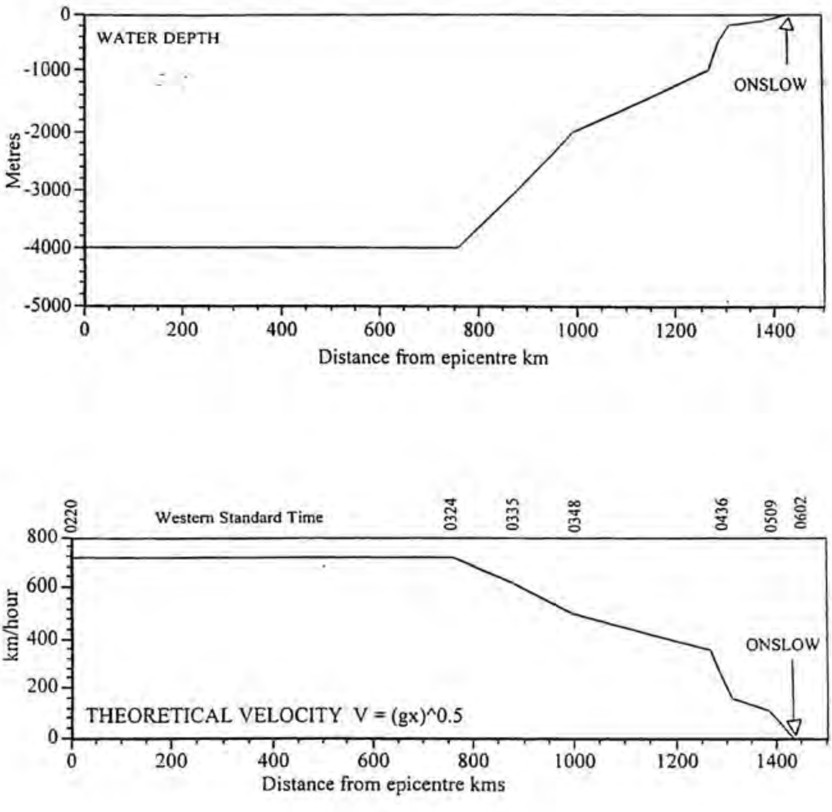

Figure 3: Calculated travel times to Onslow

The same method has been used to calculate the theoretical travel time between a set of hypothetical earthquakes at 1 degree intervals of longitude on latitude 11°S and several locations on the north-west coast of Western Australia (see Table 3).

For earthquakes between 112.0°E and 114.0°E and within one degree north or south of latitude 11°S the epicentre is in deep water, 4-6000 m. The variation in travel time will be within 6 minutes respectively. For earthquakes west of 112.0°E, travel times will increase by approximately 6 minutes per degree as the epicentres will be that much further from the north west coast.

Table 3: Calculated travel times

Epicentre	Pt Hedland	Broome	Onslow	NW Cape	Carnarvon
11.0°S	h m	h m	h m	h m	h m
112.0°E	4 12	4 26	3 28	2 40	5 16
113.0°E	4 07	4 20	3 34	2 37	5 49
114.0°E	4 01	4 10	3 44	2 36	6 28

The travel time to off-shore installations such as the Griffin Venture will be considerably shorter because the proportion of the travel path through shallow water, and hence slow velocities is significantly reduced. In the case of the Griffin Venture the travel time is approximately 70 minutes less than that to Onslow, even though the distance to the epicentre is only 40 km shorter and the travel paths are similar. The time variation will be even more evident where the continental shelf is wider. The theoretical average velocity between the 100 m and 200 m is more than double that between the 0 and 100 m contours, ie, approximately 140 km/hr and 60 km/hr respectively. However, the wave height will not be nearly as high as it is in the shallowing water depth results in the increased wave height.

TSUNAMI GENERATING SOURCE

There are four sources that could generate tsunamis that could impinge on the West Australia coast. These are:

(a) Massive volcanic eruptions
(b) Earthquakes offshore from Western Australia
(c) Earthquakes in the Indonesian Sunda Arc
(d) Massive sub-marine landslides

There has been only one massive volcanic eruption and one earthquake off-shore (ie, in 1885 near Geraldton) that has caused tsunami effects. No unusual waves were observed for the two large earthquakes shown below:

1906	Nov 19	22.0°S	109°E	Ms 7 3/4	(Gregson & Everingham, 1991)
1979	Apl 23	16.6°S	120.20°E	Mb 5.9	(Gregson, 1980)

The Sunda Arc, south of the Indonesian Islands is the most likely source of earthquake generated tsunamis affecting the north west coast of Western Australia.

For a tsunami of significance to be generated, an earthquake needs to be of shallow depth (generally less than 70 km), magnitude of 7 or more and located on the southern side of the Indonesian Islands. Earthquakes of magnitude 7 in the Sunda Arc since 1900 are shown in Figure 1 and listed in Table 4. Only 19 of these earthquakes fit these criteria and of these, 10 had magnitudes equal to or greater than the earthquake on 3 June 1994 and five had magnitudes of 7.5 or more.

In a study on statistics of tsunamis in Indonesia, Nakamurs lists six earthquakes that fit the above criteria in the period 1800 to 1900 (Table 5).

Table 4: Large earthquakes in the Sunda Arc region, 1900-1994

Date Yr	Mn	Dy	Lat °S	Long °E	Depth km*	Magnitude M
1903	Feb	27	8	106		8.1
1916	Sep	11	9	113		7 1/2
1921	Sep	11	11	111		7.5
1926	Sep	10	9	111	80	7.0
1931	Feb	10	5 1/4	102 1/2		7.1
1931	Feb	25	5	102 3/4		7.4
1933	Jun	24	5 1/2	104 3/4		7.5
1937	Sep	27	8.7	110.8	60	7.2
1938	Oct	20	9.2	123.0	90	7.3
1943	Apr	01	6 1/2	105 1/2		7.2
1943	Jul	23	8.6	109.9	90	7 3/4
1953	Jun	25	9.2	123.0	33	7.0
1953	Jun	25	9.2	123.0	33	7.1
1953	May	19	6.5	105.4	74	7
1972	May	28	11.0	117.1	33	7
1977	Aug	19	11.09	118.46	33	7.4
1978	Apr	10	11.09	116.33	33	7
1979	Jul	24	11.21	107.65	28	7
1994	Jun	03	9.3	112.4		7.2

* Where depths are not shown the earthquake is shallow, ie, less than 60 km

Table 5: Tsunamis in Indonesia

Date	Lat°S	Long°E	Depth	M	m
1815 Nov 22	8.0	115.0	150	7	1 1/2
1818 Mar 18	4.0	101.5	80	7	1 1/2
1820 Dec 29	7.0	119.0	80	7 1/2	3 1/2
1833 Nov 24	2.05	100.05	75	8	2 1/2
1857 May 13	8.0	115.05	50	7	2
1891 Oct 05	9.0	124.0	80	7	1/2

Based on the frequency of large earthquakes of shallow depth occurring south of the Indonesian Islands it would be reasonable to expect effects from tsunamis on the average of every 10 to 20 years along the north west coast of Western Australia. The extent of the effects and danger will depend on the state of the tide at the expected arrival time of the tsunami. The danger to the coast will be higher at high tide.

Four seismograph stations in Western Australia, ie, Giralia (GIRL), Marble Bar (MBL), Fitzroy Crossing (FITZ) and Kununurra (KNA) and the Northern Territory station at Kakadu (KAKA) are well located to monitor earthquakes in the Sunda Arc. FITZ, GIRL and KAKA are currently inked via satellite to the Australian Seismological Centre (ASC) in Canberra.

CONCLUSIONS

The following conclusions are drawn:

(a) Tsunamis, although infrequent, occur along the coast of Western Australia, particularly the north-west.

(b) With increased industrial development off-shore, the study of tsunamis is more significant.

(c) The most likely source is from large earthquakes in the Sunda Arc region with a frequency of one every 10 to 20 years.

(d) The travel time from the source to coast will vary considerably being both a function of distance but also depth of ocean.

(e) The wave height will vary depending on the rate of shallowing of the sea floor, coastal features such as reefs and the state of the tide.

More detailed studies are required to determine the effects of coastal features and the areas where the shelf width is narrow, to determine vulnerable areas.

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APPENDIX

TSUNAMI REPORTS

1883, August 27 (Bureau of Meteorology, 1929)
The tide at Geraldton rose to eight feet (2.4 m) at 8 pm, and again at 8.30 pm on 29 August. At Carnarvon on 28 August, a succession of tidal waves 3 to 4 feet (0.9 to 1.2 m) high occurred, causing a rise and fall of the tide three times in one and a half hours. On 30 August and the following two days, the tides were still irregular. At Cossack (near Point Samson) an extraordinary tide set in at 4.30 pm on 27 August and rose nearly 5 feet (1.5 m), then ebbed just as rapidly, all in 30 minutes. For some days afterwards, tides were erratic. A similar report was received from Ashburton, except that the tide occurred at midday. Noises were heard at Derby on the morning of 27 August, as if the banks of the Sound, some 3 miles (5 km) away, were falling in. Nothing extraordinary was noticed in the tide, however. Unusual tidal disturbances were reported on the whole of the south-west coast for several days. A sperm whale and a number of porpoises and some large fish were stranded on the beach near Mandurah.

1885, January 5 (Everingham & Tilbury, 1971)
The town was shaken by an earthquake at about 10.25 pm (WST). The intensity of shaking was quite severe, possibly MM IV. Shortly after the shock, the sea subsided three feet (about one metre) in a quarter of an hour, but there was no significant rush of tide; the water rising gradually.

1977, August 29 (Gregson & Others, 1979)
The seismic sea wave generated by this earthquake wreaked havoc on the Indonesian Islands of Sumba, Sumbawa and Lombok. Almost 150 people died or are missing, and losses amounted to one million dollars, including houses, boats and fishing gear. An investigating team reported a maximum wave height of 5.5 m above MSL at Kuta on Lombok Island (ITIC, 1977). The tsunami arrived near low tide, so

that the actual height of the wave above tide level at the time would have been greater.

Fortunately, the effects experienced along the Western Australian coastline were much less severe. As far as is known, the only damage or property loss was by rock fishermen on Barrow Island (see Figure 1). The fishermen were wet by a 4 m high wave at about 1800 WST; some of them lost fishing gear. Three more waves followed, decreasing in size. The report of the largest wave, 6 m high, at about 1750 WST, came from the lighthouse keeper at Cape Leveque. At Point Samson, six to eight 4.6 m high waves were observed at 1745 WST. In Dampier Harbour, four waves 2-2.5 m in height were observed at 1740 WST. No damage occurred, but a tug berthed at the seismic wharf broke mooring lines and a 165,000 tonnes DWT ore carrier at East Intercourse Island ranged 12 m controlled by her tension winches.

Two tide gauges located in Dampier Harbour recorded waves commencing at 1730 WST, with maximum height above sea level of 0.4 m and period between 15 and 34 minutes. Unusual activity was still evident the next day at 1400 WST. At the time of the tsunami, a wave rider buoy was being operated near Legendre Island, 34 km north of Dampier, by Woodside Petroleum Pty Ltd. This gave the earliest recorded wave arrival time of 1659 WST. Two more waves followed in the next 12 minutes. Maximum height was 1.2 m above sea level for the first wave, with a period of 30 seconds. This wave height was regarded as conservative, as the buoy only responds to waves of periods less than one minute, whereas tsunami waves are long-period waves usually in the range 15 minutes to several hours. The wave rider buoy would thus only record any high frequency component in the wave, namely the crest of the wave. The travel time to Legendre Island of 2 hrs 50 mins gives an average velocity of 366 km/h.

Another tsunami report came from Port Hedland where at about 1800 WST, three waves 1 m high were observed from an incoming ship. At 1830 WST, a wave 1.5 m high was reported from another ship anchored 12 km north of the town. At Cable Beach, an exposed westerly-facing ocean beach near Broome, a large wave was reported during the evening causing people to flee from its path. Broome itself is situated in Roebuck Bay, the entrance to which faces south, so protecting the town from the tsunami. A tide gauge in the harbour recorded 12 minute-period waves with maximum amplitude of 2.5 cm commencing at 1742 WST. No unusual waves were reported from Derby. This is not surprising, as the town lies in the lee of Cape Leveque at the end of King Sound. The entrance to the south is shallow and cluttered with small islands, coral reefs and shoals.

Coastal towns south of North West Cape lie in the lee of the Cape; they would only receive diffracted waves with, as a consequence, lesser effects. No tsunami effects could be expected along the south coast of Western Australia. A tide gauge at Geraldton recorded waves commencing at 2120 with periods between 22 and 38 minutes. The maximum wave height was 0.2 m at 2400. No unusual waves were noticed on tide gauge records from Wyndham, Fremantle, Albany or Esperance. Gauges at Port Hedland and Carnarvon were unserviceable. For more detailed information on tsunami effects and tide gauge records see Gregson and Others, 1978.

1994, June 3 (Observations on EPSO Griffin Venture)

0430 hours — The Second Officer in his capacity as the Berthing Superintendent noted a movement of the Offtake Vessel to the port side. Medium tension was maintained on the mooring hawser throughout this movement. The Offtake Vessel then moved back to the neutral position whilst still maintaining hawser tension.

0440 hours The hawser tension increased to an indicated 70 tonnes.

0440 hours The hawser started slackening as the Offtake Vessel moved to the starboard side.

0440.5 hours The Berthing Superintendent ordered the Offtake Vessel to go Dead Slow Astern.

This appeared to have no effect upon the forward movement of the Offtake Vessel, therefore the Berthing Superintendent ordered Slow Astern within a matter of seconds of the previous order.

The Offtake Vessel still continued to drift ahead very fast on the starboard side and was now about in line with the stern of the Griffin Venture.

The Berthing Superintendent radioed the First Officer in the Griffin Venture's Central Control Room and notified him of the situation.

0442 hours The riser angle alarm came up indicating that a riser angle of 14° had been reached or exceeded.

0442 hours The Berthing Superintendent ordered the Offtake Vessel to go Half Astern.

0442.5 hours The Berthing Superintendent order Full Astern. The Offtake Vessel eventually stopped before moving astern. At this time she was estimated to be 3.5 to 4.5 metres from the starboard side of the Griffin Venture with her bow about 15 metres along the Griffin Venture's aft deck.

0443.5 hours
0444.0 hours
0444.5 hours
0446.0 hours
0447.0 hours

As the Offtake Vessel came astern and it was obvious that it was going to clear the Griffin Venture, the order was given to reduce engines to Slow Astern, then Dead Slow Astern. As the bow of the Offtake Vessel cleared the stern of the Griffin Venture, the order was given to Stop Engines. The Offtake Vessel continued to move astern. The order was given for Slow Ahead, then to Full Ahead. As a precaution the First Officer told the Berthing Superintendent to stand clear as the hawser loaded up.

0447 hours The riser alarm came up, indicating that a riser angle of 14° had been reached or exceeded.

0448 hours The Berthing Superintendent observed the chain to jump out of the stopper on the Offtake Vessel. The Offtake Vessel was no longer moored to the Griffin Venture.

0450 hours The drifting Offtake Vessel resulted in the floating hose failing.

Correlations of riser alarms with observed events

Based on the chronology of events, the following comments are made with respect to the Riser Angle Monitoring Systems alarms. Note that no riser angles were recorded, just the alarms.

An explanation for the first alarm could be possibly due to the effect of solitons or solitary waves generated by the recent earthquake in Indonesia. At this stage, the effects of such small amplitude long wave length solitary waves have not been investigated in detail. However, the characteristic of a solitary wave is that it is a wave of translation and never exhibits horizontal particle velocities in the direction opposite to that of wave advance. Thus there is a net displacement of fluid in the direction of wave advance. This may have affected the first order vessel motions, the current loading and possibly the second order vessel response.

Wave particle velocities could have been of the order of 0.1 to 0.3 m^{-1} for around two minutes. These velocities would only have produced drag forces similar in magnitude to the prevailing wind driven currents. A more significant effect appears to be that of the vessels sliding down the wave profile. These solitary waves have very long wave lengths and would result in imperceptible slopes in the still water level. Both vessels would therefore feel a slight acceleration due to the gravitational component acting down the slope. The magnitude of this component appears to be an order of magnitude greater (10 to 15 tf) that due to the drag force. Based on a symmetrical wave profile, a tsunami could displace both vessels significantly but not the extend that agreed with both the observed motions. Observed displacements can be matched if there is a difference in wave profile between the front and rear faces of the wave. Under conditions with a steeper wave front face, vessel displacements over the observed time periods can occur. However, there is no information available at this stage to product the actual profile of the tsunami other than symmetrical solitary wave theory.

The direction from which such a wave would approach the site would have been stern on the moored vessels. This may have caused both vessels to move in the direction of wave propagation. As the Griffin Venture moved forward, its motion would have been opposed by the mooring system and would have reduced its net forward motion compared to that of the Offtake Vessel. The first alarm would have resulted from the Griffin Venture drifting over the mooring riser, with the Offtake Vessel drifting freely towards the stern of the Griffin Venture. Application of astern thrust would have decelerated and then accelerated the Offtake Vessel away from the Griffin Venture, bringing the vessel eventually to a halt and then giving it rearward momentum. By this time the crest of the tsunami would have passed and both vessels would have begun to slide down the back face of the wave. The extended period of astern thrust would have given additional rearward momentum to the Offtake Vessel.

North West Cape (Yardie Creek Caravan Park) (Observer - Chris White)

Unusual wave action was first noticed at 6.15 am. The wave action could not have been too much earlier as 300 live stranded fish were thrown back into the sea by the observer. The wave appears to have swept through a channel in the outer coral reef 750-1000 metres offshore and 300-400 m wide. This channel is offshore from a car park located in the sand hills. Treated pine log barriers (6m above normal high water mark - HWM) around the car park were washed away to heights of 7 m above HWM. Fish were found 300 m from the shore line. One large crayfish found wandering in the sandhills made an excellent evening meal. Along the beach the wave had washed over sand dunes 2.5 m high and stranded 1000's of fish. Rain coral up to 2 m across from the outer reef were dumped on the beach. It would require 10 men to shift them. Four kilometres south, boats left on the beach overnight were not affected. In Exmouth gulf, south of Learmonth, boats left on the beach were overturned.

Onslow (Observer - Steve Lewin)
The observer who lives on the coast was woken up at 5.50 am by what he thought was wind. However on looking out the window there was no wind but he observed swell breaking on the beach. This moved several large boulders. The water receded and a second wave at 6.00 am moved above the high water mark by an estimated 2 to 3 metres. A third swell occurred approximately 10 minutes later with noticeable effect diminishing by 6.20 am. Similar effects were also reported from Four Mile Creek, 6 km from Onslow. A tide gauge, located on Beadon Creek sheltered by groyne, which is monitored every 15 minutes showed a 15 cm rise between 5.45 am and 6.15 am, peaking at 6.00 am.

No Name Bay (N of Onslow) - (David Brennan - Woodside Petroleum)
A report was received from No Name Bay. Workers who have been re-planting vegetation in a mangrove swamp.

"On Friday morning at 6.30 am they had gone to the bay as they expected low tide but found the bay full of water. It receded quickly but then came back 2 or 3 times at 10-15 minute intervals. They left the job for the day as a bad deal".

Exmouth
Waves were observed at 6.00 am moving up to between 3 and 3.5 m above high water mark. The wave sounded like a roar of a train and came through a break in the reef at low tide when reef is nearly exposed. One caravan had to be moved from the beach.

Griffin Venture (Reported by Andrew Brooks - BHP)
The FPSO Griffin Venture is a 100,000 deadweight tonne vessel which is moored about 60 km NW of Onslow. The mooring riser floats vertically in the water and is held in place by six anchor chains. It can therefore tilt in response to the mooring loads applied by the FPSO. At the time of the tsunami the off-take tanker was a 65,000 deadweight tonne vessel moored to the stern of the Griffin Venture by a rigid mooring hawser. A floating hose is used for off-loading oil. 0430 WST.