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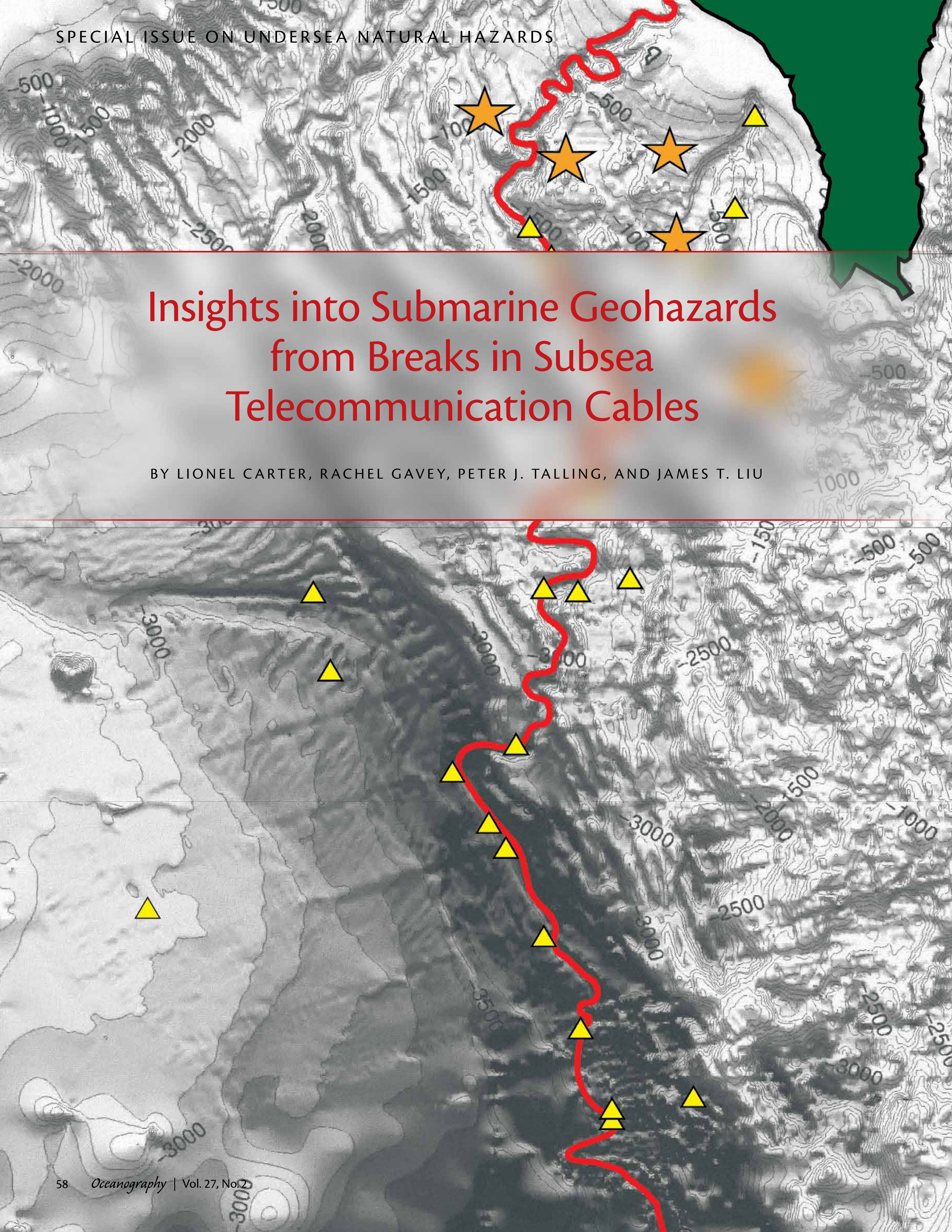

Insights into Submarine Geohazards from Breaks in Subsea Telecommunication Cables

BY LIONEL CARTER, RACHEL GAVEY, PETER J. TALLING, AND JAMES T. LIU

ABSTRACT. The original discovery of active submarine landslides and turbidity currents in the deep ocean was made in the 1950s through analysis of breaks in transoceanic communications cables. Further insights regarding the causes, frequency, and behavior of damaging submarine flows are presented here, based on recent disruptions of modern communications cables in the Strait of Luzon off southern Taiwan. In 2006, the Pingtung earthquake triggered landslides and at least three sediment density flows (a general term covering turbidity currents and similar flows). These flows sped down submarine canyons and into the Manila Trench at 12.7–5.6 m s^{-1} (45–20 km h^{-1}), resulting in 22 cable breaks. In 2009, the cables were again damaged, this time by extreme river discharge associated with Typhoon Morakot. Two cables were damaged during the main flood when debris-charged river waters dived to the seabed and down Gaoping Canyon. A second, more damaging sediment density flow formed three days later when river levels were near normal and seismic activity was low. It is suggested that this second flow resulted from deposited flood sediment that was remobilized possibly by internal wave activity. Further breaks were reported in 2010 and 2012. While historical cable break databases are incomplete, they imply that since at least 1989, density flows capable of breaking cables have been infrequent, but they increased markedly after the 2006 Pingtung earthquake—a time that coincided with a transition to more extreme rainfall associated with northward migration of typhoon tracks to Taiwan.

INTRODUCTION

Since the laying of the first submarine communication cables, this technology has served as a detector of natural hazards in the ocean. In 1883, the submarine telegraphic link that had kept the world enthralled with the volcanic activity of Krakatau (Krakatoa) in the Dutch East Indies (now Indonesia) suddenly broke in the Sunda Strait under a cataclysmic tsunami that formed during the dying phase of the eruption (Winchester, 2003). The Victorian forerunner of the Internet had temporarily succumbed to a major geohazard. By the late nineteenth century, records of externally caused breaks in submarine telegraphic cables were appearing in the science literature. Benest (1899) noted frequent repairs of cables crossing submarine canyons off Peru and Cape Verde, West Africa. Subsequent repair reports hinted at the causes of the breaks: for example, cables were freshly buried beneath sediment, sand and gravel were found in submarine canyons, steel-wire cable armor was freshly abraded, and breaks were concomitant with river floods. However, the knowledge of the times prevented attribution of the breaks to the downslope displacement of seabed sediment. Likewise, Milne (1897) alluded to three cable breaks that followed an earthquake off the Grand Banks, Newfoundland, in 1884, again without recognition of the precise cause.

The breakthrough came with the classic study of another Grand Banks earthquake, the 1929 magnitude (M_W) = 7.2 event (Heezen and Ewing, 1952). Twelve cables broke about the same time as the main seismic shock, followed an hour later by sequential breaking of 11 more cables in water depths from 3,900 m to 5,270 m. That study and subsequent seabed surveys, for example, Piper et al. (1985, 1999), showed the cable breaks concomitant with the main shock resulted from widespread submarine landslides dominated by shallow slumps. Some of this displaced sediment transformed into more fluid and mobile debris flows and a large turbidity current that sped downslope at an initial speed of 19 m s^{-1}, slowing to 3 m s^{-1} on the near-flat Sohm Abyssal Plain. Approximately 175 km^3 of sandy sediment were redeposited by the turbidity current (Piper and Aksu, 1987).

Since the Grand Banks event, cable breaks have continued to advance our knowledge of underwater geohazards (e.g., Heezen and Ewing, 1955; Houtz and Wellman, 1962; Krause et al., 1970; Dengler et al., 1984; Cattaneo et al., 2012). Over that time, the global subsea network has evolved from one dominated by telegraphic cables (ca. 1850 to 1950), then by telephonic cables (ca. 1950 to 1986), and now by fiber-optic cables (Figure 1; Box 1). This paper reports on a succession of cable-damaging events that disrupted a key part of the modern fiber-optic network off southernmost Taiwan (Hsu et al., 2008; Carter et al., 2012; Gavey, 2012; Su et al., 2012; Talling et al., 2013). Information from this network provides further insights into the triggers, frequency, and behavior of sediment density flows, a general term applied here to cover various forms of sediment-laden currents, including hyperpycnal flows, debris flows, and turbidity currents, whose movements are controlled by the density of the sediment contained in their waters (for a more detailed description of these flows, see Talling et al., 2013).

FIBER-OPTIC CABLE BREAKS

Cable break is a generic term applied here to encompass any damage caused by external forces. For fiber-optic systems, the term break covers effects that alter a cable's performance, ranging

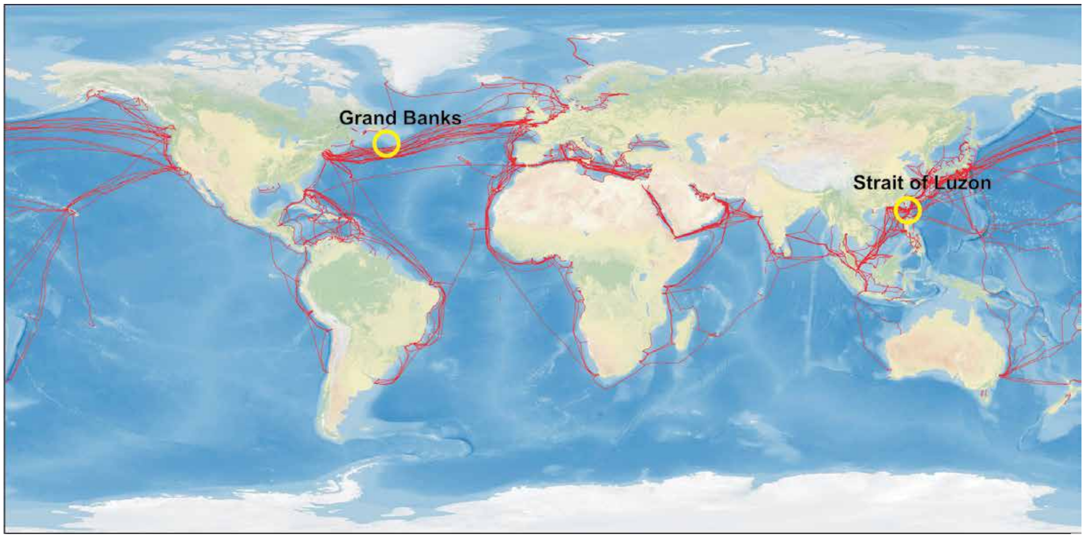

Figure 1. The global network of submarine fiber-optic telecommunications cables (red lines), most of which are owned/operated by private consortia. General localities of the 1929 Grand Banks, Newfoundland, and 2006 Pingtung, Taiwan, earthquakes and subsequent cable breaks outlined by yellow circles. *Chart courtesy of Global Marine Systems Ltd.*

from damage to optical glass fibers and/or copper power conductors under excessive stretching or bending to complete physical separation of the cable. Such effects are recorded immediately at a Network Operation Center. Break locations are subsequently determined from various electrical and optical tests carried out from land-based terminal stations (Ford-Ramsden and Burnett, 2013). Information on the break time and location allows calculation of sediment flow velocity (speed and direction), especially when multiple cables are damaged. In the case of a single break, the speed of the flow may be estimated if the flow source is known or assumed (e.g., an earthquake epicenter).

Around 150 to 200 fiber-optic cable breaks are recorded each year (Burnett et al., 2013). Between 65% and 75% occur in water depths of < 200 m and result mainly from fishing and shipping activities (Kordahi and Shapiro, 2004). In contrast, breaks attributed to geohazards comprise < 10% of the world average. However, seaward of the busy continental shelf and upper continental slope, geohazards account for at least one-third of breaks.

The recording of cable breaks on a universal, open-file database is precluded because the network (Figure 1) has many owners and operators, with most cable systems owned either individually by private cable companies or by consortia. There are also commercial and security considerations. Several major submarine cable system and service companies maintain private global databases. This paper is based on (1) protected and aggregated data supplied by Global Marine Systems Limited (UK) on a nondisclosure basis, and (2) published information from Hsu et al. (2008) and Carter et al. (2012).

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TAIWAN: A NATURAL LABORATORY

Taiwan is well suited for research by virtue of its dynamic setting. The island is located in the deformational zone between the convergent Philippine Sea and Eurasian tectonic plates. Thus, the island and surrounding seabed are exposed to frequent earthquakes that are potential triggers for sediment density flows; for example, between 1900 and 2010, 76 property-damaging earthquakes of M_L = > 6 were recorded (CWB, 2014; Ramsey et al., 2006; Wang and Shin, 1998; M_L is the local magnitude scale). Taiwan also experiences about four typhoons each year plus monsoonal rains. This mix of vigorous weather systems and high seismicity has resulted in extreme erosion. The average rate of erosion in the catchments of Taiwan's 16 largest rivers is ~ 10,000 t km^{-2} yr^{-1}, which is about 50 times greater than the global average (Kao and Milliman, 2008). Rivers carry large amounts of sediment that commonly exceed a threshold of > 40 kg m^{-3}, making the river water so dense with sediment that upon reaching the ocean, it sinks and travels over the seabed as a hyperpycnal flow (Mulder et al., 2003). Thus, rivers provide ample sediment to fuel density flows via (1) hyperpycnal flows with the potential to transform into turbidity currents (e.g., Liu et al., 2013), and (2) contributions to offshore sediment deposits that are prone to remobilization by earthquakes, storms, or some other perturbation or trigger (e.g., Su et al., 2012).

This paper focuses on the Strait of Luzon between Taiwan and the Philippines (Figure 2). A prominent seabed feature is a large drainage complex dominated by Gaoping Canyon plus several re-entrants, including Fangliao Canyon. This complex extends across the Taiwan continental shelf and slope to feed a submarine fan that extends from 2,600 m to ~ 3,000 m depth (Yu et al., 2009). From there, the canyon merges with a channel developed in the Manila Trench that descends gradually southeastward from 3,400 m to over 4,000 m depth.

The head of Gaoping Canyon is < 1 km from the mouth of the Gaoping River. Fangliao Canyon also incises the shelf but resides 10 km offshore and has no clear connection to several small rivers nearby (Hale et al., 2012). The Gaoping River is the region's dominant sediment source, with an average discharge of about 20 million tonnes per year (Mt yr^{-1}), most of which enters Gaoping Canyon (Huh et al., 2009). Thus, it is not surprising that the Gaoping and associated canyons receive sediment density flows that travel from the continental shelf and slope to abyssal ocean depths (Hsu et al., 2008; Carter et al., 2012; Su et al., 2012). This active canyon-trench system is also crossed by at least 17 fiber-optic telecommunications cables that connect Southeast Asia with the rest of the world, and that also act as de facto monitors of density flow activity.

The first major sediment density flow event considered here is associated with the M_L = 7.0 Pingtung earthquake of December 26, 2006 (Figure 3a). The main shock and aftershocks had epicenters near Fangliao Canyon and were accompanied by strong ground accelerations of ≥ ~ 80–250 cm s^{-2} (CWB, 2014). Such motions are a key mechanism for mobilizing sediment. Not only do accelerations depend upon earthquake magnitude but also upon the epicenter depth and the geology of the substrate. The Pingtung main shock was accompanied by three near-instantaneous cable breaks in Fangliao Canyon, whose margins were disrupted by landslides (Hsu et al., 2008; Su et al., 2012). At least three sediment density flows followed the landslides at various times and passed downslope to cause another 19 cable breaks. Most breaks occurred sequentially over a period of about nine hours as the main flow traveled at least 246 km from mid Gaoping Canyon into the Manila Trench at > 4,000 m depth (Figure 4). Times and distances between breaks indicate average flow speeds of 12.7 m s^{-1} along the mid-canyon (only one measurement), 6.0 m s^{-1} in the lower canyon, and 5.6 m s^{-1} in the Manila Trench (Gavey, 2012). However, the timing and location of some breaks suggest the presence of multiple flows and source areas within and outside the canyon/trench. One or two cable breaks, for example, occurred in a channel leading from the South China margin, suggesting an additional density flow may have entered the Manila Trench from the northwest (Figure 3a).

From August 7 to 9, 2009, another disturbance affected the Strait of Luzon.

BOX 1. GLOBAL FIBER-OPTIC CABLE NETWORK

Research into submarine geohazards is aiding efforts to better protect the global fiber-optic cable network, especially around the earthquake-prone Pacific Ocean rim (Figure 1). Such efforts have taken on some urgency in light of the increasing economic, societal, and strategic importance of the cable network (Carter et al., 2009; Burnett et al., 2013). Contrary to the perception that international communications are conducted via satellite, over 95% of those communications are transmitted by submarine fiber-optic cables by virtue of their ability to transmit high volumes of data and communications traffic in a rapid, economic, and secure manner. The importance of the submarine network was highlighted by the aftermath of the 2006 Pingtung earthquake. Connections between Southeast Asia and rest of the world were temporarily severed, resulting in a marked drop in Internet and communications traffic. For instance, the largest Internet service providers in China reported a 90% loss in traffic to the United States and Europe (Qiu, 2011). While some connections were quickly restored by re-routing electronic traffic through undamaged cables, the disrupted network nevertheless reduced Internet speed and accessibility for 49 days while 11 cable ships undertook repairs in the Strait of Luzon. However, subsequent improvements in technology and operations have reduced the delays that accompany major cable disruptions, as in the case of the 2011 Tōhoku-Oki earthquake off Japan.

Typhoon Morakot stalled over southern Taiwan and delivered a record-breaking rainfall of over 3,000 mm in four days (Chien and Kuo, 2011). Water discharged by the Gaoping River was a regional record of 27,447 $m^3\ s^{-1}$ (Figure 5). An estimated 150 Mt of river sediment were discharged, most presumably entering Gaoping Canyon together with sediment swept in from the adjacent continental shelf by storm waves and currents (Liu et al., 2006; Huh et al., 2009). Fangliao Canyon also received detritus from nearby rivers and the continental shelf, as manifested by a 3–12 cm thick sediment layer detected in a post-Morakot survey (Hale et al., 2012). Sediment concentrations within river floodwaters reached a measured peak of 60 kg m^{-3}, well above the 40 kg m^{-3} threshold for hyperpycnal generation. As a result, a hyperpycnal flow formed and passed down Gaoping Canyon (Flow 1 in Figure 3b; Kao et al., 2010). Flow 1 failed to break the first cable it encountered, but damaged two cables further downslope in water depths to ~ 3,200 m (Figure 4). Cables deeper than 3,200 m were not damaged even though Flow 1 extended into deeper water as evinced by a turbid, low-salinity layer at 3,700 m depth (Kao et al., 2010). Three days later, another more damaging sediment density flow (Flow 2; Figures 3b and 5) traveled down lower Gaoping Canyon/Manila Trench. At least six cables broke along a 157 km long path with the final cable break occurring at > 4,000 m depth (Figure 4). The source of Flow 2 is unclear; it may have originated in either Gaoping or Fangliao Canyon. The former is possible because of its proximity to the Gaoping River, by far the largest local sediment source (Hale et al., 2012). Most of the flood discharge probably entered the upper canyon (e.g., Huh et al., 2009) where it may have formed a quasi-stable deposit. Carter et al. (2012) speculate that such a deposit was remobilized and passed down-canyon as Flow 2—a phenomenon that has been recorded for other storms affecting the canyon (Liu et al., 2006, 2009). Seismic triggering of Flow 2 is unlikely as Typhoon Morakot occurred when earthquake magnitudes and ground accelerations were low (≤ M_L 2.0 and 0.8–2.5 $cm^2\ s^{-1}$, respectively; CWB, 2014). Similarly, wave heights had reduced by the time of this second flow (Figure 12d in Talling et al., 2013). This suggests another trigger for Flow 2—possibly turbulence caused by internal and/or surface waves known to occur within in the canyon confines (e.g., Lee et al., 2009). Flow 2 was not recorded in the upper to middle Gaoping Canyon because cables there were previously damaged by Flow 1. Nearby Fangliao Canyon is also a potential source of Flow 2. Due to its proximity to the Pingtung 2006 epicenters, Fangliao Canyon was disrupted by landslides that may have transformed into sediment density flows, judging by several cable breaks just below the junction of Fangliao and Gaoping Canyons (Figure 3b; Hsu et al., 2009; Gavey, 2012;

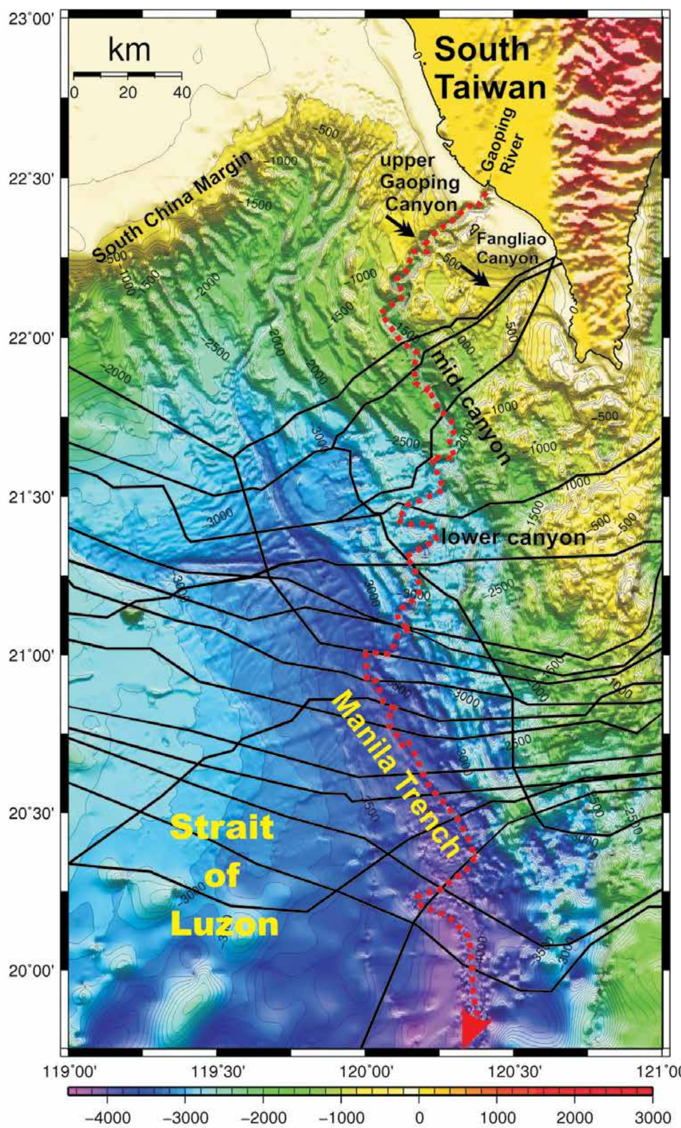

Figure 2. The seabed in the Strait of Luzon with general locations of submarine fiber-optic cables (black lines) over the upper, middle, and lower reaches of Gaoping Canyon and the Manila Trench (red dotted line traces catchment axis). Seabed depths and land elevations are color-coded to the meter scale. *Bathymetry courtesy of C.S. Liu, National Taiwan University*

Su et al., 2012). Fangliao also contained deposits from Typhoon Morakot (Hale et al., 2012) and probably some landslide debris from Pingtung 2006 (Su et al., 2012). Those deposits were potentially prone to destabilization, possibly aided by discharge of submarine groundwater during the intense Morakot rainfall, as suggested by Su et al. (2012), or by internal wave loading of the seabed (Lee et al., 2009).

INSIGHTS FROM THE STRAIT OF LUZON

Multiple Sediment Density Flows Form During an Earthquake

The 2006 Pingtung earthquake was initially accompanied by the near-instantaneous breakage of cables in Fangliao Canyon (Figure 3a). This is similar to the timing of breaks near the epicenter of the 1929 Grand Banks earthquake (Heezen and Ewing, 1952). In both cases, the cause appears to be submarine landslides. However, in contrast to the transformation of Grand Banks landslides into debris flows and a large turbidity current (Piper et al., 1999), the 2006 Pingtung event comprised at least three distinct sediment density flows (Figure 3a)—one following the main shock (M_L = 7.0) and two others following aftershocks (M_L = 5.1 and 5.5; Gavey, 2012). It is plausible that the main shock not only triggered a sediment density flow but also conditioned the seabed for failure under the weaker aftershocks.

Speeds of Sediment Density Flows

Speed depends primarily on seabed gradient, flow density, flow thickness, friction, and water entrainment at the flow margins. At high sediment concentrations, viscosity of the sediment/water mixture also plays a role. Although we have information on the seabed slope and can estimate the frictional constants, the other parameters are poorly constrained or unknown. For example, a thin but dense flow may travel at the same speed as a more dilute but thicker flow. Thus, it is not feasible to use flow speed and seafloor gradients alone to calculate sediment concentrations and hence flow density, for instance, by using a Chezy-equation type approach (see detailed analysis in Table 3 and pp. 278–280 of Talling et al., 2013).

Nevertheless, our speed data offer some insight into flow dynamics with respect to the process of ignition whereby the flow becomes denser and accelerates due to erosion and incorporation of seabed sediment (Parker, 1982). From a broad perspective, speeds along the middle to lower Gaoping Canyon and the Manila Trench exhibit a general downslope deceleration that is inconsistent with ignition but consistent with reducing slope gradient, increasing distance from source or runout, and widening of the flow path (e.g., Yu et al., 2009). However, localized accelerations are apparent in the Manila Trench at 320–340 km (Figure 4). That these

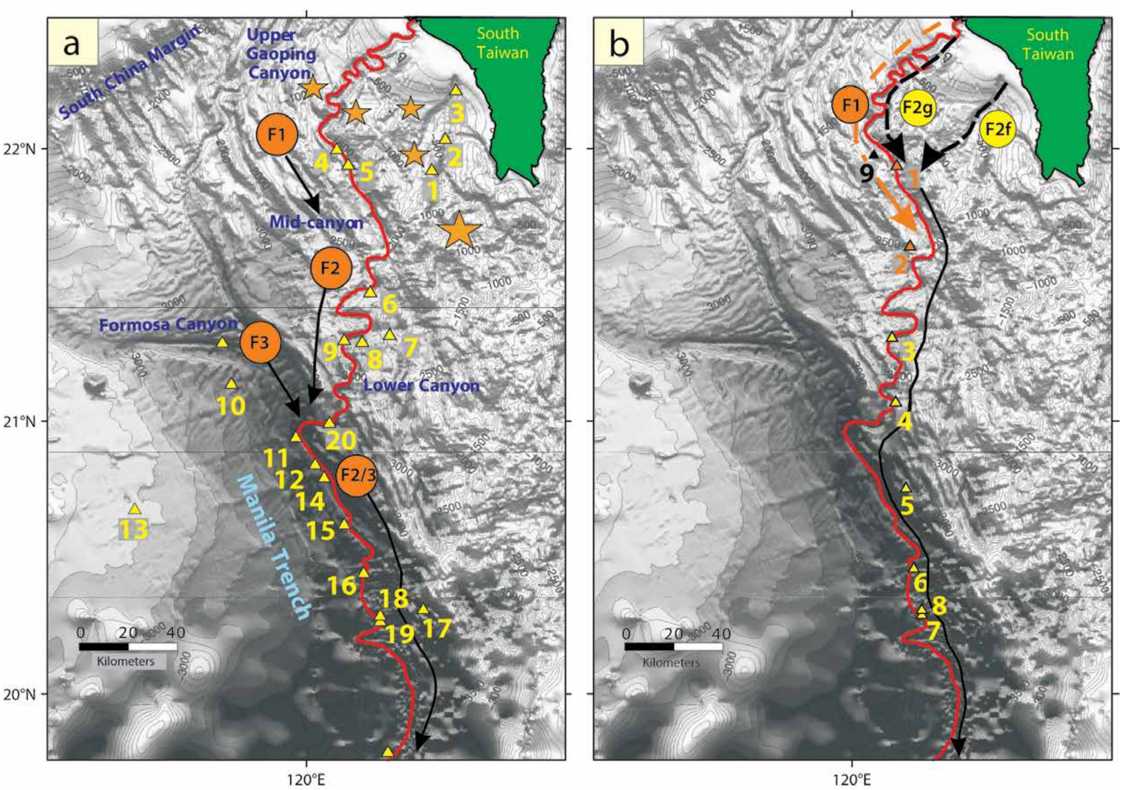

Figure 3. Cable breaks following (a) the 2006 Pingtung earthquake (epicenters of main and aftershocks = stars) when landslides and at least three sediment density flows (F1–3) were formed and damaged 22 cables crossing the Gaoping/Manila Trench system, and (b) Typhoon Morakot when two flows formed, F1 during a phase of hyperpycnal conditions associated with river flood discharge, and F2 three days later, potentially through the failure of sediment deposits in either Gaoping (F2g) or Fangliao (F2f) Canyons. Triangles are the cable breaks numbered in sequence of timing. Two breaks are not numbered because no time data are available.

accelerations occurred for both the Pingtung and Morakot events tends to preclude erroneous timing of the cable breaks. Rather, it may reflect a change in seabed gradient, channel geometry, sediment availability, or some combination of those factors. Once in the lowermost canyon and deeper (~ 260–380 km markers; Figure 4), flow speeds fluctuate within a narrow range of 5.4–6.6 m s^{-1}, apart from the local accelerations noted earlier. This would suggest that dissipation, whereby flows decelerate through the deposition of entrained sediment (i.e., the counter to ignition; Parker, 1982), is also not a prominent process, at least along that section of the flow path.

Talling et al. (2013) include a summary of directly measured sediment density flow speeds from around the world. They show that Taiwan speeds reported here are similar to those recorded for the 1929 Grand Banks and 1979 Var Canyon (off Nice, France) events, especially over seabed gradients of < 0.5°. However, in the case of specified, hyperpycnal flows, those in Var Canyon from 2005 to 2008 and Gaoping Canyon in 2008 had speeds typically < 2.0 m s^{-1}, although one hyperpycnal flow associated with the Southeast Asian Typhoon Kalmaegi reached 1.6 m s^{-1} (Liu et al., 2012). In sharp contrast, the cable-breaking flow formed at the time of hyperpycnal conditions during Typhoon Morakot reached 16.6 m s^{-1} (Figure 4b). The marked difference may reflect transformation of the hyperpycnal flow into a turbidity current due to increased canyon floor gradient or change to the more linear flow path of the mid canyon compared to the sinuous upper canyon (Figure 3b).

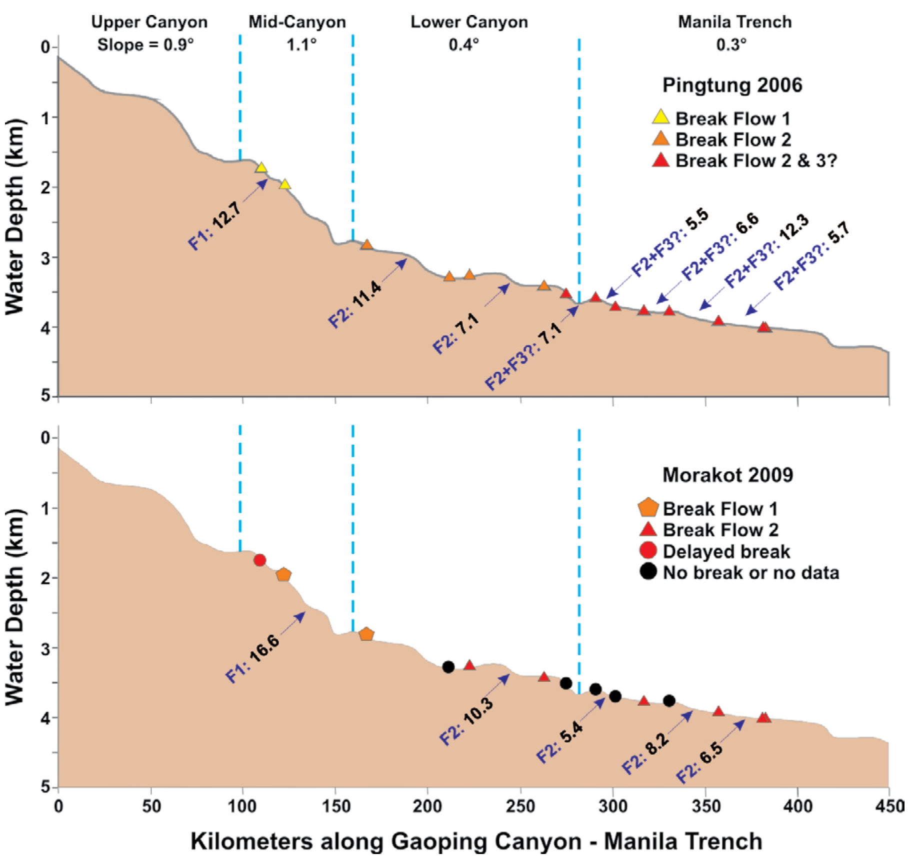

Figure 4. Distribution of cable breaks along the course of Gaoping Canyon and Manila Trench highlighting the general reduction in speed of the sediment density flows (F1–3, with speeds in meters per second) with reduced seabed slope and increased runout as measured in kilometers from the mouth of the Gaoping River. Of note is the local acceleration at 320–340 km in the Manila Trench that may reflect a local steepening or change in trench/channel morphology. At least five cables (black circles) were not damaged and/or breaks were not reported for Morakot.

Large Earthquakes May Have Long-Lasting Impacts

Destabilization of the landscape by earthquakes contributes to high rates of erosion and exceptional sediment discharge of Taiwan's rivers (Liu et al., 2013). The M_L = 7.3 Chi-Chi earthquake of 1999, for example, caused > 20,000 landslides across Taiwan. For the next five years, rivers carried higher-than-normal sediment loads (Dadson et al., 2004; Lin et al., 2008). This effect begs the question: Did the Pingtung 2006 earthquake precondition southern Taiwan for erosion under Typhoon Morakot? Onshore, the 2006 Pingtung earthquake caused loss of life and limited damage to property, but failure of hill slopes received little documentation, suggesting landslides were not extensive (Wen et al., 2008). This contrasts with the island-wide landslides caused by the Chi-Chi earthquake. That event had stronger ground accelerations that reflected its larger magnitude (M_L = 7.3) and shallower epicenter depth (7 km) compared to Pingtung 2006 (M_L = 7.0; 44–50 km depth). Offshore is a different matter because of strong ground accelerations at the Pingtung epicenters near Fangliao Canyon (Figure 3a). Parts of the canyon's walls collapsed, possibly under seismically induced liquefaction, to form one or more debris flows (Su et al., 2012). With assumed incompetent sediments redeposited in the canyon, together with additional sediment from Typhoon Morakot (Hale et al., 2012), Fangliao Canyon became a potential source of the main damaging Flow 2 (Figure 3b). However, for reasons presented previously, Gaoping Canyon is also a potential source.

This largely circumstantial argument suggests that the frequency of sediment density flows of sufficient force to damage cables is related mainly to the occurrence of large earthquakes. This may be the case, but we cannot discount the prominent role played by major storms such as Typhoon Morakot plus potential impacts of other triggers (see previous section titled Multiple Sediment Density Flows Form During an Earthquake). To better answer the question about the long-term effect of major earthquakes, a multivariate analysis of cable breaks and flow triggers is required.

River Flood Effects Can Be Complex

Cable breaks resulting from Typhoon Morakot reveal a complex delivery of sediment density flows. Initially, it was a hyperpycnal flow, but this was limited to the upper to middle reaches of Gaoping Canyon (< ~ 3,200 m). Furthermore, it took an extreme event such as Typhoon Morakot—the wettest tropical cyclone recorded over Taiwan—to produce hazardous Flow 1. Prior to Typhoon Morakot, sediment concentrations in the Gaoping River exceeded the 40 kg m^{-3} hyperpycnal threshold on at least five occasions between 1951 and 2004 (Milliman and Kao, 2005; Kao and Milliman, 2008). However, no cable damage was reported, bearing in mind the limitations of the cable break databases. Three days after Flow 1, when the river discharge was near normal (Figure 5), the more damaging Flow 2 formed. Flow 2 clearly had more force than Flow 1, as it broke at least four more cables over a longer and less inclined section of the canyon/trench system. Carter et al. (2012) suggest that Flow 2 contained more sediment than Flow 1, reflecting the former's possible origin via remobilization of sediment deposits in Gaoping or Fangliao Canyon.

Multiple Sediment Density Flow Triggers

Gaoping Canyon and the Manila Trench comprise a single submarine catchment that is subject to several triggers capable of initiating sediment density flows. These triggers include not only (1) earthquakes (Hsu et al., 2008; Su et al., 2012) and (2) extreme river floods (Carter et al., 2012; Liu et al., 2012), but also less-well-documented potential mechanisms including (3) escape of submarine groundwater fueled by extreme rainfalls (Su et al., 2012), (4) storm-wave agitation of river and shelf sediments to form fluid mud layers that pass into canyons (Hale et al., 2012), (5) turbulence associated with internal and surface wave activity in canyon heads (Lee et al., 2009), (6) escape of gas entrapped in sediments as revealed by seismic profile data (Su et al., 2012), and (7) liquefaction of sediments with elevated pore pressures as suggested by Su et al. (2012) for Pingtung 2006.

HAZARDS, CABLES, AND THE FUTURE

A key lesson from geohazard research is to avoid, where possible, active submarine canyons, especially those fed by high discharge rivers. However, submarine canyons may not be avoided easily due to a lack of viable alternative cable routes. This is the case for the Strait of Luzon. The obvious alternative route is through Taiwan Strait, but that is a zone of intense fishing, which is a major cause of cable breaks (Kordahi and Shapiro, 2004). As a consequence, a cable in Taiwan Strait would require deep burial beneath the seabed, which is an expensive operation. Research results from the Strait of Luzon suggest a safer route is to avoid Gaoping Canyon and cross the Manila Trench where sediment density flows decelerate to

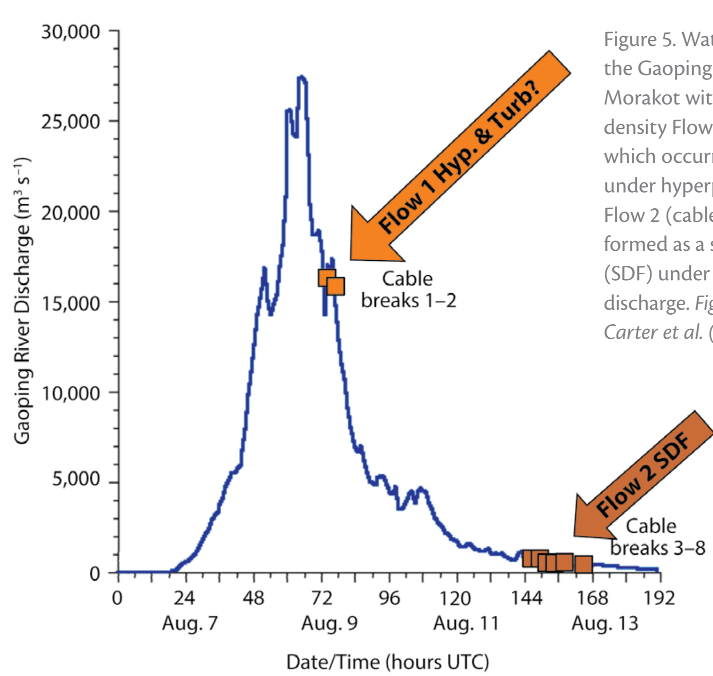

Figure 5. Water discharge profile for the Gaoping River during Typhoon Morakot with the times of sediment density Flow 1 (cable breaks 1–2), which occurred near peak flood under hyperpycnal conditions, and Flow 2 (cable breaks 3–8), which formed as a sediment density flow (SDF) under near-normal fluvial discharge. *Figure modified from Carter et al. (2012)*

a point where they do not cause cable damage. However, such a route increases the length of cable to be laid, thereby increasing cost. Alternatively, it may be possible to orient cables across the lower reach of the Gaoping Canyon (where sediment density flows begin to decelerate) in a way that reduces their drag profile to a flow. This approach is being applied to submarine pipelines in the presence of debris flows (Zakeri, 2009) and may be a possible line of research for cables while bearing in mind the marked differences in size, construction, deployment, and access of pipelines compared to deep-ocean cables.

The frequency of sediment density flows is another consideration. Crossing a canyon/channel system where the probability of a density flow is one per century may be an acceptable risk for a fiber-optic cable with a design life of ~ 20–25 years. But this is not the case for Gaoping Canyon/Manila Trench where multiple cables broke in 2006, 2009, 2010, and 2012 (Gavey, 2012, and unpublished data of author Gavey). That succession of breaks followed a decade or more of nil or few cable faults, given the limitations of our database. Certainly, earthquakes and flood-induced hyperpycnal flows occurred before 2006, but no major cable faults were reported. If correct, then the large Pingtung earthquake may have contributed to a flurry of sediment density flow activity that continues today. Significantly, the increased flow activity also coincides with an increase in extreme rainfall events (Chen et al., 2012), which is attributed to a northward shift of typhoon tracks to Taiwan. Tu et al. (2009) note that the shift may be related to warming of the central and western Pacific Ocean—a region that is responding to modern climate change (IPCC, 2013). If warming continues, there is the likelihood of continued extreme rainfall events and associated flood delivery of sediment to the Strait of Luzon and elsewhere around Taiwan in the near future. Thus, responses of submarine geohazards to modern climate change is now a consideration for the safety of submarine cable networks.

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