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Tsunamigenic slope failures: the Pacific Islands 'blind spot'?

Abstract We discuss issues related to a recognised shortcoming in existing tsunami hazard assessments for Pacific Island Countries and Territories (PICTs), that of tsunamigenic slope failures (TSFs). Currently, TSFs are most likely underrepresented as sources in existing tsunami databases for two key reasons. First, relatively low magnitude earthquakes associated with subduction zones are generally assigned as the tsunamigenic source, as opposed to the TSFs they generate. A reassessment of such 'anomalous tsunamis' may yield clues that serve to reassign their tsunamigenic source. Second, there are thousands of oceanic islands and seamounts scattered across the Pacific and flank collapse of volcanic edifices such as these is a largely unquantified tsunamigenic threat. However, while it is now possible to model such TSFs, this is unlikely to happen in the near future because of the lack of detailed bathymetry and landslide mass data. Recent developments in the identification of past tsunamis in the Pacific Islands have developed a unique range of indicators that can be used for identifying such events. These are geological, oral tradition and archaeological components that include, but are not limited to, a modified Darwinian model of atoll formation, coastal megaclasts, oral traditions of vanished islands and giant waves, and the abandonment of prehistoric coastal sites. As such, the most logical way forward is to use the multiple indicators available to us to identify evidence of past tsunamis.

Keywords Tsunamigenic slope failures · Pacific Islands · Flank collapse · Palaeotsunami indicators

Introduction and aims

There is no question that Pacific Island Countries and Territories (PICTs) are susceptible to tsunamis generated by regional and distant seismicity associated with Pacific Ring of Fire (PRF) sources (Australian Government Bureau of Meteorology 2015). In recent years, for example, the Solomon Islands and Samoa were affected by tsunamis in April 2007 and September 2009, respectively, following nearby earthquakes of magnitude M_w 8.1 (McAdoo et al. 2009; Richmond et al. 2011), while the Great Chilean Earthquake of May 1960 (M_w 9.6) caused loss of life and damage in distant Hawaii (Johnston et al. 2012) (Fig. 1). There nonetheless remains a significant limitation in all of the tsunami hazard assessments, probabilistic or otherwise, carried out for PICTs in recent years. The shortcoming is that although recognising other tsunami sources exist, the main focus in the Pacific has, and continues to be, on subduction zone events (e.g. Atwater 1987; Cisternas et al. 2005; Clark et al. 2015; Kelsey et al. 2015; Nanayama et al. 2007; Pinegina and Bourgeois 2001; Suppasri et al. 2012; Thomas and Burbidge 2009). Apart from a minority of notable exceptions (e.g. Moore and Moore 1984; Moore et al. 1994; Keating 1998; Keating and McGuire 2000; McMurtry et al. 2004; Tappin 2010), there has generally been less attention within the tsunami research community given to the potential significance of tsunamigenic slope failure (TSF) sources. Tappin (2010), for

instance, highlights how submarine slope failures may have been underestimated as a tsunami source. In the special context of PICTs, we believe the lack of attention on TSFs is a matter of continuing concern. It may be argued that since landslide (10 %) and volcanic-related events (4 %) represent only 14 % of historic tsunamigenic sources (Gusiakov 2009), there is a far greater need for researchers to focus their attention on subduction zone earthquakes. Yet, a number of ripostes may be brought against this argument, five of which are outlined below.

First, the majority of Pacific Islands are of volcanic origin. Even raised limestone islands and atolls are merely carbonate caps built on top of large submarine volcanic edifices that support them by extending to the oceanic lithosphere beneath. Since there is a suite of recognised volcanic-related tsunamigenic sources including TSFs (Keating and McGuire 2000; Fig. 2), it would be prudent to at least consider in a more systematic manner how important these are across the Pacific region. Second, the occurrence of TSFs may go unrecorded because they often occur in the absence of an associated earthquake, in which case the resultant waves are invariably assigned to unusual meteorological conditions (e.g. Goff 2011). Alternatively, TSFs may simply be ignored, dismissed or relegated as the true source in favour of their associated earthquake, if an earthquake was the trigger responsible for the submarine failure (summarised by Tappin et al. 2008). This is perhaps surprising in the face of growing recognition of the consequences of small earthquakes for slope stability in subaerial environments. Small earthquake effects on the landscape are often most notable in causing *delayed* failures following earlier larger events in which strong ground shaking essentially 'primes' the land by weakening its structural integrity (Goff and Sugawara 2014). It is reasonable to suppose that a similar process operates in submarine settings for TSFs as well.

Third, the source origins of many tsunamis recorded in the early written history of the Pacific can be equivocal (nearly 100 in the South Pacific alone), especially when no significant local earthquake was noted, such as in the Cook Islands tsunami of 7 March 1909 (NOAA 2015). Fourth, many significant local (and possibly regional?) events probably go unnoticed by the scientific community, even if local people in remote islands do indeed notice their occurrence. Fifth, the situation remains that relatively little is known about the recurrence times of large-scale TSFs, which may not be explicitly caused by volcanic or seismic events (Keating and McGuire 2000; Nunn et al. 2006).

Unfortunately, historical tsunami records throughout the Pacific Islands are short and rarely exceed 200 years (Goff et al. 2011a). Nonetheless, within the Pacific basin there are numerous *observed* historical examples of TSFs. Perhaps the most well-known is the July 1998 Papua New Guinea (PNG: Fig. 1) tsunami caused by a submarine landslide generated by a local M_w 7.1 earthquake. This event was especially significant as it did much to increase awareness of the potential for even relatively minor earthquakes to trigger submarine failures that result in destructive tsunamis. On
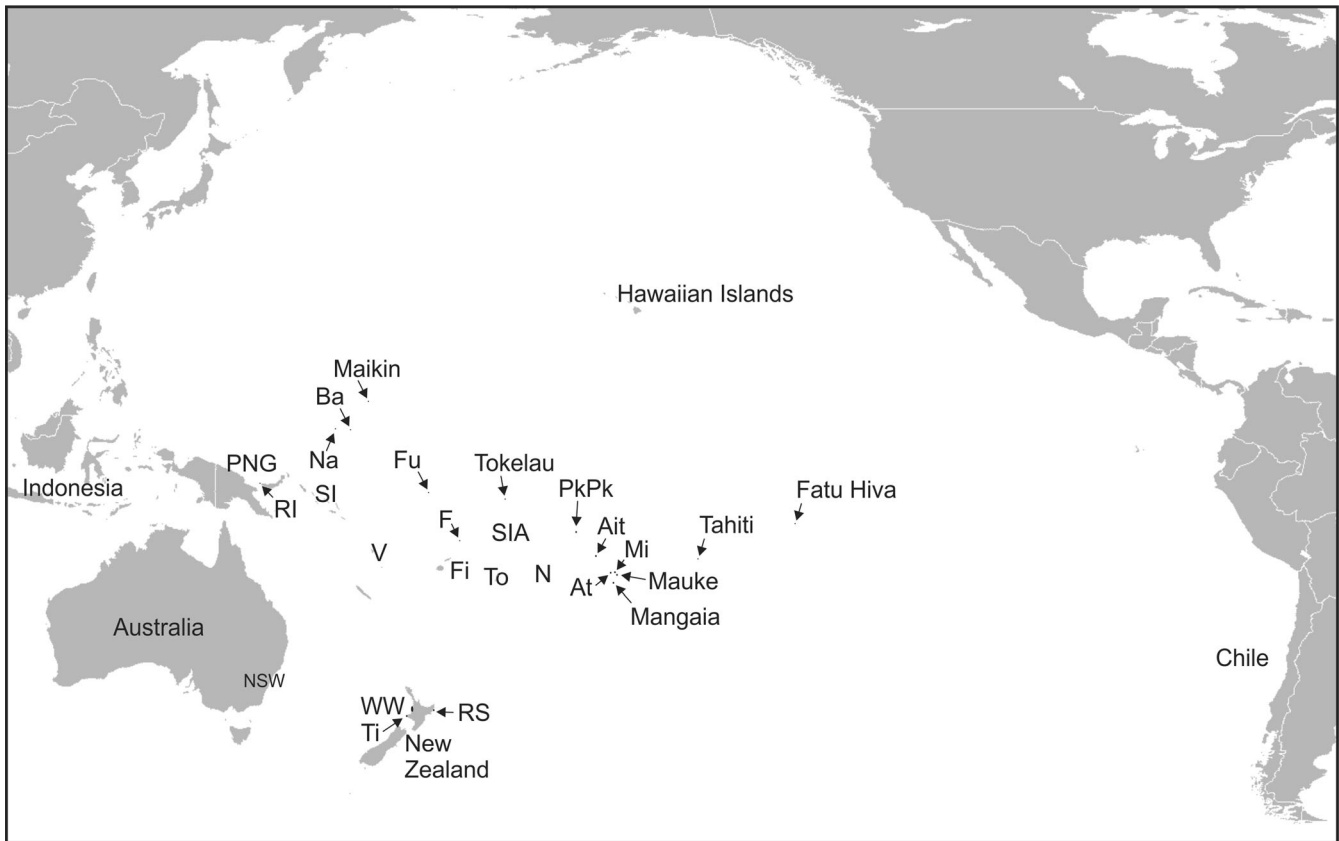
Fig. 1 The Pacific region showing locations mentioned in the text (*Ait* Aitutaki, Cook Islands, *At* Atiu, Cook Islands, *Ba* Banaba Island, Kiribati, *F* Futuna, *Fi* Fiji, *Fu* Funafuti, *Mi* Mitiaro, Cook Islands, *N* Nuie, *Na* Nauru, *NSW* New South Wales, *PkPk* Pukapuka Atoll, Cook Islands, *PNG* Papua New Guinea, *RI* Ritter Island, *RS* Ruatoria Slide, *SI* Solomon Islands, *SIA* Samoan Island Archipelago, *Ti* Tipoka, *To* Tonga, *V* Vanuatu, *WW* West Waikato)

this occasion, the tsunami was up to 15 m high and affected about 20–30 km of coastline along the northern shore of PNG (McSaveney et al. 2000; Tappin et al. 2008). Further into the Pacific basin are additional examples from the Cook Islands (Mangaia: 13 April 2010; Goff 2011), Fiji (Suva: 14 September, 1953; Rahiman et al. 2007), French Polynesia (Fatu Hiva: 13 September 1999; Okal et al. 2002), the Hawaiian Islands (Hawaii: 2 April 1868, 29 November 1975; Goff et al. 2006), and another in PNG (Ritter Island: 13 March 1888; Silver et al. 2005) (Fig. 1).

Yet, in spite of these examples, and largely as a consequence of perceptions created by short historical records, few tsunami hazard assessments have seriously (if at all) considered TSFs (Power 2013; Thomas and Burbidge 2009). Clearly, it is time that this shortcoming should be more openly addressed. In response, the aim of the current paper is to rekindle wider recognition of the potential importance of TSF for PICTs. This is achieved through the objectives of confirming the various possible submarine settings for TSFs and identifying examples of the types of evidence that may indicate past TSF events and associated palaeotsunamis. A comment then follows on the prospects for modelling the characteristics of tsunamis generated by submarine slope failures.

Settings of potential tsunamigenic slope failure

It is already understood that there are many types of submarine slope failures. These have been categorised in a number of ways by comprehensive reviews in the past (e.g. Hampton et al. 1996). A

classification by Mulder and Cochonat (1996) distinguishes between slides, plastic flows, and turbidity currents, the three types being differentiated mainly by 'motion, architecture and shape of failure surface'. For our purposes, a detailed description of the various failure processes is not necessary. More useful in the context of PICTs is to recognise the different physical settings or *landslide territories* (Hampton et al. 1996) that may be especially prone to submarine slope failures. These are listed as follows:

1. Continental shelf slopes (passive plate margins)
2. Ocean trench slopes (convergent plate margins)
3. Frontal slopes of large river deltas
4. Submarine volcanic flanks of oceanic islands and seamounts
5. Volcanic calderas (post-eruption subsidence/collapse)

As explored by Tappin (2010), the question of whether or not these various submarine failure settings are similarly capable of generating tsunamis is another matter. For type 1 above (continental shelves [passive]), examination of the literature reveals several failures with large associated tsunamis, albeit in locations outside the Pacific basin (e.g. ~8000 years BP Storegga, Norway: Long et al. 1989; 1929 Grand Banks, Canada: Tuttle et al. 2004: neither shown on Fig. 1). While potential tsunamis have been modelled for slope failures off Australia's eastern continental margin, there is no confirmed geological evidence (Clarke et al.
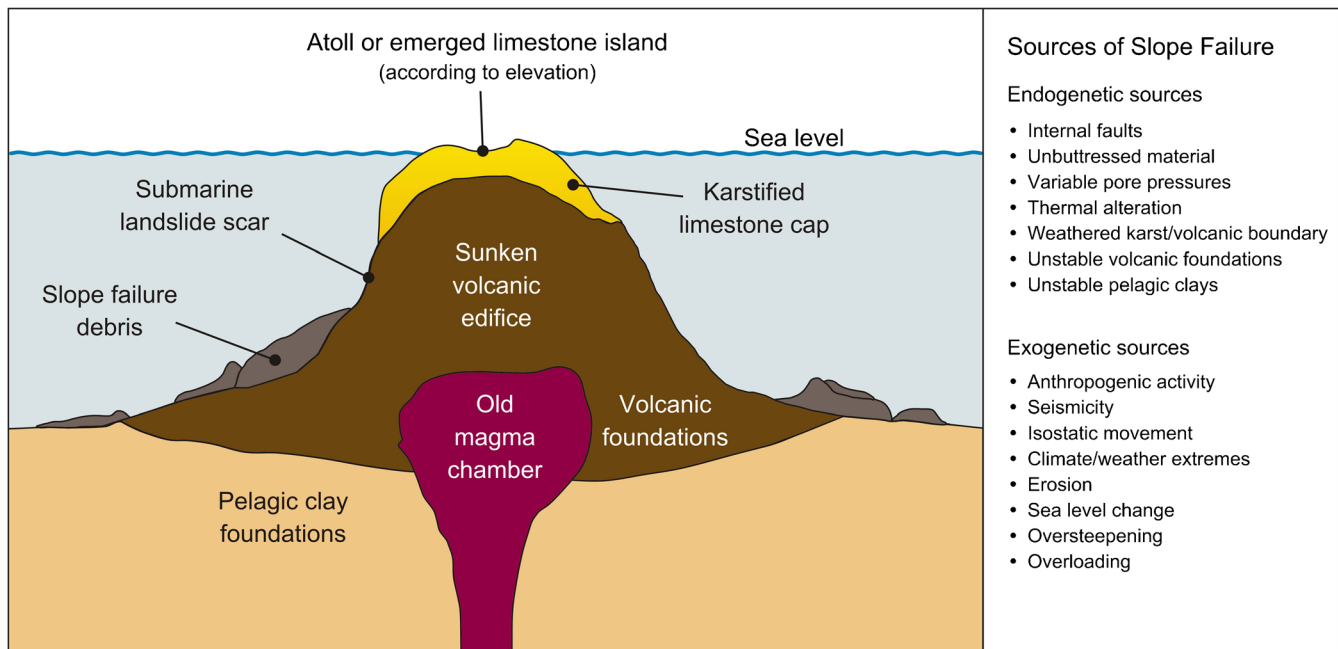
Fig. 2 Volcanic islands and seamounts (with or without a carbonate cap) are vulnerable to collapse for a variety of reasons (*listed right*), so producing submarine slope failures (*as illustrated left*). Adapted from Keating and McGuire (2000)

2014), although it is tempting to link some anomalous historic wave inundations along the New South Wales (NSW: Fig. 1) coast with such events (Goff and Chagué-Goff 2014). There is considerable evidence for slope failures associated with the type 2 setting—ocean trench slopes [convergent]). In the most conventional subduction zone setting of oceanic and continental crust, numerous potential TSFs can be recognised from multiple turbidite records along the Hikurangi margin, New Zealand (Pouderoux et al. 2014). A rare, but undoubtedly important mechanism, are subducting seamounts that appear capable of generating giant TSFs such as the massive 3300 km³ Ruatoria slide along the same margin in New Zealand (Collot et al. 2001) (Fig. 1). Although poorly researched, similar events have undoubtedly occurred on oceanic-oceanic plate convergence such as the potential tsunamigenic processes associated with Vanuatu's convergent plate boundary (Nunn et al. 2006). Numerous vanished islands adjacent to this boundary, and orphan tsunami deposits onland within the archipelago, need urgent and detailed research to determine the relationship between these phenomena (Goff et al. 2008; Nunn et al. 2006). For type 3, the remoteness and central ocean basin locations of many PICTs means that they are unlikely to be affected by tsunamis caused by debris flows on the edge of large continental river deltas. This is in addition to the fact that there actually appears to be little evidence that tsunamis are sourced from active river deltas (Tappin 2010).

Type 4, i.e. flank collapse of oceanic volcanic edifices (with either subaerial, submarine or combined slope failures), is a strong contender for the initiation of tsunamis that might locally be of high magnitude, albeit recurring over long timescales (Keating and McGuire 2000). These failures have also been referred to as lateral failures and sector collapse. Although according to Krastel et al. (2014) 'their tsunamigenic potential is highly disputed', the links between oceanic volcano subsidence, flank failure and potential

tsunamigenesis has been reinvigorated through a recent modification of Darwin's subsidence theory of atoll formation by Terry and Goff (2013), as illustrated in Fig. 3. The modification recognises that atoll shapes are invariably not circular or elliptical as proposed by Darwin but rather they exhibit arcuate 'bight-like' structures (ABLSs) in their plan form that are indicative of large submarine failures (Terry and Goff 2013). The local tsunami of April 2010 that caused erosion on the southern coast of Mangaia (Fig. 1) in the Cook Islands (Goff 2011) is one example of such an event that lends support to the notion of TSF potential on the submarine slopes of isolated islands. The southern coast of Mangaia possesses an ABLS plan form and has experienced at least three locally generated tsunamis over the past 30 years. The nature and extent of these events are indicative of a submarine landslide source (Goff 2011).

Although tsunamis resulting directly from violent volcanic eruptions are not the explicit focus here, it is nevertheless important to acknowledge that large-scale caldera subsidence may be one of the possible contributors to a tsunami induced by volcanic activity (type 5 above). Volcanic caldera formation needs to be considered as it overlaps both eruptive and gravitational processes and may involve up to five tsunamigenic processes (Paris et al. 2014). As an example, it is widely accepted that the devastating tsunami that led to approximately 36,000 fatalities in Indonesia following the eruption of Krakatau volcano in August 1883 was primarily caused by the cataclysmic violence of the explosion (VEI=6). In addition, however, caldera collapse has also been proposed as one of several possible contributors to the tsunami during the Krakatau eruption (Nomanbhoy and Satake 1995). A similar contribution of caldera collapse may reasonably be postulated for the likely tsunami generated by the titanic eruption of Kuwae volcano in Vanuatu (Fig. 4) in the mid-fifteenth century (Goff et al. 2012a; Nunn 2009). Evidence for tsunami inundation
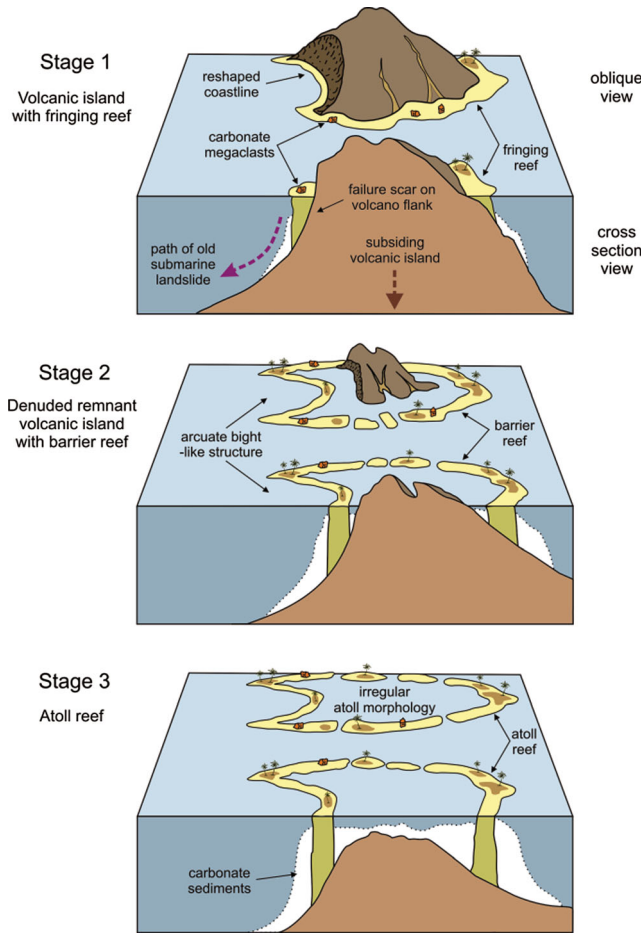
Fig. 3 Modified Darwinian model of the continuum between fringing, barrier and atoll reefs. The modified model can account for both observed irregular morphology of subaerial volcanic islands and/or configuration of subsequent atolls. Major subaerial or submarine landslide scars on the slopes of volcanic edifices, depositional lobes at depth, arcuate bight-like structures (ABLS) in the planform shape of surrounding coral reefs and large carbonate boulders (megaclasts) deposited on reef platforms may all be geomorphic signatures indicative of past failures that possibly resulted in local tsunamis. Note that flank collapse of the volcanic edifice can occur during any stage of the model, but has been shown here during stage 1 for simplicity. Adapted from Terry and Goff (2013)

includes contemporaneous deposits of carbonised tree trunks, pumice and coarse sediments rising up to at least 30 m asl on adjacent islands and as far away as the Wallis and Futuna archipelago 1500 km ENE of Kuwae (Goff et al. 2008). Even in the absence of large-scale volcanic caldera collapse, other mass movements triggered by volcanic activity, either on subaerial slopes or in the hydroexplosive zone (0–500-m water depth) may also play a part in local tsunami generation (e.g. Della Seta et al. 2012).

In summary, the most important settings of relevance to Pacific Islands would appear to be types 2 (ocean trench slope) and 4 (submarine volcanic flanks of oceanic islands and seamounts), although probably the most catastrophic but less common would be type 5 (volcanic calderas).

Evidence indicating possible tsunamigenic slope failures

In attempting to identify any potential palaeotsunamis in specific areas of investigation, there is a range of indicators that can be used (e.g. Chagué-Goff et al. 2011). While these have proven to be invaluable worldwide, the search for evidence of TSFs in the Pacific Islands requires researchers to focus carefully on a unique subset of the indicators available to them (Table 1). This is necessary because, unlike circum-Pacific Ocean countries and others worldwide, there is generally an absence of a proximal subduction zone, and this therefore puts the emphasis on attempting to identify local and regional endogenic tsunami sources. Of particular interest is that the different types of evidence listed are seen to fall into three categories that are very disparate in nature, i.e. geological evidence, oral tradition and archaeological evidence.

Geologically, unlike continental landmasses, PICTs possess 360° of coastline, no continental shelf, and usually an abundance of coarse clastic reefal and/or volcanic material. Not surprisingly, these somewhat unique traits provide the opportunity for the preservation of extraordinary *megaclast* deposits (see Terry and Goff 2014; Fig. 5) coupled with geomorphological expressions of erosion and deposition associated with TSFs. In the absence of finer sediment indicators (e.g. geochemistry and microfossils) that are often preferred, it is these associated geological indicators that guide the search for evidence of past tsunamis and likely future risk.

Prior to European colonisation of PICTs, generally in the eighteenth and nineteenth centuries, information was passed on in Pacific Islands' cultures through oral transmission. Any attempt to interpret the meaning of *euhemeristic myths* (Nunn 2014) without the benefit of indigenous environmental knowledge is entirely inappropriate, not least because there is so much to be learnt from engaging with local people. That being said, in general terms, there are two main themes relevant in the current context of TSFs that seem to prevail: that of giant waves and vanished islands. An oral recording of both such events would have likely been made at the time and passed on down the generations. Unfortunately, early European missionary practices in particular saw widespread loss of language, culture and identity, and by association, the oral traditions that probably represented hundreds of years' worth of information. Bear in mind, though, that these oral folklore indicators cannot extend further back in time than the first human arrival in the Pacific Islands, which for Polynesia for example varies from around 3500 years ago in the west to as recent as AD 1300 in the south (Kirch 2010; Mulrooney et al. 2011). The value and benefit of oral transmissions to palaeotsunami research vary immensely from island to island, but they can prove invaluable when identified and interpreted with the aid of relevant indigenous communities (e.g. McFadgen and Goff 2007).

An associated indicator, but one that is markedly different, is the archaeological component of human occupation of the Pacific Islands. In both prehistorical and contemporaneous times, the human response to catastrophic wave inundation appears to be the same, albeit with present-day populations cushioned by the benefits of international aid and assistance. People die, coastal settlements are often abandoned (although rarely permanently) and there is widespread social disruption (e.g. Goff and Nunn 2015; Goff et al. 2012b). Where permanent abandonment has been noted, this is generally seen as an adaptive strategy to repeated coastal inundations. Whether strategic abandonment is a response to repeated tsunamis or other types of high energy marine inundation (HEMI) events such as tropical cyclones is often unclear, but when considered alongside other indicators for tsunami
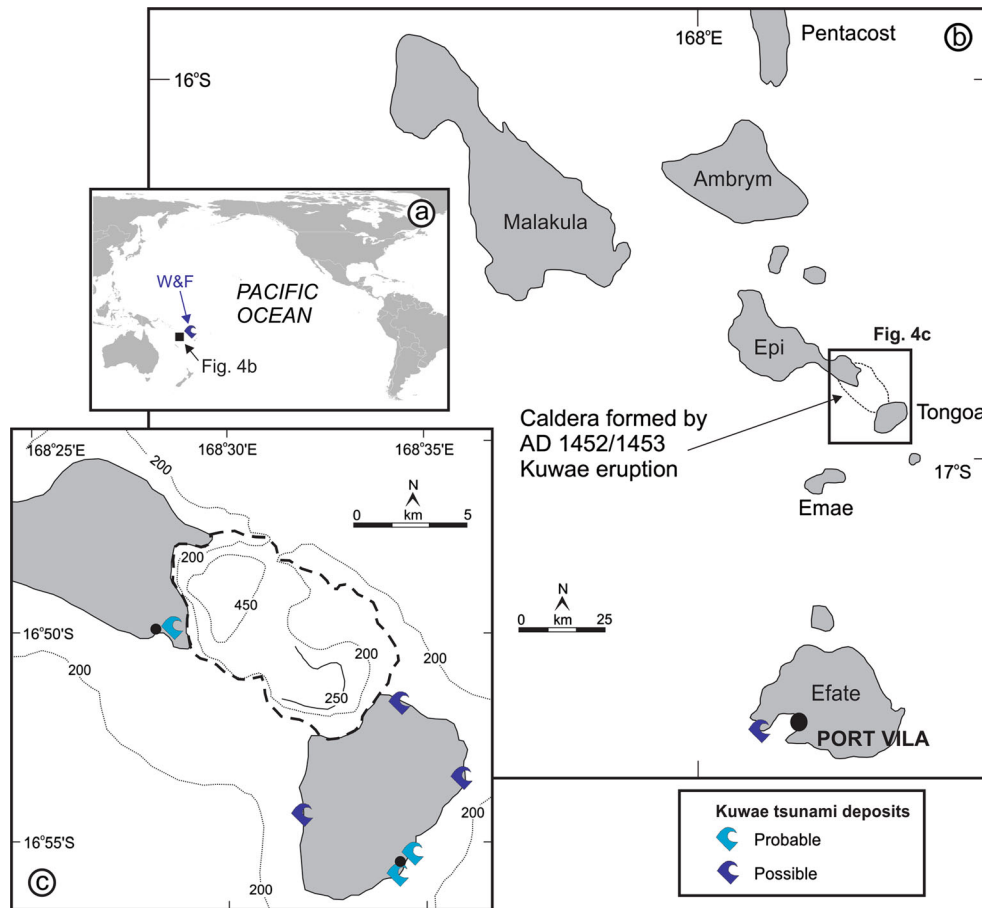
Fig. 4 Vanuatu: **a** location in the Pacific Ocean, **b** detail of central Vanuatu Islands, **c** location of Kuwae caldera (after Robin et al. 1994), showing bathymetric contours in metres below sea level. Possible and probable Kuwae tsunami deposit locations are shown (after Goff et al. 2008, 2011a, 2011b). *W&F* Wallis and Futuna archipelago, 1500 km ENE of the Kuwae caldera

inundation, such archaeological observations can become an invaluable guide to the identification of high-risk locations.

Modelling tsunamis from submarine landslides

According to McMurtry et al. (2004), 'landslide tsunami simulations have advanced to the point where the tsunamigenic potential of giant submarine landslides can be affirmed'. This is a significant assertion as it paves the way for modelling studies to tackle the complex task of investigating the form of predictive relationships between TSF volume-depth-speed characteristics and the potential size of resulting tsunamis. Didenkulova et al. (2011) modelled tsunami generation by landslides for shallow water conditions without bottom reflectance and found that tsunami wave amplitude generally varies nonmonotonically with distance. They also determined that it is possible to determine the explicit formula for wave amplitude if the landslide is moving in a fully resonant regime. Although valuable for shallow seas, such findings may have less relevance for PICTs in mid-Pacific deep water locations where volcanic edifices extend several kilometres to the sea bed.

In a recent, albeit brief, review of tsunami–landslide modelling, Heidarzadeh et al. (2014) conclude that 'The most accurate models for landslide tsunami modelling are likely those which are nonlinear, dispersive and coupled. However, application of such sophisticated and computationally-costly models is reasonable only if enough information about seafloor bathymetry and sliding mass is available'. Yet, it is precisely the bathymetry and landslide mass data that will probably prove most challenging to obtain until the flanks and foundations of the majority of Pacific Islands have been comprehensively mapped and interpreted. While there are rare examples where such work has been attempted (e.g. Suva, Fiji: Rahiman et al. 2007), it is probably fair to admit that we still remain decades away from this ambition.

Discussion

Whilst there are still numerous historical documents and datasets that need to be thoroughly investigated, the features listed in Table 1 show that there are various potential indicators of previously unrecorded TSFs and that to truly grasp their significance in the Pacific basin, extensive geological, archaeological and anthropological research is also required.

As a first pass, coarse resolution, assessment of Pacific Islands there are several datasets such as Google Earth, GEBCO bathymetry and the EarthRef seamount catalogue that can be used to identify possible features that may indicate past collapse or likely

Table 1 Examples of the range of possible indicators of previous unrecorded tsunamigenic slope failures in the Pacific Islands

	Indicator of tsunamigenic slope failure: unrecorded event	Example location (Fig. 1)	References
Geological	'Stellate shape' of oceanic volcanoes	Big Island: Hawaii	Holcomb and Searle (1991)
	Arcuate Bight-Like Structures (ABLS) in atoll plan morphology	Funafuti: Tuvalu Mangaia and Pukapuka: Cook Islands	Terry and Goff (2013) Goff (2011)
	Bathymetric imagery of failure scars and canyons on submarine flanks of island edifices, i.e. landslide erosional features	Banaba: Kiribati Nauru Niue	Krüger (2008) Krüger and Pohler (2014)
	Bathymetric imagery of lobes, i.e. landslide depositional features	Tahiti: French Polynesia Big Island: Hawaii	Hildenbrand et al. (2006) McMurtry et al. (2004)
	Coastal megaclasts	Tongatapu: Tonga Futuna: Wallis and Futuna	Frohlich et al. (2009) Goff et al. (2011a)
	High elevation coastal boulders	Mauke, Mitiaro, Atiu: Cook Islands	Stoddart et al. (1990)
	Lack of other realistic sources of known tsunamis	Mangaia: Cook Islands West Waikato: New Zealand	Goff (2011) Goff and Chagué-Goff (2015)
Oral tradition	Oral traditions of giant waves without accompanying ground shaking	Maikin: Kiribati Tipoka: New Zealand	Nunn (2014) Goff and Chagué-Goff (2015)
	Oral traditions, myths and legends of vanished islands	Vanuatu New Zealand	Nunn (2009) Nunn et al. (2006) King et al. (2007)
Archaeology	Local depopulation, social disruption, and/or unoccupied coastal areas (adaptive strategy?)	Aitutaki, Pukapuka, Mangaia: Cook Islands Futuna: Wallis and Futuna	Goff and Nunn (2015) Goff et al. (2011a, 2011b)

These indicators act as both potential evidence of past events and pointers towards locations where future risk may lie

Fig. 5 Large reef-derived coral megaclasts, such as Rebua Rock (pictured) on remote Makin Atoll in the Gilbert Islands group of Kiribati in the central Pacific, stand out conspicuously on the coastline of low-lying atoll islands where land barely reaches 3 m asl. Local legends tell the story of how the boulders were cast up by a series of giant waves in ancient times. A tsunamigenic landslide source for such waves seems likely since **a** the near-equatorial latitude (3° N) puts the atoll outside the tropical cyclone belt and **b** the legends do not mention ground shaking that might otherwise suggest a seismic source for the giant waves. Photo courtesy of Emili Artack, SOPAC (Pacific Islands Applied GeoScience Commission, Suva)

structures/features that have not collapsed but may pose a future threat. Such datasets may prove useful in helping identify priority sites for more detailed studies. In other words, multidisciplinary approaches are needed in order to build upon our current state of knowledge. As high-magnitude tsunamis have low historical frequencies, palaeotsunami studies will also prove crucial. Two examples of recent work from the Pacific Islands indicate how analysis of palaeotsunamis can provide a rich source of information.

In Tonga (Fig. 1), seven giant coral limestone blocks up to 1600t are found 10–20 m asl and 100–400 m inland on Tongatapu island (Frohlich et al. 2009). These megaclasts were laid down either sometime during the last interglacial sea-level highstand, ca. 120–130 ka or within the past 7 ka. Based upon model simulations, there were most probably deposited by a tsunami generated by either volcanic flank collapse along the Tofua arc 30–40 km to the southwest, or by undersea landslides on the submarine slopes of Tongatapu island itself. A principal finding was that comparatively small submarine slope failures (i.e. <1 km³) can produce locally large tsunamis. In the Samoan Islands archipelago (Fig. 1), the easternmost inhabited island of Ta'u exhibits a series of down-faulted benches on its southern flank, considered to be the remnant of a huge collapse approaching 30 km³ in volume. While the dating of this event is problematic (it probably dates to around 22.4±1.8 ka), a collapse of this proportion would likely have generated a locally catastrophic tsunami, with possible impacts also experienced at the regional level, including the following: up to ~20 m for the area around the villages of Ta'u; 10–15 m waves offshore of Tutuila island 104 km west; >5 m at Upolu island some 200 km west; and 1–2 m at Niue 500 km south, Pukapuka atoll (Cook Islands) 500 km northeast, the Tokelau atolls >500 km north, and Tafahi and Niuatoputapu islands in Tonga 480 km southwest (Williams et al. 2012, 2014) (Fig. 1).

Conclusions

In summary, the following key concepts should be emphasised:

- Subduction-zone seismicity is known to trigger submarine slope failures. Some of these failures are tsunamigenic. Even earthquakes of lower magnitude, traditionally deemed non-hazardous, are potentially dangerous for this reason.
- This calls into question the real source of some recorded tsunamis that were supposedly earthquake-generated, because the associated failure may have contributed wholly or in a major part to tsunamigenesis. Deeper analysis of so-called anomalous tsunamis, where inconsistencies are observed between tsunami characteristics and corresponding earthquake magnitude (Tappin 2010), may yield clues that lead to better understanding of TSFs.
- Flank collapse of volcanic edifices is an indisputable but largely unquantified threat for tsunamigenesis in the Pacific Islands, and therefore deserves greater attention. The thousands of oceanic islands and seamounts scattered across the Pacific are all potential sources of TSFs. This includes those volcanic islands without stellate shape and atolls/limestone islands without arcuate bight-like

structures, which are features indicating palaeo-collapse. Thus, it is unwise to be complacent and assume stability will prevail simply because the detailed submarine geomorphology of many Pacific Islands remains unmapped. Over time, the gradual increase in bathymetric information that becomes available for oceanic volcanoes will hopefully redress the situation.
- A unique range of possible lines of evidence exists (geological, traditional oral history and archaeological) that can help identify unrecorded TSF events. The disparate nature of indicators should be considered an advantage, as this allows multidisciplinary approaches to complement one another towards the goal of improving future tsunami risk assessments for the Pacific Islands.

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