

Chapter 1

Submarine Mass Movements and Their Consequences: Progress and Challenges

Geoffroy Lamarche, Joshu Mountjoy, Suzanne Bull, Tom Hubble, Sebastian Krastel, Emily Lane, Aaron Micallef, Lorena Moscardelli, Christof Mueller, Ingo Pecher, and Susanne Woelz

Abstract This sixth edition of the *Submarine Mass Movements and Their Consequences* volume, coincident with the seventh eponymous conference includes 61 papers that span a variety of topics and are organized into nine parts as follows: (1) Submarine mass movement in margin construction and economic significance; (2) Failure dynamics from landslide geomorphology; (3) Geotechnical aspects of mass movement; (4) Multidisciplinary case studies; (5) Tectonics and mass movement processes; (6) Fluid flow and gas hydrates, (7) Mass transport deposits in modern and outcrop sedimentology; (8) Numerical and statistical analysis; and, (9) Tsunami generation from slope failure. The breadth and quality of this body of work underpins a positive outlook and our enthusiasm for the future direction of research in this area of science as it moves towards ever more detailed analysis and monitoring. We also emphasize in this volume the need to look at mountain-scale

G. Lamarche (✉) • J. Mountjoy • S. Woelz
National Institute of Water and Atmospheric Research (NIWA), Wellington, New Zealand
e-mail: geoffroy.lamarche@niwa.co.nz

S. Bull • C. Mueller
GNS Science, Lower Hutt, New Zealand

T. Hubble
School of Geosciences, The University of Sydney, Sydney, NSW, Australia

S. Krastel
Institute of Geosciences, Christian-Albrechts-University at Kiel, Kiel, Germany

E. Lane
National Institute of Water and Atmospheric Research (NIWA), Christchurch, New Zealand

A. Micallef
University of Malta, Msida, Malta

L. Moscardelli
Bureau of Economic Geology, Austin, TX, USA now at Statoil RDI, Austin, TX, USA

I. Pecher
The University of Auckland, Auckland, New Zealand

© Springer International Publishing Switzerland 2016

G. Lamarche et al. (eds.), *Submarine Mass Movements and their Consequences*,
Advances in Natural and Technological Hazards Research 41,
DOI 10.1007/978-3-319-20979-1_1

1

outcrops to better understand our seismic imaging, to carry out statistical studies that draw on global data sets to better constrain broad behavioural characteristics, and to undertake numerical modelling to understand the sensitivity of a range of natural slopes.

1.1 Introduction

Research on submarine mass movements remains highly topical and vibrant, whether it focuses on the consequences that such events may have on human and natural environments or on process-oriented science. The consequences of submarine landslides on infrastructure and coastal communities is reasonably well-known, thanks to a few notorious events that made global headlines, such as: the 1929 Grand Banks submarine landslide, Newfoundland (Piper and Aksu 1987) that ruptured a series of submarine cables and triggered a tsunami; the collapse of reclaimed land at Nice airport in 1979 (Kopf et al. 2011), which also generated a local tsunami; the dramatic landslide-generated Papua New Guinea tsunami in 1998, which claimed more than 2,000 lives (Tappin et al. 2001); or the hyperpycnal flow that ruptured communication cables south of Taiwan following the 2009 typhoon (Carter et al. 2012).

In order to improve our understanding of the potential impacts of submarine landslides, the research has focused on a variety of processes, approaches and methodologies. Field surveys undertaken immediately after catastrophic events have provided valuable information of magnitude-frequency relationship that underpin the development of hazard studies (Tappin et al. 2001). But arguably, investigations of mass-transport deposits (MTD) and source areas has represented the richest research effort pertinent to submarine landslides. MTD vary tremendously in geometry and size, ranging over at least five orders of magnitude in volume. There is a wide diversity of physical and mechanical processes that govern initiation and emplacement of submarine landslides, which has called for a plethora of research techniques. These include geophysical surveying, (e.g., seismic reflection, multibeam bathymetry), geological sampling (e.g., coring) and geotechnical investigations, analogue and numerical modelling. More recently, state-of-the-art technologies such as the use of remotely-operated vehicle (ROV) and autonomous underwater vehicles (AUV) have unveiled unprecedented details about the morphology of MTD (Huvenne et al. 2016).

The present volume is the sixth of its kind, and is associated to the seventh conference on Submarine Mass Movements and their Consequences. It contains 61 papers, spanning a variety of topics that are organized in nine parts.

The geographic focus of the research papers produced in this volume is predominantly the European and North American continental margins (Fig. 1.1), with 27 and 10 studies herein, respectively. Oceania, with the margins of New Zealand, eastern Australia and Indonesia, features strongly, possibly in part



Fig. 1.1 Geographic distribution of paper focus for the submarine mass movement and their consequences 2015 volume. Local (*red stars*) and regional (*green rectangles*) studies are indicated

because the conference will be held for the first time in the southern Hemisphere, but more likely and most importantly because the southeastern Pacific region is highly tectonically active, which likely facilitate the occurrence of submarine landslides, at least those seismically triggered. Paradoxically, western North America is represented by only two papers, and western South America, southwest Africa and the Indian Ocean have no papers in this volume. The paucity of baseline data from some of these areas is an issue that the submarine landslide-research community should attempt to address. Another conspicuous absence is mid-ocean ridges, which is somewhat disappointing as recent studies have demonstrated that these regions present some interesting examples of submarine landslides (Ferrini et al. 2013; Gao 2006; Tucholke 2016).

Contributions from high latitude regions solely concern the northern hemisphere, specifically on the northern Atlantic, including two papers on the Canadian Arctic (Normandeau et al. 2016; Priest and Grozic 2016).

There is an increase from previous years in the number of papers on landslides affecting lakes. These studies provide valuable observations and conclusions on the tsunami hazard associated with such events as well as paleoseismicity indicators (Locat et al. 2016). Perhaps “submarine” is too exclusive, and should be replaced by “subaqueous” if only to encourage such lacustrine studies to develop. Likewise studies of submarine MTD outcrops provide a means to gather new evidence on emplacement processes.

Submarine landslides occur on a wide range of scales. However, this year we note a lesser focus on large-scale “giant” features in comparison to previous issues. This may correlate with the increase in social, economic and hazard relevance of the research, which tend to concentrate less on rare giant submarine events.

If comparing the 2003 and 2015 volume is any measure of a trend, we surmise that the research is healthy and vibrant. We note since 2003, an increase focus on lakes, as mentioned above, but also an intensification in the use of emerging technology such as AUV and ROV, numerical modelling, and progress on event observation. Although the collection of in situ observations, let alone measurements, of mass movements remains a very challenging task, it is now a conceivable objective that is attracting strong interest from some research groups, as e.g., to assess the role of pore pressure in slope stability. These ambitions are being invigorated by new technology deployed from the ocean surface and mechanisms to make observatories on the ocean floor directly. Better multibeam bathymetry, including micro bathymetry from underwater vehicles and viable 3D-seismic data sets, has led to major improvement in our understanding of landslide dynamics, internal geometries and the failure process, and it is now well-accepted that major landslides are multiple events. Concentrated seafloor mapping efforts, at margin scales, has also allowed the development of frequency-size relationships. Of major importance was the scientific drilling of landslide deposits (e.g. IODP 308 in the Gulf of Mexico, and IODP 340) which allowed a quantitative assessment of specific pre-conditioning factors for individual landslides and an understanding of recurrence rates at targeted sites.

1.2 The 2015 Volume

1.2.1 *Part I: Submarine Mass Movement in Margin Construction and Economic Significance*

The Society for Underwater Technology estimates that the cost of damage to pipelines caused by submarine mass movements is about \$400 million annually (Mosher et al. 2010). This direct economic risk to exploration and production platforms is most relevant to small events with short reoccurrence intervals, and warrants ongoing research investment to enhance our understanding of processes and risk prediction. The study of submarine landslides also has an important geopolitical connotation as, their geomorphology has been used to define the distal toe of the continental slope and Extended Continental Shelf (ECS) by the UN Convention for the Law of the Sea (UNCLOS) (Mosher et al. 2016).

While it is generally accepted that submarine mass movements have a role in the development of petroleum systems (in particular in generating traps and seals), the understanding of the processes involved remains limited. It is estimated that ~90 % of submarine landslides are mud-prone but recent exploration has found some sand-rich MTD that could be considered petroleum reservoirs (Beaubouef and Abreu 2010; Meckel III 2011). Submarine landslides have proven to play a role defining hydrocarbon reservoir location and geometry, facies distributions, development of stratigraphic traps and integrity of seal intervals. In this volume, a specific case study in the Gulf of Mexico is analysed by studying fabric development and

pore-throat reductions of a local MTD that is clearly linked to a reservoir interval (Cardona et al. 2016). Such approaches, where seismic scale observations are combined with rock properties, provides a glimpse into the future study of MTD in the context of hydrocarbon systems.

It is noticeable that with the global increase in deep-water hydrocarbon exploration and production, the need to study and understand, let alone forecast, the occurrence of submarine landslides will continue to be the focus of the community (Omeru et al. 2016). Issues such as security of offshore infrastructure, and economic relevance of hazard and risk are the focus of contributions in following parts of this volume.

1.2.2 Part II: Failure Dynamics from Landslide Geomorphology

The complexity and variety of physical mechanisms involved in submarine failures is still up for debate. Whilst the consequence on human life is of paramount importance, the potential impact that any submarine landslides may have on seafloor or coastal infrastructures is increasingly concerning, especially with the increasing development of high seas infrastructures associated with deep-sea petroleum exploitation, communication cable and deep sea mining. There is also a rising awareness about the potential impact that submarine landslides can have on the natural environment. For the first time to our knowledge, these consequences could be ecologically positive, as suggested in the case of the Ionian Sea where hard strata and irregular small-scale topography resulting from landslides are likely to have facilitated cold water coral (re-)colonization (Savini et al. 2016). This shows linkages developing between submarine landslides research and economic, social and environmental issues.

1.2.3 Part III: Geotechnical Aspects of Mass Movement

Advances in geotechnical technology has been driven by the need for quality data required to quantify slope sensitivity response to deformation. Such progress in the recent past is being driven by engineering concerns around seafloor stability with respect to infrastructure hazard (Forsberg et al. 2016). Unprecedented insights into mass movement are now being offered by recent technological advances, in the laboratory (Torbahn et al. 2016), through the comparison between laboratory to in-situ observations (Kluger et al. 2016), and by correlating geophysical and in-situ geotechnical experiments (Stegmann et al. 2016). The confines offered by fjords and estuaries make perfect natural laboratories to study detailed geotechnical aspects of mass movements that can then provide insight into less accessible submarine processes (Forsberg et al. 2016; Kluger et al. 2016; Mastbergen et al. 2016; Turmel et al. 2016).

1.2.4 Part IV: Multidisciplinary Case Studies

High resolution bathymetric imaging combined with advanced geotechnical methods are truly providing significant advances in the field. Shipboard and AUV multibeam bathymetry remains unarguably the most used tool in submarine landslide investigations. Great advances in this technique mean that very high resolution studies are increasingly becoming routine. However, the significance of these data is further amplified when combined with multidisciplinary field investigations. We are very pleased to see outstanding contributions from investigations in the very challenging environment of the northern Arctic, revealing insights of previously unsurveyed areas (Forwick et al. 2016; Laberg et al. 2016; Normandeau et al. 2016). As well as a case study examining micro scale controls on mass movement complexes (Kuhlmann et al. 2016), another study reveals the long-term failure history of a confined subaqueous environment (Lindhorst and Krastel 2016).

1.2.5 Part V: Tectonics and Mass Movement Processes

The hazard and risk associated with submarine mass movement remains a fundamentally important focus of the scientific community. Intense efforts have been made to improve our understanding of the relation between tectonics and mass movement occurrence (Katz et al. 2016; Locat et al. 2016; Moore and Strasser 2016). The effect of tectonic activity on seismic strengthening is a hypothesis that is being supported by a comparison of shear strength in cores from active and passive margin settings (DeVore and Sawyer 2016). The use of submarine landslides to develop paleoseismic records at local or regional scales is building momentum and is providing some beneficial outcomes for constraining earthquake recurrence intervals and improving seismic hazard assessment (Chapron et al. 2016; Gracia et al. 2013). Other studies use a generic modelling approach to tackle the overarching question on the role of earthquakes in slope destabilization (Trandafir and Popescu 2016).

1.2.6 Part VI: Fluid Flow and Gas Hydrates

Understanding the role that fluids plays in pre-conditioning slope instability remains a significant challenge. New contributions made herein on the role of gas in slope failures (Gwiazda et al. 2016; Micallef et al. 2016) shed light on the possibility that fluids have a controlling influence on landslide basal failure planes. These observations are largely the result of recent technological developments. Similarly, the role of gas hydrates in submarine landslides remains a controversial one. Crutchley et al. (2016) present a series of different slope failure scenarios on the New Zealand continental margin that highlight a range of processes related to gas hydrates that could weaken sediments.

Priest and Grozic (2016) picks up on the widespread observations that climate change is destabilizing gas hydrate deposits in the Arctic regions. Using a modelling approach, they provide a thought provoking thesis on the role that climate change could play in inducing large slope failures.

1.2.7 Part VII: Mass Transport Deposits in Modern and Outcrop Sedimentology

Marine geophysical (seismic, multibeam echosounder) and geological (sediment cores, seafloor operations) still lack the fine-scale information and cross-sectional insights on mass failure processes that can be preserved and yielded from the study of fossilized landslides in outcrops onland. Outcrop investigations provide detailed insight into the kinematics (Ogata et al. 2016) and internal mixing and structure (Sobiesiak et al. 2016) of MTD. Sympathetic to these approaches are fine-scale sedimentological studies that provide a modern context of present day seafloor processes (Postma et al. 2016; Sawyer and Hodelka 2016). The link between onland outcrop studies of MTD and detailed marine studies is one that deserves to be strengthened given the benefits of cross pollination between these disciplines.

1.2.8 Part VIII: Numerical and Statistical Analysis

Statistical models allow us to develop rules and quantify relationships that encompass our analysis. Better understanding of magnitude-frequency relationships for submarine landslides is imperative if we are to develop robust hazard models (Clare et al. 2016; Mueller et al. 2016). GIS models developed to predict where slope failures can occur often become the underpinning driver for hazard assessments (Borrell et al. 2016; Dabson et al. 2016; Haneberg 2016), while advanced numerical modelling can be the key to understanding the sensitivity of individual slopes to external perturbations (Huhn et al. 2016). Numerical modelling and statistical analysis theme continues to run strongly in this volume, and reflect the state-of-the-art in terms of our general understanding of spatial causes of submarine landslides.

1.2.9 Part IX: Tsunami Generation from Slope Failure

Tsunamis are one the biggest hazards to coastal environments caused by submarine landslides. In this volume we have papers covering a broad range of landslide-related tsunami generation, including volcanic generation (De Lange and Moon 2016), landslides into an ice-covered lake (Leblanc et al. 2016), and advanced models that couple landslide deformation processes to wave generation (Wang et al. 2016). With increasing coastal populations and on-going climate change,

the need to continually refine and test robust tsunami hazard assessments is more pressing than ever. These papers capture some of the diverse range of processes that need to be considered in these assessments.

1.3 Looking to the Future

Of excellent augur to the future is the announcement in 2015 of the IGCP-640 S⁴SLIDE (Significance of modern and ancient submarine slope landslides – <https://sites.google.com/a/utexas.edu/s4slide/>). This project builds on the success of IGCP-511 and IGCP-585, and is the third IGCP project that focuses on submarine landslide-related science. This will no doubt continue to promote the research and foster relationships across the globe.

The S⁴SLIDE project intends to create an international and multidisciplinary platform to allow geoscientists from academia and industry to sustain a dialogue conducive to the integration of findings from different fields into a more cohesive understanding of submarine landslides. The initial project submission, listed the following series of key scientific questions as those needing to be addressed in the near future:

1. What is the nature of the interaction between local structural controls, seafloor morphology, sediment supply, relative sea-level fluctuations, current-controlled sedimentation and submarine landslides in lacustrine and marine environments?
2. What role do transient, turbulent-laminar flows play in the formation of submarine landslides?
3. What is the impact of climatic variations on the occurrence of submarine landslides?
4. What is the role of submarine landslides in the realm of hydrocarbon exploration and production?
5. Do we understand the hazard that submarine landslides poses in mid-oceanic ridges with regard to the developing deep-sea mining activities?
6. What are the indicators of incipient submarine slope instability in different geological-tectonic settings?
7. How do submarine landslides evolve after initiation and how do their dynamics affect their impact on coastal areas, including the generation of tsunamis?
8. Is it possible to develop a submarine landslide early-warning system?

The initial strategy was included in the S⁴SLIDE proposal to address the above key questions:

1. Continue of increase investment in sub-seafloor characterization and sampling to reduce data uncertainty in the third dimension.
2. Generate statistically significant submarine landslide data sets to allow robust probabilistic stability and hazard assessment.
3. Repeat multibeam surveys to address dynamic slope behaviour during failure and transient phenomena in slope failure preconditioning and triggering.

4. Advance the capability to model submarine landslide triggered tsunamis, particularly by better constraining the disintegration of material during failure.
5. Promote multiscale quantitative geomorphological investigations by integrating field measurements, remote sensing, and numerical models.

We are very enthusiastic about the future direction of research in Submarine Mass Movements and Their Consequences. As we move toward ever more detailed analysis with surgical seafloor operations, we also need to step back and take in the broad context offered by mountain scale outcrops of our seismic imaging, carry out unifying statistical studies that draw on global data sets, and explore numerical modelling to understand the sensitivity of natural slopes.

New IODP drilling proposals may also offer unprecedented opportunities. A couple of completed IODP projects on landslides have already contributed to great gains in our understanding of failure processes. However with at least two proposals in the system to date, and the linkages developing through S⁴SLIDE, we expect to see some major paradigm shifts in our understanding of landslide architecture and controlling influences. Installing monitoring equipment in IODP holes may offer that opportunity to monitor landslide controls and we encourage the whole community to consider how an IODP proposal could advance this science over the next decade.

The rich scientific literature on the topic of submarine mass movement is testimony to the strength and agility of the research community, exemplified by the biannual Submarine Mass Movements and Their Consequences symposium and the high standard of material included in this book. We greatly look forward to contributing to the sixth volume and seeing just how much our understanding of these fascinating and societally important processes have advanced.

Acknowledgments We would like to thank all those who accepted to review the manuscript for this volume. Indeed the list is too long to itemise here. Thank you to Alan Orpin (NIWA) and Gareth Crutchley (GNS Science) for reviewing this manuscript, and to Janet George (Absolutely Organised) for organising the SMMTC2015 portal.

References

- Beaubouef RT, Abreu V (2010) MTCs of the Brazos-Trinity slope system; thoughts on the sequence stratigraphy of MTCs and their possible roles in shaping hydrocarbon traps. In: Mosher DC, Shipp RC, Moscardelli L, Chaytor JD, Baxter CDP, Lee HJ, Urgeles R (eds) Submarine mass movements and their consequences. Springer, Dordrecht
- Borrell N, Somoza L, León R, Medialdea T, Gonzalez F, Gimenez-Moreno C (2016) GIS catalogue of submarine landslides in the Spanish continental shelf: potential and difficulties for susceptibility assessment. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 499–508
- Cardona S, Wood L, Day-Stirrat R, Moscardelli L (2016) Fabric development and pore-throat reduction in a mass-transport deposit in the Jubilee gas field, eastern gulf of Mexico: consequences for the Sealing Capacity of MTDs. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 27–38

- Carter L, Milliman JD, Talling PJ, Gavey R, Wynn RB (2012) Near-synchronous and delayed initiation of long run-out submarine sediment flows from a record-breaking river flood, offshore Taiwan. *Geophys Res Lett* 39:L12603
- Chapron nE, Simonneau A, Ledoux G, Arnaud F, Lajeunesse P, Albéric P (2016) French alpine foreland Holocene paleoseismicity revealed by coeval mass wasting deposits in glacial lakes. In: Lamarche G, Mountjoy J (eds) *Submarine mass movements and their consequences*. Springer, Dordrecht, pp 341–350
- Clare M, Talling P, Challenor P, Hunt J (2016) Tempo and triggering of large submarine landslides – statistical analysis for hazard assessment. In: Lamarche G, Mountjoy J (eds) *Submarine mass movements and their consequences*. Springer, Dordrecht, pp 509–518
- Crutchley G, Mountjoy J, Pecher I, Gorman A, Henrys S (2016) Submarine slope instabilities coincident with shallow gas hydrate systems: insights from New Zealand examples. In: Lamarche G, Mountjoy J (eds) *Submarine mass movements and their consequences*. Springer, Dordrecht, pp 401–410
- Dabson O, Barlow J, Moore R (2016) Morphological controls on submarine slab failures. In: Lamarche G, Mountjoy J (eds) *Submarine mass movements and their consequences*. Springer, Dordrecht, pp 519–528
- De Lange W, Moon V (2016) Volcanic generation of tsunamis: two New Zealand palaeo-events. In: Lamarche G, Mountjoy J (eds) *Submarine mass movements and their consequences*. Springer, Dordrecht, pp 559–568
- DeVore J, Sawyer D (2016) Shear strength of siliciclastic sediments from passive and active margins (0–100 meters below seafloor): insights into seismic strengthening. In: Lamarche G, Mountjoy J (eds) *Submarine mass movements and their consequences*. Springer, Dordrecht, pp 173–180
- Ferrini VL, Shillington DJ, Gillis K, MacLeod CJ, Teagle DAH, Morris A, Cazenave PW, Hurst S, Tominaga M (2013) Evidence of mass failure in the Hess Deep Rift from multi-resolutional bathymetry data. *Mar Geol* 339:13–21
- Forsberg CF, Heyerdahl H, Solheim A (2016) Underwater mass movements in lake Mjøsa, Norway. In: Lamarche G, Mountjoy J (eds) *Submarine mass movements and their consequences*. Springer, Dordrecht, pp 191–200
- Forwick M, Laberg J,S, Husum K, Gales J (2016) Submarine mass wasting on Hovgaard Ridge, Fram Strait, European Arctic. In: Lamarche G, Mountjoy J (eds) *Submarine mass movements and their consequences*. Springer, Dordrecht, pp 253–264
- Gao D (2006) Gravitational sliding on the Mid-Atlantic Ridge at the Kane transform: implications for submarine basin-slope degradation and deformation. *AAPG Bull* 90:159–176
- Gracia E, Lamarche G, Nelson H, Pantosti D (2013) Preface: marine and lake paleoseismology. *Natl Hazard Earth Sci Process* 13:3469–3478
- Gwiazda R, Paull C, Caress D, Lorenson T, Brewer P, Peltzer E, Walz P, Anderson K, Lundsten E (2016) Eel canyon slump scar and associated fluid venting. In: Lamarche G, Mountjoy J (eds) *Submarine mass movements and their consequences*. Springer, Dordrecht, pp 411–418
- Haneberg W (2016) Incorporating correlated variables into GIS-based probabilistic submarine slope stability assessments. In: Lamarche G, Mountjoy J (eds) *Submarine mass movements and their consequences*. Springer, Dordrecht, pp 529–536
- Huhn K, Stroyk F, Kock I (2016) Quantifying the key role of slope material peak strength – using discrete element simulations. In: Lamarche G, Mountjoy J (eds) *Submarine mass movements and their consequences*. Springer, Dordrecht, pp 537–546
- Huvene V, Georgiopoulou A, Chaumillon L, Lo Iacono C, Wynn R (2016) Novel method to map the morphology of submarine landslide headwall scarps using Remotely Operated Vehicles. In: Lamarche G, Mountjoy J (eds) *Submarine mass movements and their consequences*. Springer, Dordrecht, pp 135–144
- Katz O, Reuven E, Elfassi Y, Paldor A, Gvirtzman Z, Aharonov E (2016) Spatial and temporal relation of submarine landslides and faults along the Israeli continental slope, eastern Mediterranean. In: Lamarche G, Mountjoy J (eds) *Submarine mass movements and their consequences*. Springer, Dordrecht, pp 351–360

- Kluger MO, Kreiter S, L'Heureux JS, Stegmann S, Moon V, Mörz T (2016) In situ cyclic softening of marine silts by vibratory CPTU at Orkdalsfjord test site, mid Norway. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 201–210
- Kopf A, Kasten S, Bles J (2011) Geochemical evidence for groundwater-charging of slope sediments: the Nice airport 1979 landslide and tsunami revisited. In: Mosher D, Shipp RC, Moscardelli L, Chaytor JD, Baxter CDP, Lee HJ, Urgeles R (eds) Submarine mass movements and their consequences. Springer, Dordrecht
- Kuhlmann J, Huhn K, Ikari MJ, Krastel S (2016) Do embedded volcanoclastic layers serve as potential glide planes? – an integrated analysis from the Gela Basin offshore southern Sicily. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 273–280
- Laberg JS, Baeten N, Vannestec M, Forsberg CF, Forwick M, Hafliadason H (2016) Sediment failure affecting muddy contourites on the continental slope offshore northern Norway – lessons learned and some outstanding issues. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 281–290
- Leblanc J, Turmel D, Therrien J, Locat J (2016) Observations of coastal landslide-generated tsunami under an ice cover: the case of Lac-des-Seize-Îles, Québec, Canada. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 607–614
- Lindhorst K, Krastel S (2016) Mass wasting history within lake Ohrid Basin (Albania/Macedonia) over the last 600ka. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 291–300
- Locat J, Turmel D, Habersetzer M, Trottier AP, Lajeunesse P, St-Onge G (2016) Earthquake induced landslides in Lake Éternité, Québec, Canada. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 361–370
- Mastbergen D, van den Ham G, Cartigny M, Koelwijn A, de Kleine M, Clare M, Hizzett J, Azpiroz M, Vellinga A (2016) Multiple flow slide experiment in the Westerschelde Estuary, The Netherlands. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 241–249
- Meckel III LD (2011) Reservoir characteristics and classification of sand-prone submarine mass-transport deposits, SEPM Special Publication 96, 432–452
- Micallef A, Mountjoy J, Krastel S, Crutchley G, Koch S (2016) Shallow gas and the development of a weak layer in submarine spreading, Hikurangi margin (New Zealand). In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 419–426
- Moore G, Strasser M (2016) Large mass transport deposits in Kumano Basin, Nankai Trough, Japan. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 371–380
- Mosher DC, Shipp RC, Moscardelli L, Chaytor JD, Baxter CD P, Lee HJ, Urgeles R (2010) Submarine mass movements and their consequences – 4th International Symposium. In: Advances in natural and technological hazards research. Springer, Dordrecht
- Mosher D, Laberg JS, Murphy A (2016) The role of submarine landslides in the Law of the Sea. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 15–26
- Mueller C, Mountjoy J, Power W, Lane E, Wang X (2016) Towards a spatial probabilistic submarine landslide hazard model for submarine canyons. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 589–598
- Normandeau A, Joyal G, Lajeunesse P, Francus P, Lamoureux S, Lapointe F (2016) Late-Holocene Mass Movements in High Arctic East Lake, Melville Island (Western Canadian Arctic Archipelago). In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 311–320
- Ogata K, Pini GA, Festa A, Pogačnik Z, Lucente C (2016) Meso-scale kinematic indicators in exhumed mass transport deposits: definitions and implications. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 461–468

- Omeru T, Cartwright J, Bull S (2016) Kinematics of submarine slope failures in the deepwater Taranaki Basin, New Zealand. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 61–70
- Piper DJW, Aksu AE (1987) The source and origin of the 1929 grand banks turbidity current inferred from sediment budgets. *GeoMar Lett* 7:177–182
- Postma G, Hoyal D, Abreu V, Cartigny M, Demko T, Fedele J, Kleverlaan K, Pederson KH (2016) Morphodynamics of supercritical turbidity currents in the channel-lobe transition zone. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 469–478
- Priest J, Grozic J (2016) Stability of fine-grained sediments subject to gas hydrate dissociation in the Arctic continental margin. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 427–436
- Savini A, Marchese F, Verdicchio G, Vertino A (2016) Submarine slide topography and the distribution of vulnerable marine ecosystems: a case study in the Ionian Sea (eastern Mediterranean). In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 163–170
- Sawyer D, Hodelka B (2016) Tiny fossils, big impact: the role of foraminifera-enriched condensed section in arresting the movement of a large retrogressive submarine landslide in the Gulf of Mexico. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 479–486
- Sobiesiak M, Kneller B, Alsop GI, Milana JP (2016) Inclusion of substrate blocks within a mass transport deposit: a case study from Cerro Bola, Argentina. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 487–496
- Stegmann S, Kreiter S, L'Heureux JS, Vanneste M, Völker D, Baeten NJ, Knudsen S, Rise L, Longva O, Brendryen J, Hafidason H, Chand S, Mörz T (2016) First results of the geotechnical in situ investigation for soil characterisation along the upper slope off Vesterålen – Northern Norway. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 211–220
- Tappin DR, Watts P, McMurtry GM (2001) The Sissano, Papua New Guinea tsunami of July 1998: offshore evidence on the source mechanism. *Mar Geol* 175:1–23
- Torbahn L, Strege S, Kwade A, Trandafir A (2016) A novel micro-shear tester for failure analysis of fine and cohesive granular matter. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 221–228
- Trandafir A, Popescu M (2016) Insights into effectiveness of simplified seismic displacement procedures to evaluate earthquake behavior of a deepwater slope. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 381–390
- Tucholke BE (2015) Massive submarine rockslide in the rift-valley wall of the Mid-Atlantic Ridge. *Geology* 20:129–132
- Turmel D, Locat J, Parker G, Konrad JM (2016) Knickpoint migration induced by landslide: evidence from laboratory to field observations in Wabush Lake. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 229–239
- Wang X, Mountjoy J, Power W, Lane E, Mueller C (2016) Coupled modelling of the failure and tsunami of a submarine debris avalanche offshore central New Zealand. In: Lamarche G, Mountjoy J (eds) Submarine mass movements and their consequences. Springer, Dordrecht, pp 599–606