Significance of Modern and Ancient Submarine Slope LandSLIDEs IGCP-640

A global database of subaqueous landslides: Summary of discussions

Meeting location: The Royal Trafalgar, London - Whitcomb Street, Trafalgar Square London WC2H 7HG [held 23-24 January 2017]

Document compiled by Mike Clare (NOC Southampton)

Context: It has been widely recognized that subaquatic landslides are common in lacustrine and marine environments. They pose a risk to coastal communities and offshore infrastructure. They can play an important role in the distribution and diversity of deep-sea ecosystems. Furthermore, their deposits can have importance for hydrocarbon exploration and production activities, acting as potential seals, and in some cases reservoir units. During the past decades geoscientists have made many important contributions towards the improved understanding of submarine landslides. Efforts by the geo-modelling community have helped fill the gap between submarine landslide occurrence, dynamics and tsunami genesis. However, our lack of understanding of the causal mechanisms and timing of submarine landslides has hampered progress in the development of deterministic and probabilistic assessment tools which are essential to implement appropriate mitigation measures.

S4SLIDE: The S4SLIDE project (*Significance of Modern and Ancient Submarine Slope LandSLIDEs*) builds upon the extremely successful E-MARSHAL and IGCP-511 proposals also known as the Submarine Mass Movements and Their Consequences project. As with its predecessors, the IGCP-640 project focuses on facilitating the interaction of scientists, engineers, industry and government representatives, and other parties interested in submarine mass movements and their geohazard potential, especially those from historically under-represented countries. S4SLIDE seeks to create an international and multidisciplinary platform allowing geoscientists from academia, government, and industry to sustain a dialogue conducive to the integration of findings from different fields into a more cohesive understanding of submarine landslides.

Underlying rational for a global database: Many developments have been made in the recent years on improving our understanding of subaqueous landslides in a number of different settings, in both modern and ancient timescales. The S4SLIDE community recognises, however, that there is still a large amount of valuable data that is underexploited and stored in many disparate databases. **We see much value in building a coherent and peer-curated global database of consistent subaqueous landslide data that can be made available to a large number of end-users**, to advance: 1) the understanding of subaqueous landslides, and 2) to support complementary research.

We explored the mechanics of bringing fruit to this aim at a **workshop on 23rd and 24th January 2016**.

Following from this workshop an abstract was submitted for the upcoming conference on submarine mass movements and their consequences in British Columbia in 2018

Meeting Agenda

Attendees:

Marco Patacci – Leeds University
David Voelker –MARUM
Ricardo Leon – Geological Survey of Spain
Lesli Wood – Colorado School of Mines
Jason Chaytor - USGS
Aggeliki Georgiopoulou – University College Dublin
Mike Clare – National Oceanography Centre Southampton
James Hunt – National Oceanography Centre Southampton
Michael Steventon – Imperial College London
Davide Gamboa - BGS
Aaron Micallef - Uni Malta
Sebastian Krastel - Kiel Uni

Lorena Moscardelli – Statoil (Skype on day 1)

Day One: 23rd January 2017

10:00 – coffee, introductions and housekeeping

10:30 – Background to a global subaqueous landslide database (Jason Chaytor)

11:00 – Objectives for the database – what do we want to achieve? What are the end-goals? What are the science questions? How will a database allow us to address them?

12:00 – What already exists? Showcase of existing databases (David Voelker, Marco Patacci, Ricardo Leon, Davide Gamboa, Jasper Moernaut showed database examples),

12:30 – Lunch

13:15 – Continue showcase of databases and data sets

> **What are the challenges and how do we create a consistent database? What aspects of existing databases/data sets do we want to include?**
>
> Specific discussions on how to collate existing data
>
> Showing/sharing of existing data to explore how problematic some of the issues are
>
> *Data examples presented*

15:00 "How to measure a landslide and what to call it" – specific discussion on metrics and how to standardise approaches [incl. dial in to USA for Lorena Moscardelli]

Day Two: 24th January 2017, 09:00 start

> **What are the next steps for the database? Logistics, mechanics and funding…**
>
> **What can/should we do immediately?** E.g. through IGCP portal, and in terms of publication(s)

15:00 Meeting close

1. DRIVERS FOR A GLOBAL DATABASE

Jason Chaytor kicked the meeting off and outlined some key questions to address:

Why are we here? To do good science, but we have a mandate (from IGCP) to make that science available to a wide audience (i.e. share data and findings). One of the key S4SLIDE aims is to target developing countries, recognising that subaqueous landslide research is not cheap and the S4SLIDE community should help by transferring knowledge, expertise etc. Developing countries have other priority areas on which they need to spend money.

How do we make science and engineering available to broader communities? One community that is increasingly engaged with is tsunami modelling, but there is a lot of uncertainty about what parameters to use for landslide-source tsunami. We think we can describe morphology well, but many uncertainties surround their age, preconditioning and triggering mechanisms, how to deal with incomplete records etc. It is difficult to explain these uncertainties to groups that want hard quantitative inputs.

A fully global database of subaqueous landslides that is vetted, curated and updated is highly desirable by a number of groups, and would enable answering of big questions BUT everyone has a different wat of defining subaqueous landslides (e.g. source area, deposit, age etc).

Can a global database be created?

Is it technically possible? Can it be done efficiently?

What about with limited funding? How do you get an organization to fund through a national or international program?

How do you even define a landslide*?* ***How do we establish a consistent approach to that?*** There is more than one way! Whatever the approach, it is important to refer back to peer-reviewed literature. USGS databases all rely upon metadata and peer-review to ensure data quality standards are met.

Geochronology – there are lots of different ways to get an age for a slide and with various errors associated.

Jason explained that the more he has worked on landslides, over last decade, he has seen an evolution. Questions on environmental forcing are being raised more and people are turning to a database they have built from published literature. **What does the morphology of my landslide tell me about timing, geologic environment, age, etc. and how does that compare to other events?**
We need to identify where the gaps are.

Discussion following Jason's comments
Logistic questions

- Where is it hosted?
- Who curates?
- Who manages and peer reviews?
- How do you define a landslide? Depends (this was a key item for discussion later). Need some consistencies in how and what you collect.
- Database needs to be continuously curated otherwise it becomes useless
- What you collect is a function of what you can see!

We discussed some examples of community databases. Some examples listed below:

Publications that reference databases or inventories on a >regional basis

Morphometrics of Submarine Landslides:

- **Submarine landslides of the Mediterranean Sea: Trigger mechanisms, dynamics, and frequency-magnitude distribution:** Urgeles and Camerlenghi (2013) http://onlinelibrary.wiley.com/doi/10.1002/2013JF002720/pdf
- **Submarine landslide geomorphology, US continental slope:** McAdoo et al. (2000) http://faculty.vassar.edu/brmcadoo/McAdooetal.pdf
- **Size distribution of submarine landslides along the U.S. Atlantic margin:** Chaytor et al. (2009) http://www.sciencedirect.com/science/article/pii/S0025322708002594
- **Morphology of late Quaternary submarine landslides along the U.S. Atlantic continental margin:** Twichell et al. (2009) http://www.sciencedirect.com/science/article/pii/S0025322709000255
- **Size distributions and failure initiation of submarine and subaerial landslides:** Ten Brink et al. (2009) http://www.sciencedirect.com/science/article/pii/S0012821X09004464
- **Landslides in the North Atlantic and its adjacent seas: an analysis of their morphology, setting and behaviour:** Huhnerbach and Masson (2004) http://www.sciencedirect.com/science/article/pii/S0025322704002774
- **Morphometry of mass-transport deposits as a predictive tool:** Moscardelli and Wood (2015) http://gsabulletin.gsapubs.org/content/early/2015/07/08/B31221.1.abstract
- **Submarine slope failures along the convergent continental margin of the Middle America Trench:** Harders et al. (2011) http://onlinelibrary.wiley.com/doi/10.1029/2010GC003401/full

Morphometrics and frequency of lacustrine landslides:

- **Frontal emplacement and mobility of sublacustrine landslides: Results from morphometric and seismostratigraphic analysis:** Moernaut and De Batist (2011) http://www.sciencedirect.com/science/article/pii/S0025322711001071
- **A number of papers that compile landslides in Swiss, Chilean, Alaskan lakes (primarily for palaeoseismology) e.g.** http://onlinelibrary.wiley.com/doi/10.1111/sed.12003/full
  http://onlinelibrary.wiley.com/doi/10.1111/sed.12193/full
  http://www.sciencedirect.com/science/article/pii/S0025322716300767
  http://www.sciencedirect.com/science/article/pii/S0025322715300499

Frequency/age distribution of submarine landslides:

- **Timing and frequency of large submarine landslides: implications for understanding triggers and future geohazard** Urlaub et al. (2013) http://www.sciencedirect.com/science/article/pii/S0277379113001601
- **Sea-level–induced seismicity and submarine landslide occurrence:** Brothers et al. (2014) http://geology.gsapubs.org/content/41/9/979.short
- **Distal turbidites reveal a common distribution for large (>0.1 km3) submarine landslide recurrence:** Clare et al. (2014) http://geology.gsapubs.org/content/42/3/263.abstract
- **Long-term (17 Ma) turbidite record of the timing and frequency of large flank collapses of the Canary Islands:** Hunt et al. (2014)
- **Late Pleistocene submarine mass movements: Occurrence and causes**: Owen at al . (2007) http://onlinelibrary.wiley.com/doi/10.1002/2014GC005232/full
- https://www.researchgate.net/publication/223509969_Late_Pleistocene_submarine_mass_movements_Occurrence_and_causes

Geotechnical properties of submarine landslides:

- **Elevated shear strength of sediments on active margins: Evidence for seismic strengthening:** Sawyer and DeVore (2015) http://onlinelibrary.wiley.com/doi/10.1002/2015GL066603/full

Global and regional terrestrial landslide databases

- **Database of large terrestrial landslides** Korup et al. (2007) http://www.sciencedirect.com/science/article/pii/S0012821X07004785
- **Catalogue of fatal terrestrial landslides worldwide:** Petley (2012) http://geology.gsapubs.org/content/40/10/927.short
- **Landslide databases as a tool for integrated assessment of landslide risk** by KloseUseful introductory text at https://books.google.co.uk/books?id=qbb-CQAAQBAJ&pg=PA29&lpg=PA29&dq=%22landslide+database%22&source=bl&ots=bvl18RLpWj&sig=-om2ggAMol4EfLxlWHoE_ZTRkew&hl=en&sa=X&ved=0ahUKEwiNm-TSorrRAhXDXBQKHZjwCRw4ChDoAQhNMAk#v=onepage&q=%22landslide%20database%22&f=false
- Kirshbaum et al. (2010) http://link.springer.com/article/10.1007/s11069-009-9401-4
- Local databases e.g. Malamud et al. (2004) http://onlinelibrary.wiley.com/doi/10.1002/esp.1064/full

Ongoing submarine landslide databases in construction:

ASTARTE: Assessment, STrategy And Risk Reduction for Tsunamis in Europe

The ASTARTE Mass Transport Deposits data base a web-based reference for submarine landslide research around Europe Paolo Marco De Martini · Galderic Lastras · David Völker, Sébastien Migeon - this is a web-based compilation that widely coincides with Urgeles & Camerlenghi and is a deliverable of the ASTARTE EU project which ends next year. It will allow to extract geomorphological information easily...

- Reports are available such as recurrence rates of tsunamis of earthquake, volcanic and landslide origin http://www.astarte-project.eu/files/astarte/documents/deliverables/d2-9/D2.9-vs3-full.pdf
- Publications arising from the project to date: http://www.astarte-project.eu/index.php/publications.html

Open-Access Databases – predominantly for terrestrial landslides:

USGS Landslide Inventory Pilot Project

- The purpose of the Inventory Project is to provide a framework and tools for displaying and analyzing landslide inventory data collected in a spatially aware digital format from individual states. http://landslides.usgs.gov/research/inventory/

Geoscience Australia - Australian Landslide Database

- A 'virtual' database which brings information across databases together and gives users the latest landslide data. The database is a spatial index of the available information about landslide events in Australia and provides a range of information related to an event, including its causes and consequences. This is developed through the landslide database interoperability project. **The interoperable approach** allows the virtual database to be tailored to meet the needs of various users and decision makers. This will ensure that the database is useful to all levels of government, geotechnical professionals, emergency managers, land use planners, academics and the general public. It will provide direct access to spatial data and allow users to simultaneously search and query different landslide databases for the most up-to-date information available. The combined search results can be displayed as reports, graphs, maps, statistics or tables, and data can be queried against background datasets, such as topography, geology and geomorphology.

http://www.ga.gov.au/ausgeonews/ausgeonews200812/landslide.jsp

Geological Survey of Ireland Landslide Database

https://www.gsi.ie/Programmes/Quaternary+Geotechnical/Landslides/National+Landslide+Database.htm

BGS-hosted national landslide database of Great Britain

- Each landslide is documented as fully as possible with information on location, name, size and dimensions, landslide type, trigger, damage caused, movement date, age and with a full bibliographic reference. The database is linked to a GIS which displays the landslides as point data. http://www.bgs.ac.uk/research/engineeringGeology/shallowGeohazardsAndRisks/landslides/NLD.html
  http://link.springer.com/article/10.1007/s12665-011-1304-5
  http://nora.nerc.ac.uk/4694/1/CF_BGS_Tokyofinal.pdf

University of Oklahoma Global Landslide Database

- Global interactive map of landslide and variables http://eos.ou.edu/hazards/landslide/

Landslide inventories in Europe and policy recommendations for their interoperability and harmonisation

- Europe-wide review of terrestrial landslide databases. Tables 4.1 and 4.2 in the document here provide weblinks to individual country databases or inventories. http://esdac.jrc.ec.europa.eu/ESDB_Archive/eusoils_docs/other/EUR25666EN.pdf

NGDC/WDS Global Historical Tsunami Database

- The Global Historical Tsunami Database consists of two related files containing information on tsunami events from 2000 B.C. to the present in the Atlantic, Indian, and Pacific Oceans; and the Mediterranean and Caribbean Seas. **https://www.ngdc.noaa.gov/hazard/tsu_db.shtml**

Other marine geological databases:

- EMODnet Geology - http://www.emodnet-geology.eu/geonetwork/srv/eng/catalog.search#/home
- PANGAEA https://pangaea.de/

Miscellaneous:

- **International disaster databas**e (very broad including biological, climatological, geophysical, hydrological, meteorological, technological disasters that can be searched by time, location, disaster, damage amount etc.) - http://www.emdat.be/database
- USGS Quaternary Fault and Fold Database - http://earthquake.usgs.gov/hazards/qfaults/
- Catalogue of Icelandic Volcanoes - http://futurevolc.vedur.is/
- Seamount Biogeosciences Network Seamount Catalog - https://earthref.org/SC/

2. WHO WILL USE A GLOBAL DATABASE AND WHY? WHAT WILL IT ENABLE?

To decide what is included, it is important to look at the end user(s). The hope is this can be broad and widely accessible, but we need to understand their needs. The funding customer is important too! A number of end applications (and questions both industry and science-facing) were identified and discussed. This informed later discussion on what data should and could be included in a database.

Tsunami Hazard: Provide chronology and age dates for tsunami is critically important for USGS. How do we host long-term records and what are the limitations of the long-term records? Size of events, speed, directionality are also important for modelling of tsunamis.

Hosting landslide dates for multiple applications: Different methodologies produce different ages. Dating methods vary in their approach, sample needs and cost. Frequency that something occurs; recurrence intervals is pretty critical. Aggie – dating of marine failures is a great problem Jason – can we only get a 40,000 year record?

Tool for risk assessment and decision makers [better informed estimates for landslide frequency and magnitude e.g. impact to coastal and offshore infrastructure]. Within this is an improved **understanding of triggers for submarine slope failures**, especially where such triggers can be constrained e.g. do certain triggers yield a suite of landslides of a certain size? [and what of other metrics?]. Often the trigger is not equivocal however.

Provision of data for forward models (e.g. include geotechnical data of unfailed slopes in landslide-prone regions?)

Hydrocarbon industry e.g. guidance on derivation of volumes from 2D observations, implications for reservoirs, fluid flow etc

United Nations Convention on Law of the Sea – landslide run-out can control where international boundaries exist (e.g. Mosher et al., 2016)

Improved understanding of links between benthic ecology and their distribution/biodiversity/density and subaqueous landslides Landslides may **impact on benthic communities** (destruction of habitat), form new habitats (emplaced rough seafloor, hardgrounds etc.) and thus important to know. Development of benthic colonisation may reveal new insights into recency of landslides. E.g. disturbance gradients.

Providing the basis for statistical analysis and to **robustly test outstanding hypotheses** that are currently either only qualitatively addressed or by relatively small sample sizes? (e.g. links to gas hydrate dissocation, sea level etc). Do current datasets provide too few observations for us to make conclusive statements? This is certainly true for most datasets that look at landslide frequency and correlation with sea level.

Comparison of landslides between margins (e.g. active vs passive, high sedimentation vs low) and **robustly test correlations/controls/trends**

Enable data gap analysis and **inform future strategies of data collection**. e.g. **what regions are well vs underrepresented**? Is there a **bias to characterisation of "sexy" landslides** (e.g. really big tsunamigenic) **and less attention paid to smaller landslides** which may actually be more frequent? **What timescales are well characterised,** and are not? (e.g. bias towards very recent Holocene and lack of data prior to that – thus informing what can and cannot be done statistically). **Carbonate landslides appear to be underrepresented.**

Are there trends in landslide scale (e.g. thickness, run-out, volume) and are they real, or related to acquisition parameters? Can we discern biases vs real trends? E.g. do hull-mounted datasets in deep-water “miss” landslides that would be captured by AUV flying closer to seafloor? Are we comparing apples with apples? Some landslides in Chilean lakes are <10 cm thick and therefore not imaged!

How does **morphometry or sublacustrine and submarine landslides** compare (scale dependence vs independence)? **What can we learn from it?** Are there fundamental controls that can be scaled? **Is it appropriate to study easier-to-access lacustrine and fjord sites (incl. direct monitoring) and make inferences for much larger landslides in deeper water,** or are there different mechanics in play? What are the physical controls on landslide size, volume, run-out (and other metrics)? Are these location/region-specific or can we identify more general controls? Bring together communities (e.g. experimental, lake and marine landslide communities).

How much organic carbon is then reworked and retransported to deep water? What is the real efficiency of carbon burial globally in the marine realm? How does that vary between margins/settings? Will need to know frequency of failures, depth and volumes of sediment mobilised. A global database could facilitate global estimates of organic carbon reworking and redeposition. **What about carbon sequestration too? What is the sealing capacity of landslide deposits?**

Guide for future investigations – e.g. what techniques (geophysical, coring etc) should be used for survey and sampling based on previous experiences in similar sites, nearby?

3. WHAT DATA SHOULD BE INCLUDED?

Morphometric information seems to be the sensible place to start as it gives us a spatial reference for the location of landslides, and information on their scale that is relevant to pretty much all of the above applications. It is relatively straightforward to also add in information on the age of landslides.

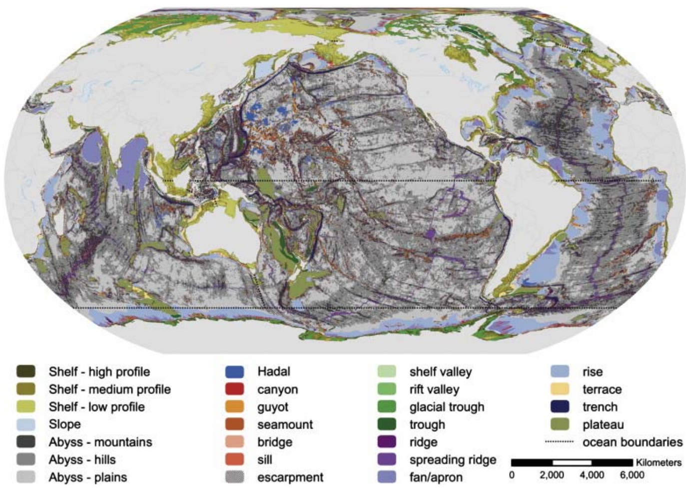
Why are morphometrics important?

- Scale important for seafloor geohazards assessments
- Size and mass are a big component of basin stratigraphy
- Run out to height drop ratio gives insight into the physics of the process of landsliding
- Areal coverage that could act as seafloor habitat
- Volumes involved interesting for organic carbon transport (and burial efficiency)
- Helps with interpretation of geophysical data

However, there was a lot of interest in including other data / information that enables much more and could push the science further forwards. In particular, the **inclusion of geotechnical and physical properties data (incl. pore pressure data)** was of interest to many in the group. Davide Gamboa has collated a lot of IODP/ODP physical property data in an informal way. This should include characterisation of landslide deposits (e.g. to understand their influence on fluid flow etc) but also of unfailed slopes to try and address forward slope stability modelling and why some slopes fail and others do not. An improved integration with geomechanics and geotechnics disciplines is welcome and could lead to some big forward steps in knowledge.

It was decided that **as a first step, we should aim to demonstrate that we can form a successful database with morphometric data, but design the database such that it is future-proofed to allow inclusion of additional data types**. Hence, discussion turned to existing database such as the ASTARTE tsunami database and Leeds Turbidite Research Group database. **Deciding what data should be included is key to deciding on which platform we should host the database.**

Additional layers to include in the database for context could include GEBCO/ EMODNET bathymetry, global structural map(?), Geomorphology of the Oceans map (see below)from Harris et al 2014 (Harris, P. T., Macmillan-Lawler, M., Rupp, J., & Baker, E. K. (2014). Geomorphology of the oceans. Marine Geology, 352, 4-24.)



List of parameters that can be readily recorded in a first iteration of the database:

ID
Parent_ID
Name
Aliases
Sources
Data_repositories
Object_type [single event, multiple events]
Landslide_type [attached detached]
Data source
Contact person and role
Mapper

Lat_centrepoint
Long_Centrepoint
Lat_Scar_centre
Long_scar_centre
Tectonic Setting [active margin, …]
Geomorphic Setting [fjord lake, …]
Water_depth_min
Water_depth_max

Slope_gradient – measured laterally away from the scar outside of the zone of deformation
Slope_gradient_notes (text)
Slope_gradient_toe – measured in front of the toe outside of the zone of deformation

Depth_below_seafloor_metres
Depth_below_seafloor_twt
Age_years
Age_period

Data_type {multiple choices} [chirp 3d seismic 2d seismic]
Data_hor_resolution
Data_vert_resolution

Seafloor features [pockmarks compression ridges]

Total_length – from head scarp to the end of the deposit
Deposit_Length
Evacuation_area_length
Scarp_perimeter – includes the side scarps
Composite_scarp_height – height difference from the max convex point in the top to the max concave point at the bottom
Evacuation_height – height difference from the top of the scarp to the glide surface
Scarp_surface_nature [concave, stepped, …]
Max_scar_width
Max_deposit_width – orthogonal to deposit length
Thickness_max, thickness_max_twt
Thickness_mean, thickness_mean_twt
Thickness_other, thickness_other_twt
Thickness_other_type, Thickness_other_twt_type [apparent, median]
Volume
Volume_notes (text)
Basal_surface_type [smooth rugose]
Upper_surface_type [smooth rugose]

4. HOW TO DESIGN A DATABASE AND WHAT PLATFORM TO CHOOSE?

Key points:

- **Terminology must be standardised in some way**
- Uncertainty of size and recurrence intervals is an ongoing problem
- Morphometrics are important, but we need to tie in to good sedimentologic data
- How do we report the sediments and grain sizes?
- **Keen to present data spatially as well as having the option to interrogate the quantitative information** (e.g. in SQL form)
- ArcGIS is one option for a platform (with hierarchical attribute tables) but the online accessibility can be difficult.
- **Google Fusion looks very promising as a platform** and would be compatible with ArcGIS allowing for creation of attribute tables, inclusion of shapefiles and/or coordinates (plotted on a map view) and is open access (or could have restrictions/permissions if sensitive data included).

Recent experiences from the group of building databases:

David Voelker: Presented an overview of the ASTARTE (Assessment, strategy and risk reduction for Tsunamis in Europe) project. This includes a GIS database of tsunamigenic offshore faults, landslides and also onshore tsunami deposits. The database is hosted by the Instituto Naionale di Geoficia a Volcanologia (INGV - Paolo Marco de Martini and Antonio Patera). They have offered to host a larger database and expand the ASTARTE database, but they stress that they will not curate or vet data – they will simply host it within the existing framework.

David also referenced datasets that he is involved with that could be available for a database: South China Sea (125 slides0, East Australia (250 slides), Central America (145 slides), Chile (60 slides).

Marco Patacci: Leeds University (Turbidite Research Group) have been building a database for the oil industry to capture architecture and geometries of sedimentary systems. It is a relational object oriented database.

Leeds Uni have developed a 50 page standard that defines how objects are measured and categorised. It was agreed by the group that **we need clear definitions or a standard**, but that we would hope to do it more concisely than this. When you make a standard and you make a definition, it does not really matter what the definition is. They allow a lot of different measurements and definitions (for example length is documented in different ways) but it is important that you explain how it is collected and what those terms mean to each author.

Marco explained how it is important to get the design right at the outset. E.g. Strongly spatially oriented database versus data that is purely relationship-oriented.

The TRG database mostly comprises outcrop data; hence variables such as lengths, widths, not really sure where you are spatially. The database is very object oriented. For example, they have a submarine channel – length, width, grain size along a line for instance, sinuosity, etc.

Advanced GIS databases should be used to INTEGRATE various types of data so that we can 1) host them spatially and 2) interrogate them to create cross plots and understand quantitative relationships.

Inputting the data into the database will require dedicated people who are trained with the standard.

Gatekeeper(s) needed to vet that the data meets the standard quality.

Ricardo Leon: Geological Survey of Spain has collated a database of submarine landslides offshore Spain. This primarily includes morphometric data as well as age information (and will include information on "activity").

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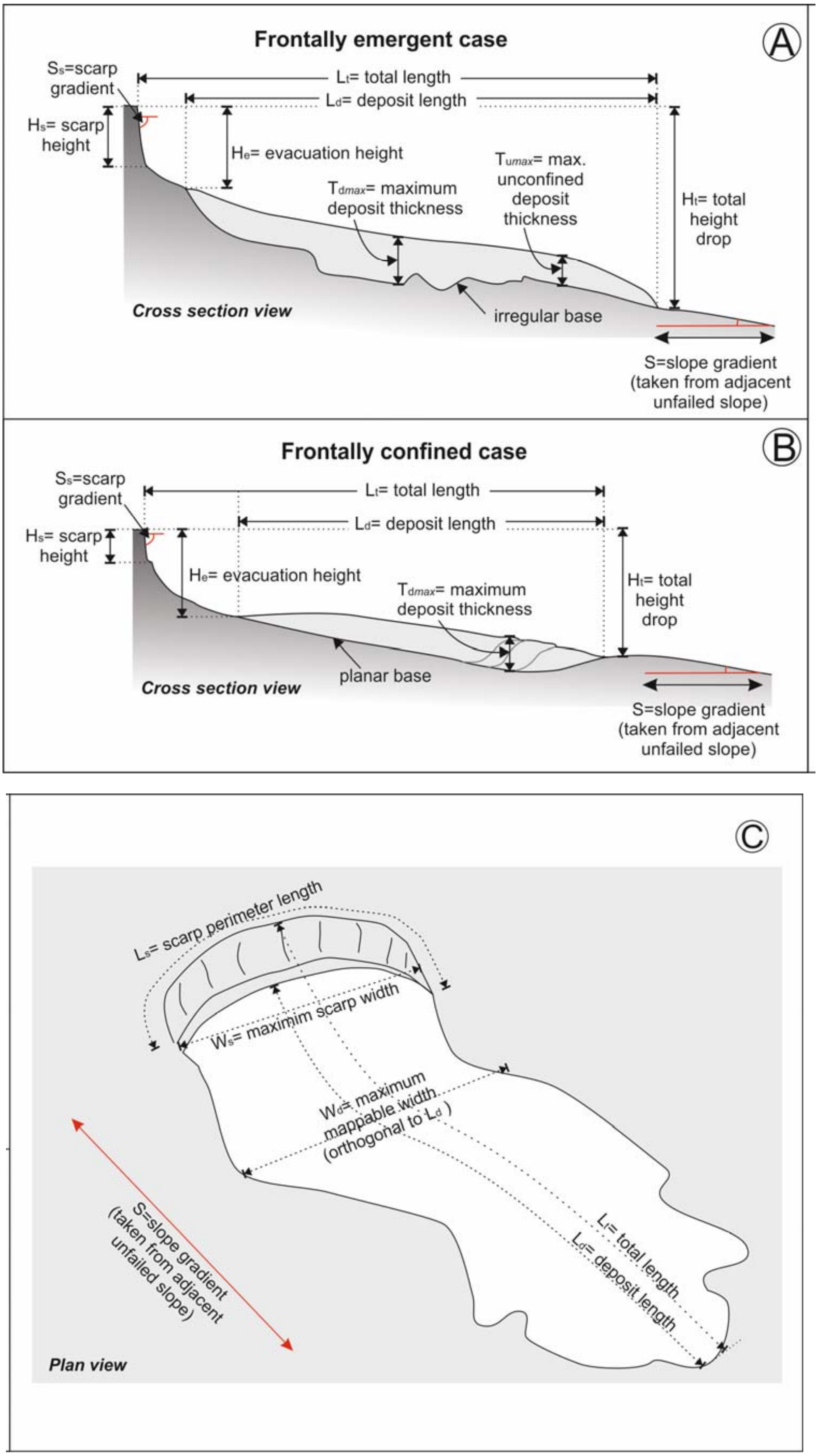
5. HOW DO YOU MEASURE A LANDSLIDE?

Some of the key discussion points were as follows:

- How are we making measurements? Not consistently at the moment
- How to measure length? Distance from scar (straight line or curved)? Length of deposit? Distance along failed area?
- How to compare measurements between different datasets?
- Which datasets allow us to measure what? What are the limitations of certain datasets? E.g. we cannot expect Storegga sized (or much smaller) landslides to be mappable from outcrop data!
- Scaling relationships from experimental, lake to full scale continental margin collapse?
- How to measure height?
- Do we have to measure things in the same way? E.g. outcrop vs remote geophysical sensing
- Thickness – there can be much variability along-strike as well as down-dip. Most simple is to measure average thickness.
- How can we include core data (e.g. at a point, and that may include stacked landslide deposits without areal extent)
- Should runout blocks be included as part of the slide runout length? Event if they are detached from the slide mass?
- Important to define frontally confined or emergent – no need to define slump, debris flow etc as it can be subjective and vary down-slope
- Estimates of runout length and volume will be variable if just consider multibeam – may increase once sub-bottom profiler data are interrogated. Examples provided from Chilean lakes by Jasper Moernaut.
- Useful to present associated features (e.g. pockmarks) that provide contextual information
- How to measure slope? Slope of the headscar, slope of the glide plane, slope of the unfailed slope…
- What about landslide complexes? In the database these could have a parent-child relationship (e.g. parent is complex, children are individual failure elements)
- Useful to measure scarp height as well as the height of displacement (which may be larger than the scarp height)
- If measured from seismic data – present the two way travel time as well as depth (and reference the assumed seismic velocity for the conversion in the metadata)
- Is there erosion or not at the base? Useful information to know.
- Apparent vs actual measurements (e.g. 2D seismic and outcrop measurements are likely to be underestimated.

It was agreed that all attendees would provide annotated examples of their data with the following key parameters measured (where possible) to explore the applicability and potential pitfalls of the approach. This should include a wide range of data types and settings (geographically and geologically). Before this, two examples (one "easy" and one "difficult") will be shared with the group so we can all try and measure the parameters and compare the results. The thinking being, that we as a group should be competent to do this well! So it will be interesting to compare the results as a sensitivity assessment.


A
Frontally emergent case
S_s=scarp gradient
L_t= total length
L_d= deposit length
H_s= scarp height
H_e= evacuation height
T_{umax}= max. unconfined deposit thickness
T_{dmax}= maximum deposit thickness
H_t= total height drop
Cross section view
irregular base
S=slope gradient (taken from adjacent unfailed slope)
B
Frontally confined case
S_s=scarp gradient
L_t= total length
L_d= deposit length
H_s= scarp height
H_e= evacuation height
T_{dmax}= maximum deposit thickness
H_t= total height drop
Cross section view
planar base
S=slope gradient (taken from adjacent unfailed slope)
C
L_s= scarp perimeter length
W_s= maximim scarp width
W_d= maximum mappable width (orthogonal to L_d)
L_t= total length
L_d= deposit length
S=slope gradient (taken from adjacent unfailed slope)
Plan view

Summary identifying information	**ID**	Sequential (automated)
	Parent ID	Parent refers to landslide complex, individual ID nos are for each mappable landslide
	Name	Published or otherwise
	Aliases	Other names for the same landslide
	Landslide type	Simple definition = is it frontally confined or frontally emergent? For reasons of simplicity and to avoid complications in interpretation, this is not in relation to classifications that include translational, rotational, debris flow etc.
	Object type	Single or multiple events (Multiple events will be linked to a parent ID)
	Depth below seafloor (m)	For landslide measured from subsurface data this is the depth to the top of the landslide deposit. If calculated from seismic data, the TWTT should also be referenced in the adjacent column. If mapped from MBES data without seismic or core sample calibration this will not be possible to complete.
	Depth below seafloor TWTT	For landslides measured from subsurface geophysical data, indicate the depth in two way travel time (milliseconds) to the top of the landslide deposit.
Measured landslide morphometrics	**Latitude centrepoint**	This is the centrepoint of the mappabale feature. It is recognised that the entirety of a landslide may not be mappable due to data coverage limitations etc, hence this is primarily intended to locate the feature on the global database. In WGS 84
	Longitude centrepoint	This is the centrepoint of the mappabale feature. It is recognised that the entirity of a landslide may not be mappable due to data coverage limitations etc, hence this is primarily intended to locate the feature on the global database. In WGS 84
	Water depth min	This is the minimum water depth for the mappable feature in metres.
	Water depth max	This is the maximum water depth for the mappable feature in metres
	Total Length L_t	Total mappable length of slide from upslope limit of headscarp to downslope limit of connected deposit (excludes outrunner blocks). This is measured along the course of the landslide if possible (e.g. from MBES data), otherwise this is a straight line (e.g. measured from 2D seismic data) and is an "apparent" length measurement
	Deposit Length L_d	Total mappable length of slide deposit (excludes outrunner blocks). This is measured along the course of the landslide if possible and hence is not necessarily a straight line (e.g. from MBES data), otherwise this is a straight line (e.g. measured from 2D seismic data) and is an "apparent" length measurement
	Evacuated Length L_e	Equal to Lt minus Ld
	Length notes	Is this measured from a section and is an apparent measurement (and thus may be an underestimate), or otherwise how was the distance calculated?
	Scarp perimeter length L_s	Length of scarp perimeter (includes side scarps)
	Scarp height H_s	Height difference from the max convex point in the top to the max concave point at the bottom
	Evacuation height H_e	Height from upslope limit landslide deposit to upslope limit of headscar
	Scarp width W_s	Maximum scarp width

	Scarp surface nature	Concave, stepped etc
	Maximum deposit width W_d	Maximum deposit width (measured orthogonal to deposit length, Ld)
	Maximum deposit thickness (m) T_{dmax}	Maximum measured deposit thickness in metres
	Maximum deposit thickness (TWTT) T_{dmax}	Maximum measured deposit thickness in two way travel time (in milliseconds)
	Maximum unconfined deposit thickness (m) Tumax	Maximum measured unconfined deposit thickness in metres
	Maximum unconfined deposit thickness (TWTT) T_{umax}	Maximum measured unconfined deposit thickness in two way travel time (in milliseconds)
	Thickness notes	How was thickness calculated? E.g. Derived from MBES, measured from seismic (with which assumed seismic velocity?), or calibrated with core sampling data?
	Total height drop H_t	Height from downslope limit of landslide deposit and upslope limit of headscarp
	Slope gradient S	Measured laterally away from the scar outside of the zone of deformation. This is intended to give an estimate of the gradient of the unfailed slope. In degrees
	Slope gradient notes	Notes added here to indicate the distance of lateral offset of the measurement, distance over which gradient was measureed and any uncertainties etc.
	Slope gradient of headscarp S_s	Maximum slope of the headscarp
	Slope gradient of headscarp notes	Where was this measured?
	Slope gradient toe S_t	Measured in front of the toe outside of the zone of deformation. In degrees
	Slope gradient toe notes	Notes added here to indicate the distance of lateral offset of the measurement, distance over which gradient was measured and any uncertainties etc.
Interpreted landslide metrics	**Basal surface type**	Description of basal surface (e.g. rugose, planar etc)
	Upper surface type	Description of upper surface (e.g. rugose, smooth etc)
	Volume (km^3)	Calculated deposit volume in km3
	Volume notes	How was volume calculated? What are the assumptions?
	Age (years)	If known, this is the age of the landslide in years. This may be an absolute value or a constrained age (e.g. >45 ka)

	Age error	Where available, the error ranges of the dates should be presented
	Age notes	Information on the dating method, uncertainities, where the sample was taken and any assumptions should be referenced. Here the source of the age should also be referenced.
	Seafloor features	Useful extra information, about seafloor features in vicinity or in association with the landslide deposit, such as evidence of fluid expulsion (e.g. pockmarks)
Metadata	**Data type**	Data on which the mapping was based - High level statement (e..g. bathymetry, combined bathymetry and geophysics, core, deep seismic). Will be a drop down menu
	Data type notes	Data on which the mapping was based - more details can be provided here on combinations of sources (e.g. hull-mounted MBES, AUV data, 2D/3D seismic, sediment cores etc.). This may be a combination of sources
	Data source	Reference to where the data came from e.g. the data provider and the cruise etc. This should include a hyperlink.
	Data repositories	Where can the raw/processed data be found if they are available? This should include a hyperlink if available.
	Publication source	Where is the peer-reviewed source? If not, then link to cruise report or equivalent. If not published then this needs to be flagged. This should include a hyperlink.
	Depth below seafloor notes	Notes to accompany the depth. For instance, is it the only measureable depth, an average depth or maximum depth. What was the assumed (or calibrated) seismic velocity?
	Data Contact	Who is the contact for this dataset?
	Database entry attribution	Who entered the data in the database?
	Database entry notes	Any specifics to the data that was entered. For example, was length recalculated from that in the original published material?
	Data horiz resolution	What is the horizontal resolution of the data from which the measurements were made?
	Data vert resolution	What is the vertical resolution of the data from which the measurements were made?
	Additional notes	Comments on any other information/considerations that should be borne in mind when using these data

6. WHAT ARE THE POTENTIAL (AND IMMEDIATE) FUNDING SOURCES?

UK NERC funding

UK NERC (Natural Environment Research Council) may be viable if we can spell out a compelling enough science case. What is novel? What "step change" is possible?

For an industry-facing output, NERC Pathfinder call may be useful (£10-£20K pumpr-priming funds available to lead on to larger project c. £250k).

NERC International Opportunities Fund may be useful. It was decided that this is a no-brainer to pitch a proposal. Mike Clare will progress this once the call comes out (expected in May). Last year's call details below:

"NERC is inviting proposals for Pump Priming and Pump Priming Plus grants to its International Opportunities Fund (IOF). The IOF scheme provides resources to NERC-supported researchers to allow them to forge long-term partnerships with overseas scientists that add value to current NERC-funded science. IOF grants are pump-priming, to help stimulate novel research collaborations. Mature research collaborations should apply to NERC's Standard or Large Grant schemes, which allow for overseas project partnerships, or to other appropriate sources of funding.

Proposals for IOF Pump Priming grants may request funding of a maximum of £40k (at 80% FEC) for up to two years duration.

Proposals for IOF Pump Priming Plus grants may request funding of a maximum of £250k (at 80%FEC) for up to three years duration."

Since the workshop **Mike Clare has been awarded £20k through NERC to start creating a database of landslides offshore from Small Island Developing States** that are in receipt of Official Development Aid.

EU Funding

David Voelker will explore what EU funding opportunities may exist.

Cost Actions (http://www.cost.eu/COST_Actions) could provide financial support for networking, meetings, workshops etc. COST is supported by the EU Framework Programme for Research and Innovation Horizon 2020. The next collection date is expected to be 7 September 2017.

7. ADDITIONAL PEOPLE TO INVITE TO CONTRIBUTE

Some discussion was had on the basis of who else should be brought into email discussions and invited to future meetings. Some suggestions were:

- Morelia Urlaub – GEOMAR (numerical modelling and landslide age database)
- James Goff - PANGEA Research Centre, Sydney (data on atolls, South Pacific etc) [Mike Clare will be meeting with James in July so will discuss this then)
- Lara Perez - GEUS Geological Survey of Denmark and Greenland (data on Arctic and Antarctic slides)
- Maarten Vanneste – NGI (with good links to geotechnical aspects)
- Andrew Green – University of Kwazulu-Natal, South Africa (data on African landslides)
- Katrin Huhn – Bremen, Germany (links to laboratory experiments – Mike Clare will see her in March so will discuss this then). She is running the new Horizon 2020 SLATE project
- Samantha Clarke/Tom Hubble – Sydney University (data on Australian landslides)
- Marc De Batist (Ghent Uni, Belgium) and Michi Strasser (Innsbruck Uni) – lacustrine studies as well as a number of marine studies including offshore Japan.

8. FUTURE DIRECTIONS AND ACTIONS

- David Voelker to explore EU funding opportunities.
- Mike Clare to explore UK funding opportunities. SOME INITIAL FUNDING (£20K) WON SINCE MEETING
- David Gamboa to present poster at GeolSoc meeting and report back. DONE. POSITIVE FEEDBACK.
- Lesli Wood and Zane Jobe to present poster at AAPG meeting
- Mike Clare to distribute attribute table for measuring landslide morphometrics with summary cartoon/schematics illustrating the “standard” defined in the workshop. CIRCULATED.
- Sebastian Krastel to share “difficult” example for mapping submarine landslides. CIRCULATED.
- David Voelker to share “easy” example for mapping submarine landslides. CIRCULATED.
- All attendees and others to map these two examples and provide metrics to Mike Clare and David Voelker to compile. AWAITING SEVERAL RESULTS.
- All attendees to provide annotated example(s) of subaqueuous landslide with the defined metrics measured (to be incorporated in paper for S4SLIDE conference in 2018). Ideally this will include a wide variety of settings, landslide types and data types to show how the method can work and identify some pitfalls for future guidance. NONE PROVIDED YET.
- David Voelker to feed back results of workshop to ASTARTE committee at project close out meeting in April.
- Mike Clare to synthesise an abstract for S4SLIDE conference in 2018 (due Feb 2017). SUBMITTED.
- Mike Clare to set up dummy database to start population with data from attendees to test the framework. ATTRIBUTE TABLE CIRCULATED.