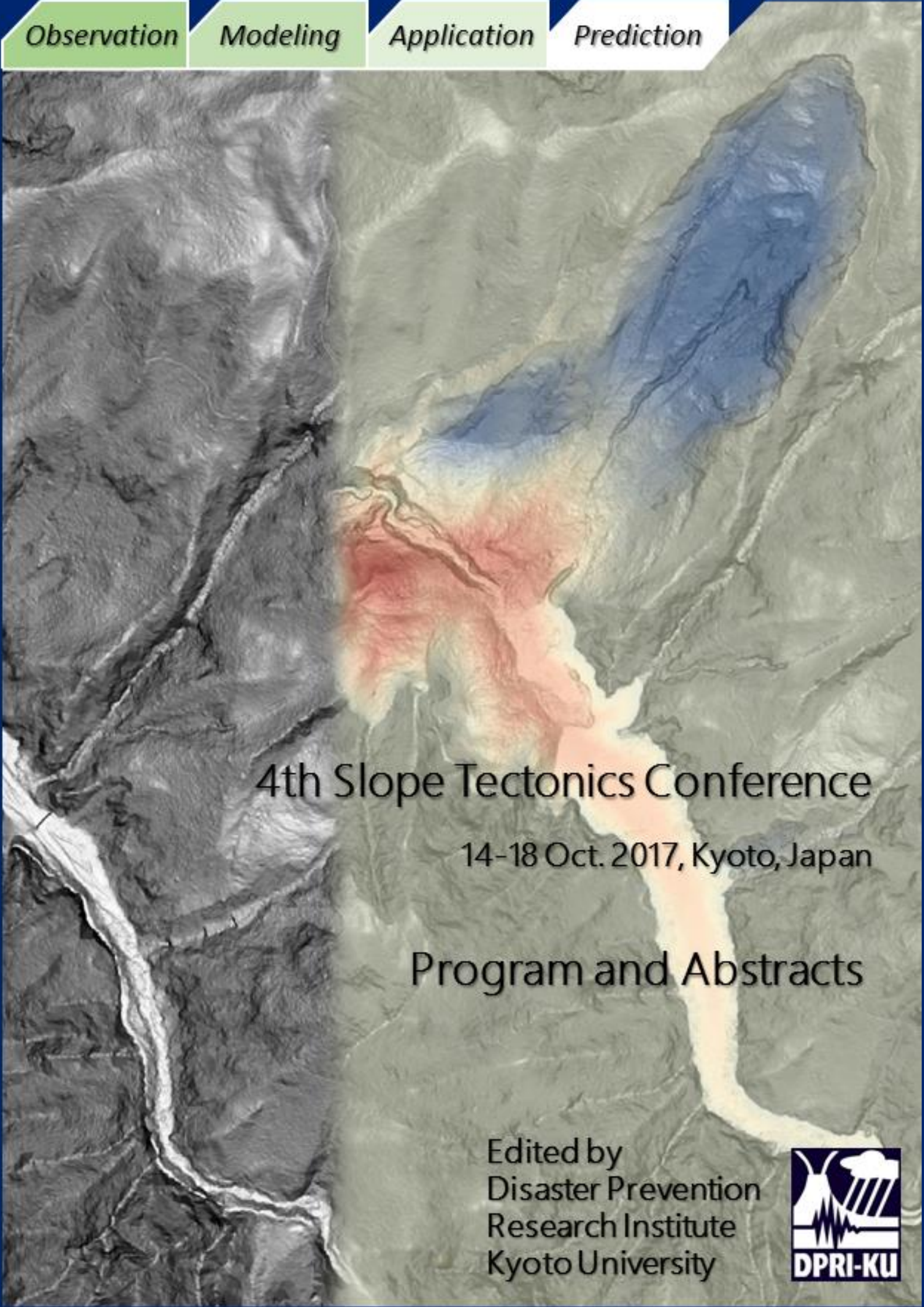
Observation Modeling Application Prediction



4th Slope Tectonics Conference

14-18 Oct. 2017, Kyoto, Japan

Program and Abstracts

Edited by
Disaster Prevention
Research Institute
Kyoto University

DPRI-KU

Contents

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Japan Society of Engineering Geology	The Geological Society of Japan	The Japan Landslide Society
Association for Disaster Prevention Research	Global Alliance of Disaster Research Institutes	Disaster Prevention Research Institute, Kyoto University

4th Slope Tectonics Conference 2017 Kyoto

Welcome to Japan and DPRI-Kyoto University

We are very pleased to be able to host the 4th Slope Tectonics Conference in Kyoto. The conference has been successfully held in Lausanne, Switzerland in 2008, Vienna, Austria in 2011, and Trondheim, Norway in 2014 and this 4th conference is the first conference in Asia.

Japanese islands are located on an area with high tectonic activity and humid climate, and have been suffering from various landslide hazards induced by earthquakes, rainstorms, and heavy snowfall. Our field trip goes to the Kii Peninsula, which is underlain by accretionary complexes and suffered from large landslide disasters. We will see catastrophic landslides and their preparatory processes including deep-seated gravitational slope deformation and rock weathering.

Slope tectonics is a young geoscience discipline that deals with slope movement processes controlled by various factors; the slope movements include very slow to extremely rapid phenomena, which are in other words natural hazards.

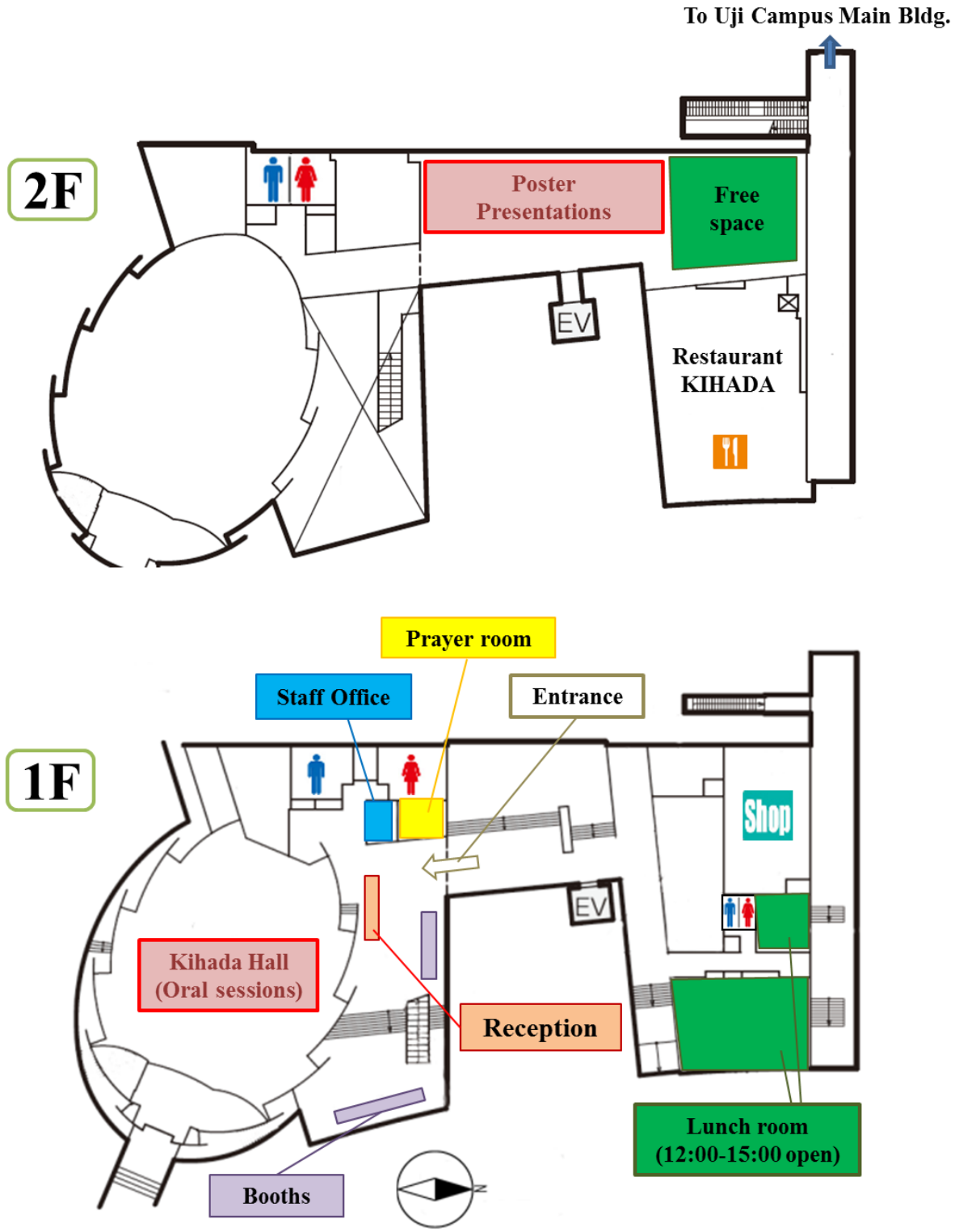
This 4th Slope Tectonics Conference is held as a symposium of DPRI and is supported by three academic societies, two academic organizations, 11 private companies of geological engineering, and Kyoto Prefecture and Kyoto Convention & Visitors Bureau. We are very glad to organize this conference based on such a solid foundation.

We have 80 papers from 14 countries/areas, and we are sure that we will have fruitful discussions. We hope all the participants enjoy the conference, Kyoto, and Japan in this beautiful season.

14 October 2017

Masahiro Chigira
Chair of the 4th Slope Tectonics Conference

Conference venue - Uji Obaku Plaza



Program of the 4th Slope Tectonics Conference

Oral sessions at Kihada Hall

October 14, 2017 (Saturday)

15 min for each = 12 min talk + 3 min discussion

9:30 9:30~9:45		Opening **Welcome addressing (Prof. Nakagawa and Prof. Chigira)**
Session 1 (9:45~11:00)		Chairs: Jaboyedoff Michel, Baron Ivo
Time	**Presenter**	**Title**
9:45~10:00	Corominas Jordi	Geological structure and relief as controls for the occurrence of large slope failures in the Pyrenees
10:00~10:15	Kojima Satoru	Geomorphological and geological characteristics and development history of deep-seated gravitational slope deformation in the Kanmuriyama area, central Japan
10:15~10:30	Briestensky Milos	Active tectonics affecting the development of deep seated gravitational slope deformations in the Western Carpathians
10:30~10:45	Hirata Yasuto	Rain-induced landslides of granite porphyry which was weathered with many corestones in higher elevations
10:45~11:00	Matsushi Yuki	Multi-scale mass movements in a dip slope of accretionary complex with contact metamorphism and extensive high-angle faulting: a case in Hira Range, central Japan
Break (11:00~11:15)		
Session 2 (11:15~12:30)		Chairs: Giovanni Crosta, Briestensky Milos
Time	**Presenter**	**Title**
11:15~11:30	Chigira Masahiro	Deep-seated gravitational slope deformations that develop to catastrophic landslides
11:30~11:45	Yassaghi Ali	Allochthonous Collapse Structures in Zagros Fold Thrust Belt
11:45~12:00	Matsuoka Norikazu	A multi-method approach to detecting bedrock fracturing and rockfall activity in the Southern Japanese Alps
12:00~12:15	Arai Noriyuki	Rain-induced rockslides controlled by a thrust fault and river incision in an accretionary complex in the Shimanto Belt, Japan
12:15~12:30	Baron Ivo	Deciphering large deep-seated gravitational slope deformation stress states in active tectonic settings using contemporary three-dimensional fault-slip data
Lunch + Poster (12:30~14:30)		

Session 3 (14:30~16:00)		Chairs: Dong JJ, Alfaro Pedro
Time	**Presenter**	**Title**
14:30~14:45	Kang Keng-hao	Geological model of a potential large-scale landslide and its implication on the possible failure mechanism - paleo and future in southern Taiwan
14:45~15:00	Carey M. Jonathan	Simulating the behavior of slow-moving landslides using a Dynamic Back Pressured Shear Box (DBPSB)
15:00~15:15	Yang Che-Ming	Revisit the classical Newmark displacement analysis for earthquake-induced wedge slide - The kinematics and initiation of the Daguangbao landslide
15:15~15:30	Sezaki Shotaro	Rockslide simulations based on the elasto-plastic finite element method considering the balanced cross-section concept
15:30~15:45	Agliardi Federico	Influence of non-persistent slope-scale brittle features on DSGSD mechanisms and activity
15:45~16:00	Lin Ching-Weei	Large-scale landslide susceptibility assessment of Kaoping River Watershed in Southern Taiwan
Break (16:00~16:30)		
Session 4 (16:30~17:45)		Chairs: Corominas Jordi, Revellino Paola
Time	**Presenter**	**Title**
16:30~16:45	Brideau Marc-Andre	Methodology to estimate the rock avalanche frequency for a specific slope
16:45~17:00	Jaboyedoff Michel	3D failure surface and volume estimation of large rock slope instabilities: a review of a bottleneck problem
17:00~17:15	Wei Lun-Wei	Revealing the evolution of slope deformation by adopting UAV techniques
17:15~17:30	Rau Ruey-Juin	Continuous GPS observations on deep-seated gravitational slope deformation in the Lushan area, central Taiwan
17:30~17:45	Migon Piotr	Using Electrical Resistivity Tomography to detect internal structures of deep-seated gravitational deformations
Banquet (17:45~20:15)		

October 15, 2017 (Sunday)

Session 5 (9:15~10:45)		Chairs: Esposito Carlo, Brezny Michal
Time	**Presenter**	**Title**
9:15~9:30	Hermanns L. Reginald	Cosmogenic nuclide ages of back scarps of the Litledalen and Nomedalstinden Deep Seated Gravitational Slope Deformations (DSGSD), Northern Norway, indicate that DSGSDs can survive glacial cycles
9:30~9:45	Tseng Chia-Han	Study on a dip-slope by inclinometers and GPS monitoring at the Huafan University campus in northern Taiwan
9:45~10:00	Derron Marc-Henri	Slope deformation imaging of sandbox analogue models (LiDAR and InSAR)
10:00~10:15	Osawa Hikaru	Seasonal fluctuations in pore-water pressures of a landslide in a seasonally snow-covered area
10:15~10:30	Chen Rou-Fei	Deformation characteristics and surface monitoring of deep-seated gravitational slope deformation in the Tienchih area, southern Taiwan
10:30~10:45	Brezny Michal	Gravitational transpression folds formed in the large-scale sackung: an example from flysch Carpathians
Break (10:45~11:00)		
Session 6 (11:00~12:30)		Chairs: Hermanns L. Reginald
Time	**Presenter**	**Title**
11:00~11:15	Crosta B. Giovanni	Activity of large slope instabilities and denudation rate in the European Alps
11:15~11:30	Lu Jia-Hao	A case study on the comparison of blogging applied to core description with well logging results in potential landslide area
11:30~11:45	Troon Marko	An introductory, geostatistical and geomorphological review of the effects of geohazards and severe weather events as a retrospect throughout 2009/2010 in Norway
11:45~12:00	Zhao Siyuan	The response of catastrophic landslides to fluvial incision in the upstream of Minjiang River, Western Sichuan, China
12:00~12:15	Zerkal V. Oleg	The influence of tectonic agents on the activity of landslides on the west Caucasus area (Russia)
12:15~12:30	Sato Tatsuki	Geological background of landslides induced by the 2016 Kumamoto earthquake in the Aso caldera with special reference to the weathering processes

Lunch + Poster (12:30~14:30)		
Session 7 (14:30~15:45)	Chairs: Jon Carey, Bertolo Davide	
Time	**Presenter**	**Title**
14:30~14:45	Yamada Masumi	Dynamic movement history of the 2017 Iiyama landslide revealed from drone image and seismic data
14:45~15:00	Doi Issei	Behavior of a gravitational deformation slope during earthquake shaking revealed by seismic observation
15:00~15:15	Ma Ning	On the co-seismic responses of a deep-seated landslide: Insight by monitoring
15:15~15:30	Inagaki Hideki	Relationship between distance from active fault and scale of slope failure in Japan
15:30~15:45	Kuo Hsien Li	Assessing Rainfall Threshold for Large-scales Landslide by Exacting occurrence Time of Landslides from Seismic Records
Break (15:45~16:00)		
Session 8 (16:00~17:15)	Chairs: Tsou Ching-Ying, Troon Marko	
Time	**Presenter**	**Title**
16:00~16:15	Matsuura Sumio	Observations of pore-water pressure during failure in a moving landslide body
16:15~16:30	Wang Gonghui	The internal structure of Nagatono landslide dam and landsliding mechanism
16:30~16:45	Bertolo Davide	The Mont de La Saxe Landslide (Valle d'Aosta-Italy) - Evolution a large alpine landslide controlled by different hydrogeological components
16:45~17:00	Lin Hsi-Hung	Geological characteristics and multi-disciplinary observation in the active deep-seated slope deformation in slate in LuShan, Taiwan
17:00~17:15	Li Kuo-wei	The activity assessment of potential large-scale landslide by means of multi-staged images and data from aerial photographs
Closing (17:15-18:00)		

Poster session at the poster hall (2F)

Core time: 13:30-14:30 of Oct. 14 & 15, 2017

Please check poster number to locate the display board. You can display your poster from 09:00 Oct 14 to 17:00 Oct 15. It is noted that tiding up of the posters should be finished **before 17:00 Oct 15**.

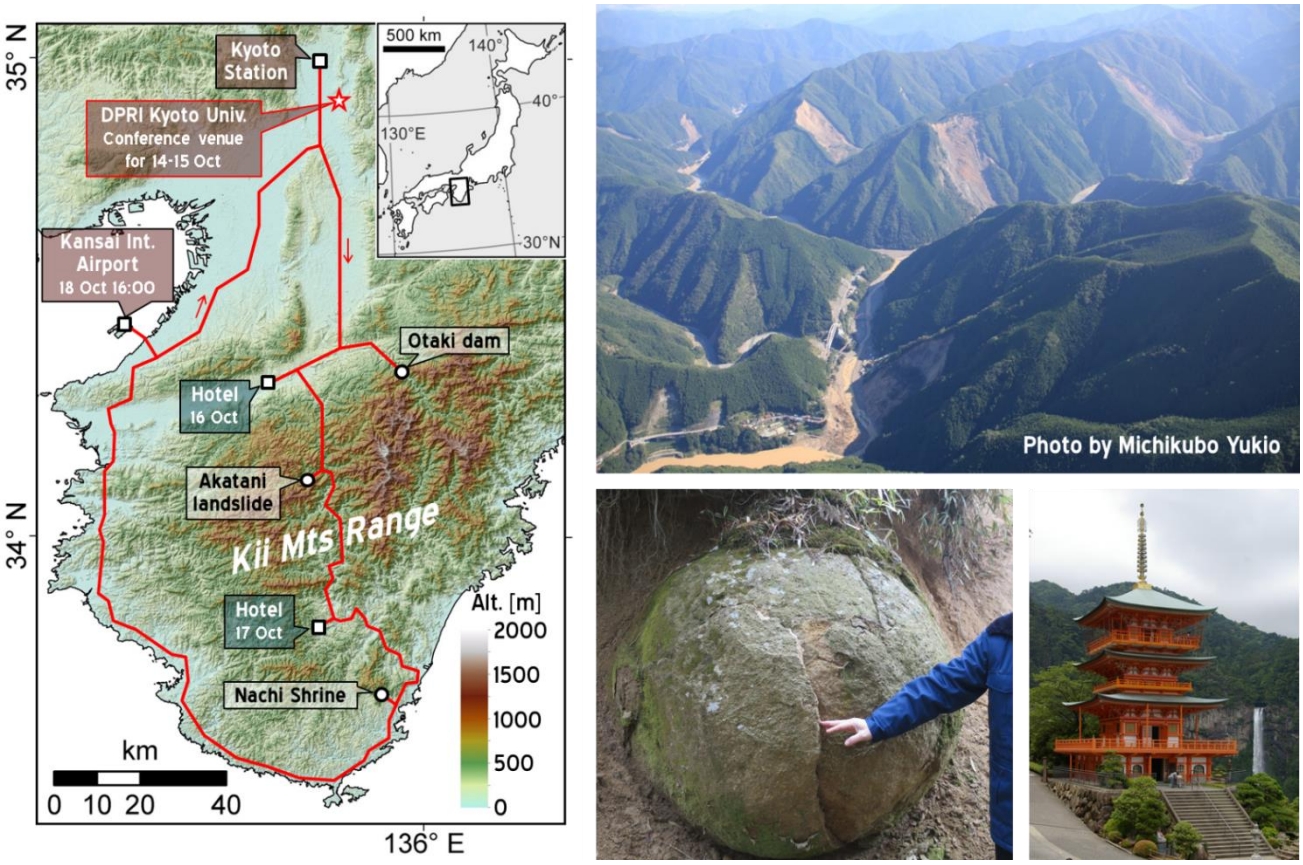
No.	Author	Title
P1	Fujii Yukiyasu	Geological background of Nagiso debris flow occurred on July 9 2014, in Nagano prefecture, central Japan
P2	Ando Naomi	Temperature and sound survey on steep tea farm area and salt pan site
P3	Jiang Yao	Shear surfaces of simulated shear zones control mechanical behaviors of granular materials
P4	Hsieh Yu-Chung	Normal faulting and gravitational slope deformation in the central range of Taiwan
P5	Chen Mien-Ming	How deep-seated gravitational slope deformations are transformed into large-scale landslides: an example of 2009 Typhoon Morakot
P6	Krogh Kaja	The Kassen and Hakaneset rock slope instabilities along fjord lakes in Telemark, Southern Norway
P7	Liu Chih Hsuan	Dynamic process analysis for the initiation time of the Aso-bridge co-seismic landslide
P8	Tsou Ching-Ying	Coupling fluvial processes and landslide distribution toward geomorphological hazard assessment: a case study in a transient landscape in Japan
P9	Nagata Hidehisa	Gravitational deformation around Tokugo-toge Pass, Northern Japan Alps
P10	Tajika Jun	A huge frontal bulge of the Horomoe landslide, Shiretoko Peninsula, Hokkaido, northern Japan
P11	Ohta Takehiro	Numerical study on influences of gravity and geometry to large-size landslides
P12	Yokoyama Osamu	Gravitational slope deformation and its transformation into catastrophic landslides during earthquakes in a slate area
P13	Nishiyama Nariaki	Distribution of highly saline groundwater in the areas with many landslides in the southern Niigata Prefecture
P14	Kikuchi Teruyuki	Deformation measurement of slow velocity landslide by analysis of three-dimension point clouds
P15	Kawabata Daisaku	Effects of geological division on geomorphic parameters in Japan based on the spatial analysis of the seamless geological map of Japan

P16	Yamakawa Yosuke	A risk evaluation method for deep-seated landslides based on stream water chemistry
P17	Komata Shinjuro	Sorting out landslide topography in Japan by knick line distribution, and geological signs of landslide occurrence
P18	Furuki Hirokazu	Structural features and formative processes of a sliding zone of a large rockslide
P19	Yagi Hiroshi	Bell-shape index indicating top-heavy profile of high relief mountain and gravitational deformation
P20	Watanabe Tatsuya	Integrated landslide survey using UAV-SfM and geophysical technologies: a case study in Rikubetsu, Hokkaido, Japan
P21	Ota Yoshimasa	Locations and ages of large mass movements in a high-relief mountainous area underlain by accretionary complex: a case of the Katsuragawa Valley along the Hanaore Fault, central Japan
P22	Istiyanti L. Mega	Characteristics of soil layers on shallow landslides triggered by rainfall at Izu Oshima, Japan
P23	Sato P. Hiroshi	Interpretation of L-band InSAR images to detect landslide surface deformation along Minjiang River, Western Sichuan, China
P24	Doshida Shoji	Evaluation of secondary slope failure susceptibility using detailed topographic data,
P25	Goto Satoshi	Geotechnical study on fluidized landslide at Aso volcanological laboratory in the 2016 Kumamoto earthquake
P26	Watanabe Honami	Breaking-off of hanging glaciers at Mt. Langtang Lirung, Nepal Himalaya
P27	Hata Hitomi	The study of rockfall and topographical change in Shirouma-Daisekkei, the Northern Japanese Alps
P28	Esposito Carlo	Time-dependent analysis of a complex rockslide constrained by geomorphic markers
P29	Guerriero Luigi	Nucleation and kinematic significance of deformational structures in earth flows
P30	Alfaro Pedro	Time-dependent modelling of a mountain front retreat due to a fold-to-fault controlled lateral spreading,
P31	Chai Shaofeng	Dynamic responses of the intact and remodeled loess slope under the coupling effect of earthquake and rainfall: Insights on shaking table model tests
P32	Kimura Takashi	Landslide history in post-caldera central cones of Aso volcano, Japan
P33	Sasaki Natsuki	Geomorphological control on distribution and development of wetlands on large-scale landslides in Ou Mountain Range, NE Japan

P34	Ohta Ryoga	History of mass movements and paleolake formation revealed by depression-filling sediment records in a tectonically active mountainous area: a case study in Mt. Kushigata, Koma Range, central Japan
P35	Sasaki Yasuhito	Slope deformation problem in Quaternary volcanics by the 2016 Kumamoto Earthquake
P36	Dattola Giuseppe	An application of the MIBSA to slow moving landslides

Post-conference excursion to Kii Peninsula (16-18 Oct 2017)

The destination of the post-conference excursion is the Kii Mountain Range, where a severe rain-induced landslide disaster occurred in 2011. Please check the Field Trip Guide, distributed for pre-registered participants, for the time and place of meeting at 16 Oct morning. The seats for the field trip had been fully reserved. We are sorry not to be able to accept additional participation.



Road map to the Kii Peninsula.

Abstracts

Geological structure and relief as controls for the occurrence of large slope failures in the Pyrenees

Corominas Jordi[1*], Mavrouli Olga[2], Ruiz-Carulla Roger[1]

[1] Universitat Politecnica de Catalunya ([*]Email: jordi.corominas@upc.edu)
[2] University of Twente

The occurrence of large rock slope failures (RSF) is unevenly distributed in the mountain either in time or in the space. The role of the lithological, structural and relief controls for the development of large RSF has been highlighted in several research works. In the Pyrenees large RSF are present, mostly in formerly glaciated valleys. Large landslides are often found associated to the steep walls of the glacier cirques and to weak and heavily tectonized lithological formations while large DSGSD are associated to the particular arrangement of the slope fracture pattern. The overall number and density of large RSF in the Pyrenees is significantly smaller (up to one order of magnitude) than the observed in other mountain ranges. This fact has been justified by the relatively weak imprint of glacial erosion and the low mean rates of neotectonic uplift of the range. We discuss here the role of the geological structure in constraining the development of large RSF. Although large anaclinal RSF may be expected by the combination of the breakage of rock bridges with the coalescence of unfavourable dipping discontinuity surfaces, this type of large failure is rarely observed in the Pyrenees. In this contribution, we discuss the role of the fracture pattern of the rock mass in constraining the volume of the potential failure by comparing the features of two similar granodiorite outcrops. We conclude that the presence of highly persistent fault sets plays a key role in controlling the lateral enlargement of the sliding surface and consequently, the size of the overall failure.

Geomorphological and geological characteristics and development history of deep-seated gravitational slope deformation in the Kanmuriyama area, central Japan

Kojima Satoru

Dept. Civil Eng., Gifu University (Email: skojima@gifu-u.ac.jp)

Double ridges and the sediments accumulated in the linear depression between them in the Kanmuriyama area in central Japan were examined geomorphologically, geologically, and geophysically. Geomorphological studies in the field by using the detailed topographic map made by 1 m-mesh LiDAR DEM indicate that the double ridges are features of deep-seated gravitational slope deformation that the basement rock mass is sliding to the east by slumping. The basement rocks in this area are composed of Triassic chert and Jurassic sandstone generally trending WNW-ESE, and the depression between the ridges is filled with muddy sediments. We obtained cores of the sediments by hand-auger boring, the lithology of which is, from younger to older, alternating peat and carbonaceous mud, light gray sticky lacustrine mud, and yellowish-brown mud and silt with basement rock clasts. The thickness of the sediments is 280 cm at maximum, and is thinning to the east, that is consistent with the formation model of the double ridges by the eastward slumping. The AMS-14C ages of wood fragments and the ages of tephra sandwiched in the sediments clarified that the double ridges formed about 10 ka and have been stable until now, and that the average sediment accumulation rate is 0.25 mm/year. The electrical resistivity survey shows clear difference of resistivity at the boundary between the basement rocks and the sediments. The results of survey also indicate the existence of not only eastward sliding plane, but also westward sliding plane.

Active tectonics affecting the development of deep seated gravitational slope deformations in the Western Carpathians

Briestensky Milos*, Stemberk Josef

Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic
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Long term systematic 3-D monitoring of fault slips was used to demonstrate the influence of recent tectonic movements on deep seated gravitational slope deformations (DSGSDs) across different geological regions of the Western Carpathians. This systematic monitoring is managed by IRSM using a sensitive TM71 3-D extensometer. The extensive monitoring network TecNet (www.tecnet.cz), preferably situated underground within the caves, galleries or tunnels, includes also caves connected to DSGSDs. We describe the active fault slips recorded within caves formed inside the DSGSDs in the flysch formation of the Outer Western Carpathians (Knehyne and Cyrilka Caves in the Moravskoslezske Beskydy Mts., monitored since 2002 and Velryba Cave in the Javornik Mts., monitored since 2005) as well as in the limestone formation of the Inner Western Carpathians (Driny Cave in the Male Karpaty Mts., monitored since 2005 and Parohy Cave in the Velka Fatra Mts., monitored since 1973). Previous geomorphological and geological studies defined the extent of the slope deformations as well as their relationship to the fault structures crossing the monitored slope deformations. We define their kinematics behavior based on long term systematic 3-D monitoring. The monitored faults of Knehyne Cave displayed significant dextral strike-slip trends (0.06 and 0.015 mm/year) as well as lateral spreading (0.2 and 0.01-0.05 mm/y). The second site, Cyrilka Cave, displayed sinistral-strike slips of 0.01 mm/y and lateral spreading of 0.02 mm/y. The monitored fault slips coincide with the assumed recent tectonic stress field with a maximum compression NW-SE within this part of the Outer Western Carpathians flysch. Driny Cave displayed dextral strike-slips along the NW-SE striking fault (0.02 mm/y) and sinistral strike-slips along the SSW-NNE striking fault (0.07 mm/y). The maximum calculated compression is in a NNW-SSE direction. The last of the presented examples, Parohy site, displayed subsidence of 0.07 mm/y and dextral strike-slips of 0.032 mm/y.

Rain-induced landslides of granite porphyry which was weathered with many corestones in higher elevations

Hirata Yasuto[1*], Chigira Masahiro[2]

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[2] Disaster Prevention Research Institute, Kyoto University

Typhoon Talas brought heavy rain in the Kii Peninsula, Japan on September 2–5, 2011, causing hundreds of debris avalanches and debris flows in a granite porphyry area in the southern eastern part of the peninsula. We made field investigation and precise analyses for weathering to clarify the geological and geomorphological background of the landslides, and found that most of the debris avalanches included a lot of boulders of granite porphyry commonly larger than 1 m in diameter. Their sources were mostly in a weathered zone in-situ and were partly in debris on nearby sedimentary rocks. The Large bodies of granite porphyry have high-angle columnar joints and develop low-angle sheeting joints near slope surfaces. Granite porphyry is weathered from the joint surfaces and become a spheroidal corestone with the exfoliation by the oxygen diffusion owing to the original structure in a column. The weathering zones involving corestones form a thick mantle on low-relief surfaces in higher elevations, which are incised by erosion and mass movements. Some of the joints acted as sliding surfaces in and before the disaster. The rain-induced debris avalanches occurred near the margins of the thick weathering mantle in the granite porphyry area and went down to nearby valleys as debris flows.

Multi-scale mass movements in a dip slope of accretionary complex with contact metamorphism and extensive high-angle faulting: a case in Hira Range, central Japan

Matsushi Yuki[1*)], Hiramatsu Hisaki[2)]

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[2)] Division of Earth and Planetary Sciences, Graduate School of Science, Kyoto University

This study revealed the factors controlling gravitational hillslope deformations and landslides in varying scales in a tectonically-active, high-relief mountain range, focusing on geological structures and bedrock properties affected by contact metamorphism and extensive faulting. The study site is the western part of the Hira Range, central Japan. The hillslopes are located in an elevation range from 300 to 1000 m, forming the eastern side-slopes of deeply-incised valley of the Ado River along an active strike-slip fault, Hanaore Fault System. Bedrock in this area consists of Jurassic accretionary complex, composed mainly of alternate beds of sandstone and mudstone with chert layers, which had been extensively fractured by the activity of sub-parallel faults nearby the valley bottom. Cretaceous granite intruded in this area thermally metamorphosed the eastern margin of the sedimentary rocks. We investigated the lithological, mineralogical, and mechanical properties of bedrocks, as well as distributions of faults and topographic signals of hillslope deformations. The largest-scale of gravitational deformation extends to a whole-relief of the mountain, which seems to be affected by the development of the hornfels ridge on the crest and long-term deepening of the main valley. The mid-sized mass movements at the lower part of the hillslopes occur in response to river incision in a shorter timescale, which are triggered by undercutting through smaller-scale shallow landsliding at the slope toe nearby the trunk river. Extensive fracturing and weakening of bedrock resulting from the active high-angle faulting promote the occurrence of slope deformation and landslides, and thus influence the landscape evolution in this area.

Deep-seated gravitational slope deformations that develop to catastrophic landslides,

Chigira Masahiro[1*)], Arai Noriyuki[2)]

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Earthquake-induced or rain-induced catastrophic landslides cause enormous disaster because of their suddenness, large volume and high mobility. Their potential sites, therefore, must be predicted, but its methodology is not established yet. We know that those catastrophic landslides are mostly preceded by gravitational slope deformation, which can be a clue for the site prediction. Here we report characteristic features and internal structures of gravitational slope deformations that precede rain-induced or earthquake-induced catastrophic landslides from case histories.

Gravitational slope deformation forms many brittle open fractures, which are the groundwater pathways so pore pressure build up does not likely occur. Our recent experiences of gigantic rain-induced catastrophic landslides in accretionary complexes suggest that they had a wide crush zone with gouge at their base, which seals fractures and prohibits water leakage from the deformed rock mass. 2009 Shiaolin landslide in Taiwan by typhoon Morakot was bounded by a fault and bedding plane.

Earthquake-induced gigantic landslides, on the other hand, have somehow different geological structures of preceding gravitational deformation because it is induced by shaking rather than pore pressure build up even though preceding rainfalls have some effects on their occurrence. Typical gravitational slope deformations of them are flexural toppling, buckling, and sliding of undercut slopes. Flexural toppling of foliated rocks with rigid, massive rocks in higher elevations may be more susceptible than homogeneous rock mass probably because of shaking behavior. Buckling of parallel or underdip cataclinal slopes forms very unstable slopes; typical landslides of this type were Chiu-feng-erh-shan landslide by 1999 Chi-Chi earthquake Taiwan and Qingping landslides by 2008 Wenchuan earthquake. Another type of gravitational deformations that precedes catastrophic failure during earthquakes occurs on a buttressed slope like the Madison landslide by the 1959 Hebgen Lake earthquake in the USA.

Allochthonous Collapse Structures in Zagros Fold Thrust Belt

Yassaghi Ali

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Collapse structures in Zagros fold-thrust belt occur as a landslide, or as Cascade fold shape (collapse folds). Collapse folds in the most cases occur where the competent limestone rocks sliding over the incompetent shale and marl units. Harrison and Falcon (1934, 1936) have introduced this type of structures as collapse structures for the first time. They believed that these structures developed by bending or breaking of Tertiary or middle Cretaceous competent limestone rocks overlaying incompetent shale and marl rocks during folding and erosion of top structures. These collapse structures somehow are autochthon and their final locations are not far from their origin. However, there are large allochthonous masses in which their distance from their origin rocks are greater than the common collapse structures. An example of such masses are large allochthonous masses mapped in Dowgonbadan area located in Dezful Embayment of Zagros and show characteristics differ to the belt common collapse structures. In this paper, the influences of both gravity and thrusting on development of these masses are presented. Evidence such as the volume of the masses, the greater spacing between the masses and their origin, and the occurrence of crushed zone on the base of the masses are considered as criteria to separate these masses from common collapse structures and therefore they are classified as allochthonous collapse structures. Thus, thrust faults as well as gravity are proposed as the main features control the development of these types of collapse structures in the Zagros.

A multi-method approach to detecting bedrock fracturing and rockfall activity in the Southern Japanese Alps

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Multi-method monitoring has been conducted to detect the timing and trigger of rockfall activity on a high-mountain rock cliff composed of Cretaceous sandstone and shale in the southern Japanese Alps (Aresawa rockslide, 2900 m ASL). The monitoring programme includes manual collections of rockfall debris (3–5 times per year), as well as automated data logging of time-lapse photography of rockface (daily), crack opening, rock temperature, moisture (3–4 h intervals) and meteorological elements (air temperature and precipitation at 10 min intervals). A stereographic pair of sequential photographs allows visual identification of the location of new erosion at daily resolution. Combined with precipitation data, the photographs also indicate the type of precipitation (rain or snow). Six years (2010–2016) of debris trapping showed major rockfall activity in winter (between November and May) and occasional activity associated with heavy rains in summer. The rockwall experienced heterogeneous debris production mainly reflecting joint spacing. Time-lapse photography displayed at least 6–12 rockfall events per year within the shot area. The integration of multiple data suggests that at least three types of rockfall processes recur annually. In summer and early autumn, occasional heavy rainfalls raise the rock moisture content close to the saturation level, often triggering significant rockfalls, probably due to raised water pressure in rock joints and/or lubrication of joints. In late autumn and late spring, light or intermediate rainfalls are sometimes followed by high moisture, shallow freezing, rapid thawing and eventually by small-scale rock flaking. In early winter and early spring, the same process occurs as in the second case, apart from that rainfall is replaced by snowfall.

Rain-induced rockslides controlled by a thrust fault and river incision in an accretionary complex in the Shimanto Belt, Japan

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We investigate the geology and geomorphology of the Akatani and Akatani-east rockslides (volumes of >1000000 m^3) in the Kii Mountains, Japan, which were induced by the heavy rainfall of Typhoon Talas in 2011. Our analysis reveals that thrust faults in the underlying Shimanto accretionary complex influenced the likelihood and position of the rockslides. We analyzed 1-m resolution digital elevation models (DEMs) obtained from light imaging, detection and ranging (LiDAR) data collected before and after the landslides. We examined the distribution of outcrops of thrust faults that contain uncoherent brittle crush zones and we analyzed borehole data for the Akatani rockslide. The Kawarabi thrust, which has a brittle crush zone of ~6 m wide, acts as the sliding surface for both landslides. The thrust fault dips ~34° downslope and is cut by high-angle faults and joints along one or both sides of the landslide body. Prior to failure, the upper part of the slope contained small scarps, suggesting that the slopes were already gravitationally deformed. The slope instability can be attributed to long-term river erosion, which has undercut the slope and exposed the thrust fault at the base of the slope. The crush zone of the Kawarabi thrust is mechanically weak and has lower permeability than surrounding fractured rocks. The groundwater level, monitored in boreholes, suggests that the Kawarabi thrust is a barrier to groundwater flow, leading to an instantaneous rise of the water table and pressure buildup during intense rainfall events. The weak and impermeable nature of the thrust fault played an essential role in the generation of gravitational slope deformation and catastrophic failure during periods of increased rainfall. Thrust faults are a common feature of accretionary complexes, including in the Shimanto Belt, and the mechanism of slope failure stated above may be typical of rockslides in accretionary complexes globally.

Deciphering large deep-seated gravitational slope deformation stress states in active tectonic settings using contemporary three-dimensional fault-slip data

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Stress is a fundamental factor controlling deep-seated gravitational slope deformations (DSGSD) and knowledge of the internal stresses is essential for a proper understanding of their evolution and activity. Furthermore, the role of contemporary regional tectonic stresses on the activation of DSGSDs has rarely been studied. We have applied our new numerical technique for determining contemporary stress states, calculated from three-dimensional movement data from active tectonic and/or landslide fault monitoring on two large DSGSDs, one located along the tectonically active Periadriatic Fault in the Eastern Alps and one on the eastern flank of the El Hierro volcano in the Canary Islands. Contrary to classic paleostress methods, which calculate the stress field on the basis of existing faults´ kinematic markers, our method requires only the orientation of the monitored fault plane and a three-dimensional vector of displacement between adjacent fault blocks. This approach necessitates three major assumptions, which are valid due to monitoring in near surface settings: (i) the validity of Anderson´s Theory, in which one of the principal stress vectors is vertical; (ii) lithostatic stress is negligible or close to zero; and (iii) the direction of the total stress acting on the fault plane is identical to the direction of the fault movement. In this contribution, we discuss several different stress states and their origin in relation to both internal landslide deformation and regional tectonic processes. We compare these regional tectonic states to the regional fault kinematics, seismicity, and, in case of the El Hierro, to the focal mechanism of the ML = 5.1 earthquake on 27 December 2013. Our study, supported by Austrian Science Foundation (FWF) Project P25884-N29 and Czech Science Foundation (GACR) Project GJ16-12227Y, shows that this approach is promising for estimating the recent stress field and its time variations.

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Geological model of a potential large-scale landslide and its implication on the possible failure mechanism - paleo and future in southern Taiwan

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After the large-scale landslide occurred at the Shiaolin village during the 2009 Morakot typhoon, delineating the potential large-scale landslide areas is continuously being derived using LiDAR DEM. However, information for hazard prevention obtained hardly from the delineations of the landslide features. In this paper, a potential large-scale landslide that preliminary determined with a high risk was selected to explore its possible failure mechanism. The potential large-scale landslide site of Luigui locates in Kaohsiung, southern Taiwan, where the tectonic is relatively active. An active Chaochou thrust fault is located in the west of the study area. Regional rock formation is mainly composed of argillite with occasional thin layers of meta-sandstone. The strata are overturned and dip to the east. Generally, the slope faces to the west and shows clear topographical features of landslides. Intense field works, including field geology, eight boreholes drilling, and borehole tele-viewings, are carried out to construct the geological model. The multi-staged stereoscopic pairs of aerial photographs and high-resolution DEM extracted from airborne LiDAR are utilized to identify the landslide features and the possible geomorphological evolution. The investigation results showed that the colluvial deposits were formed by paleo sliding along the shear bands caused by gravitational deformation. The potential slope failures may occur mainly as sliding along the interface of colluvial deposit and rock formation or the interfaces of different-staged colluvial deposits. However, the probability of large-scale landslide is limited since the interfaces are gentle. Two giant gullies developed in the central and the north of this large-scale landslide. Also a local highway was built across the toe of the landslide area. Local slope failures at the highway slopes and the gully slopes may be the major hazards at the area.

Simulating the behavior of slow-moving landslides using a Dynamic Back Pressured Shear Box (DBPSB)

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Understanding how slow-moving landslides accelerate and decelerate and under what circumstances they may catastrophically reactivate are important for both hazard management and implementing appropriate landslide mitigation. The recent availability of high resolution landslide monitoring data over time periods that record movement patterns in response to triggering events (e.g. pore water pressures fluctuations and earthquake shaking) and innovative geotechnical testing equipment provides an opportunity to simulate landslide movement responses in the laboratory.

We used a Dynamic Back Pressured Shear Box (DBPSB) to replicate loading conditions on a landslide shear plane using samples collected from the basal shear zone of the Utiku landslide complex, New Zealand. The DBPSB is based on a standard direct-shear device, modified to allow the measurement and control of pore water pressure and dynamic application of normal stress and shear stress and is capable of carrying out static direct shear testing on soils whilst controlling back pressure and measuring pore water pressure in the sample. During each test, we measured the deformation response of the landslide shear surface to changes in pore water pressure and simplified dynamic loading. The results have been calibrated with high-resolution ground movement, pore-water pressure and rainfall records available for the landslide since 2008.

Relating the deformation patterns observed in the laboratory with the movement pattern records from the landslide provides a new ability to quantitatively examine how active landslides may behave in response to earthquakes and pore water pressure fluctuations.

Revisit the classical Newmark displacement analysis for earthquake-induced wedge slide - The kinematics and initiation of the Daguangbao landslide

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The Newmark displacement analysis (NDA) for the earthquake-induced wedge sliding has been introduced during 80's. It is surprisingly to find little follow up studies can be found in the literature. The classical NDA for rock wedge assumes a ridge wedge. The vertical acceleration and the horizontal accelerations perpendicular to the sliding direction were neglected. In addition, the friction coefficients of sliding surfaces are assumed unchanged during sliding. This study tries to evaluate the significance of the aforementioned assumptions on the initiation and kinematics of a wedge with different geometry, which subjected to synthetic earthquake shaking. We defined a wedge deformability index (R) to derive a general equation to consider the influence of shear stress perpendicular to the intersection line, which is dominated by the deformability of wedges. Accordingly, the influence of rigid wedges assumption can be evaluated. Shear resistance ratio (S_r) was used to consider the strength reduction along intersection line during sliding. The influence of constant strength assumption can also be assessed. Based on the calculations of the hypothetical cases, the aforementioned factors strongly influence the wedge failure initiation, permanent displacement, and sliding velocity. We further evaluate the influences of R and S_r on the stability of Daguangbao (DGB) landslide, which is a super-large atypical wedge failure controlled by the bedding plane and zigzag stepping-out joint system, adopting NDA. The velocity-displacement dependent friction laws (VDFL) of the bedding parallel fault gouges and dolomite joints were obtained via rotary shear tests. The seismic records of MZQP station were used. The results show that the influences of R and S_r are significant for the stability of DGB landslide. Therefore, the influence of internal structures, which dominating the deformability of rock wedge, on the wedge stability should be carefully evaluated.

Rockslide simulations based on the elasto-plastic finite element method considering the balanced cross-section concept

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The process from gravitational deformation such as toppling to formation of slip plane on rockslide is becoming reproducible by balanced cross-section used in structural geology. On the other hand, the elasto-plastic finite element analyses have achieved a remarkable development during recent years and they are becoming applicable for numerical simulations for rockslide phenomena. With coupling of the finite element analysis and the balanced cross-section concept, a new method to analyze rockslide mechanisms can be developed and it would be used for estimation of progressive failure modes developing in the slope based on the observations of apparent surface topography. As the result, this study indicates possibility of reproduction of buckle folding and warping. This result suggests that it is possibility to grasp premonitory phenomenon of landslide. In this paper, we describe these results in detail.

Influence of non-persistent slope-scale brittle features on DSGSD mechanisms and activity

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The influence of inherited tectonic structures on Deep-Seated Gravitational Slope Deformations (DSGSD) has been related to steep and low-angle faults, tectonic boundaries and large folds. We investigate the unexplored controls of non-persistent master fractures on the kinematics and activity of the Corna Rossa DSGSD (Valfurva, Italian Central Alps). This extends over 10 km^2 and affects a 1500 m high formerly glaciated slope in quartz-phyllites of the Austroalpine Campo nappe. These underwent brittle deformation stages since Miocene, resulting in different fracture systems from outcrop to regional scale. Among these, a persistent swarm of WNW trending steep fractures cuts the N valley flank and abruptly terminates into the Corna Rossa ridge (3000m asl), whereas a sub-parallel en echelon lineament starts in the lower slope sector and continues to SE.

Morpho-structural analysis of field, aerial and HRDEM data, quantitative analysis of satellite D-InSAR products and 3D geometrical and FEM numerical modelling allowed reconstructing a peculiar DSGSD, occurring through a complex series of gravitational shear and extensional zones up to 450 m deep. The entire slope is actively deforming in distinct sectors: 1) NW sector, characterized by pure sliding mechanisms testified by scarps, reaching up to the crest and showing highest radar LOS displacement rates, and nested toe rockslides moving at some cm/yr; 2) SE upper slope sector (above 2200 m asl), showing lower displacement rates and dominant extension along a 100 m wide graben at slope crest and multiple system of steep scarps and counterscarps downslope; 3) SE lower slope sector, showing mechanisms similar to sector 1 on smaller scale and displacement rates. Our results outline the occurrence of a transfer zone, accommodating gravitational strain heterogeneity between two separate “faults” by dominant extension along very deep-seated semi-graben structures, with key implications on the kinematics, activity and progressive failure potential of different slope sectors.

Large-scale landslide susceptibility assessment of Kaoping River Watershed in Southern Taiwan

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The susceptibility of large-scale landslides (with an area over 10 ha) transformed mainly from deep-seated landslide in Kaoping River Watershed, southern Taiwan is evaluated using the weight of evidence (WOE) method. High-resolution LiDAR derived DEM taken in 2005 and 2010 are used to recognize deep-seated landslides sized over of 10 ha according to their topographic signatures, such as main escarpment, trench, double ridge, and crown cracks. Landslides that are sized over 10 ha and triggered by the 2009 Typhoon Morakot are also mapped.

The study result shows that 53 large-scale landslides occurred during Typhoon Morakot in 2009, and all of them fell within 261 deep-seated landsides that have been recognized in the 2005 LiDAR DEM of Chishan river watershed, one of main of Kaoping River. Within the Kaoping River watershed that covered an area 3320 km^2, 1044 deep seated landslides with an area over 10 ha are recognized in 2010 LiDAR DEM and 390 landslides occurred during the Typhoon Morakot. Therefore, there are 1434 training samples in landslide susceptibility analysis when we assume 390 landslides are also transformed from deep seated landslides as we observed in the Chishan River Watershed.

In the weight of evidence analysis, eight control factors including lithology, rock strength, slope gradient, normalized difference vegetation index (NDVI), distance to fold axis or fault, distance to river channel, elevation difference, and degree of dip slope are used to evaluate the susceptibility of large-scale landslides. The weighting value of each control factor is calculated and the susceptibility is divided into high, moderate and low, three levels in total. The study results show that 63%, 30% and 7 % of landslides occurred during Typhoon Morakot are classified in the category of high, moderate and low susceptibility, respectively.

Methodology to estimate the rock avalanche frequency for a specific slope

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Estimating the rock avalanche frequency for a specific slope (f-specific) is difficult as rock avalanches usually occur only once at a given location. It is therefore not possible to determine frequencies of occurrence for a specific slope based on repeat events, such as commonly done for debris flows or rock falls. This paper presents a methodology based on desktop, field and laboratory analyses to estimate a range of rock avalanche frequencies for a slope near the site of a historical and pre-historic rock avalanche in British Columbia, Canada. A regional rock avalanche inventory over a 3,500 km^2 rectangular area centered on the slope of interest and encompassing a variety of geological groups and formations was used to derive a regional rock avalanche frequency (f-regional). The results of the desktop analyses (literature review, geomorphic mapping, potential failure scenario, potential failure volume, and kinematic analyses), fieldwork (photogrammetry, outcrop mapping, geomorphic observations and trenching) and laboratory testing (tephra geochemistry and radiocarbon dating) were considered for adjusting the f-regional to the slope-specific conditions. First, to examine the influence of the regional-scale geology or tectonic structure, the value of f-regional was estimated for the area of a series of concentric circles centered on the slope of interest. Secondly, f-regional was scaled for the area occupied by the slope of interest providing f-specific. Thirdly, f-specific was further adjusted, if necessary based on field observations and measurements, to account for site specific kinematics conditions and evidence of recent or ongoing large scale deformation.

3D failure surface and volume estimation of large rock slope instabilities: a review of a bottleneck problem

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The accurate determination of failure surfaces of large slope instabilities is an important topic because it is closely related to the mechanism of failure. In addition, these surfaces define the volume conditioning the run-out distance. In most cases, the failure surfaces are controlled by discontinuities, both at outcrop and slope scale (e.g. fractures, bedding and/or schistosity, and faults). The planes controlling the development of the failure surface are deduced from field work, hi-resolution digital elevation models and from any additional information. However, this is strongly dependent on the data available and accessibility. There are several ways to produce reliable failure surfaces by combining available surface data with theoretical approaches. The first step is to delineate the limits of the slope instability.

Several examples will be given starting from manual construction based on geological interpretation using several cross-sections. The discontinuities visible at the surface can be projected at depth to define the maximum volumes. However, the surface is more complex for large volumes and often develops as a circular failure by following several discontinuities. This is often supported by numerical modelling. The issue is then to balance between pre-existing structures and stress field controlling the new failure zones. The failure surfaces are thus controlled by both pre-existing surfaces and newly created surfaces. They often follow shapes of quadratic surfaces or splines. One solution is to use the sloping local base level (SLBL), which allows to create surface of known curvature. SLBL can also include some constraints such as planes and fixed limiting slope angles. The advantage of this quick method is that it can be applied to a single case or automatically to an inventory of rock instabilities. Eventually, new emerging technics based on inversion of the surface displacements and rheological law permits to get estimation of failure surfaces.

Revealing the evolution of slope deformation by adopting UAV techniques

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Catastrophic landslide is one of the most serious nature disasters that causes economic losses and fatalities. The mechanism and precursor of this kind of landslide are still not well understood. However, slope deformation and DSGSD can always be observed in past cases and may provide a crucial clue for understanding the evolution of landslide. In this study, we choose the basin of Butangbunasi River in which a total 80 million m^3 landslide occurred. The giant amounts of landslide materials not only leaded to huge sediment yields but also changed the confining pressure and reactived the procedure of slope deformation.

The bedrock in Butangbunasi River from old to young (also from downstream to upstream) consists of Chaochou formation (slate and argillite), Changchihkeng formation (interbedded sandstone and shale) and Tangenshan formation (massive sandstone interbedded with shale). These formations are separated by two reverse faults named Tulungwan and Gaozhong respectively. There are at least four joint sets as well as the bedding plane can be found in the field, creating a good environment for slope deformation such as flexural toppling and bulging. We generate three-dimensional digital elevation model with an economical way by adopting photogrammetry and the UAV acquired images, trying to observe the evolution of these slope deformations. The preliminary results show that the activity of slope deformation and the followed slope failure may be evaluated through the method proposed in this study.

Continuous GPS observations on deep-seated gravitational slope deformation in the Lushan area, central Taiwan

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The Lushan area has been documented with noticeable creeping behaviors accompanying heavy rainfalls during last decades and is considered as one of the potentially most hazardous deep-seated landslides in central Taiwan. For the purpose of reducing attendant landslide hazards, having knowledge of the threshold of infiltrating rainfall that leads to landslide and the geometry and dynamics of subsurface slip surfaces are the key factors for the understanding of landslide mechanics. We have setup 7 single-frequency and 1 dual-frequency GPS stations in the Lushan area since November 2013 and the GPS data are processed with software RTKLIB and Bernese, respectively. During the three-year observations, we divide 7 sites into 3 areas according to their spatial distribution which are side, center and bottom. For all the stations, the horizontal displacement creeps at a constant rate of about 30 mm/yr along the dip-slope direction for both dry and wet seasons. For the vertical motion, stations in the central part move upward with velocities of 5 mm/month during dry season, however, the motion switches gradually into moving downward at a rate of 7 mm/month during the rainy season. On the side area, the stations present slow subsidence velocity of 20 mm/yr. The bottom sites move downward at a rate of about 10 mm/month in dry season and move obscurely in wet season. We evaluate the hydrological process during rain infiltration in saturated material base on the Richard's equation. We use viscoplastic sliding-consolidation model to simulate the relationship between the groundwater and surface displacement. Both observed and model predicted displacements start to move downward after the time of the highest groundwater level. We consider that different station time series between center and side area is affected by the general elevation of the ground water and the development of graben-like fractures on the central area.

Using Electrical Resistivity Tomography to detect internal structures of deep-seated gravitational deformations

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A persistent problem in the recognition of anatomy of deep-seated gravitational slope deformations is limited access to bedrock outcrops. The problem is particularly acute in forested and regolith-covered terrains, an example of which are the Kamienne Mountains, Sudetes range, in Central Europe. Availability of high resolution LiDAR data significantly improved our ability to map the areal extent of deformation using characteristic topographic signatures (landforms), but these data offer little clues to what is happening at depth. Electrical Resistivity Tomography (ERT) technique has a potential to detect discontinuities which may be interpreted as failure planes or zones. It has been used in selected localities in the study area, with results which can be interpreted with variable degree of confidence. At Mt. Rogowiec ERT images revealed diversity of slope deformations, including (1) lateral spreading and sinking of rigid volcanic caprock blocks in deformable sedimentary substratum in crest setting, (2) deep-seated rotational slides in hillslope settings. At Mt. Turzyna an evolving deep-seated gravitational slope deformation was investigated and the ERT images appear to show a failure zone which is yet to achieve continuity within the affected rock mass. Further localities in different topographic settings will be investigated using ERT in the near future, with the results interpreted against surface geomorphological mapping.

Cosmogenic nuclide ages of back scarps of the Litledalen and Nomedalstinden deep seated gravitational slope deformations (DSGSD), Northern Norway, indicate that DSGSDs can survive glacial cycles

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Cosmic-ray exposure dating at the top of multiple sliding surfaces of large unstable rock slopes from Western Norway suggests a start of sliding directly following deglaciation. Alternatively, rock slopes could have slid prior to glaciation and traces of deformation got eroded by the ice sheet. Flat, highly elevated paleosurfaces show a large extent in northern Norway, and 21Ne dating of depth profiles provided minimum ages for three of them ranging from 137±15 kyr to 185±30 kyr, indicating that the Scandinavian ice sheet was non-erosive during the LGM on those surfaces. The Litledalen and Nomedalstinden DSGSDs developed on such high flat mountains and their back scarp intersects such mountain plateaus. Cosmogenic nuclide ages for the Litledalen back scarp all predate deglaciation (70±15 kyr). The top sample of the Nomedalstinden back scarp predates deglaciation also, while the lower samples postdate deglaciation (20±2 kyr). Both DSGSDs are strongly deformed and the surface is covered by rock glaciers, although some of the lobes might represent rock-avalanche deposits, as they are related to a pronounced depletion zone above the deposit and the lateral rims of the lobes cross rock glacier deposits. We sampled one lobe with characteristics of rock-avalanche deposits on the flanks of each of these DSGSDs. Ages obtained fall within 11.5 and 10 kyr and thus right after deglaciation in this region. Deformation rates measured by satellite born InSAR technology using several satellites are in the order of a few mm/yr today and vary over the slope. It is however not clear if these deformation rates only indicate creep of the surface layer or deeper deformation. These data show that DSGSDs can survive glacial cycles and become active after glacial retreat again, resulting in short lived failures either in form of rock avalanches or rock glaciers.

Study on a dip-slope by inclinometers and GPS monitoring at the Huafan University campus in northern Taiwan

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Slope failure events easily occur after intense rainfall, especially resulting from typhoons and accordingly cause a great loss of human lives and property. At the northern end of the Western Foothill belt in northern Taiwan, Huafan University campus is established on a dip-slope about 20° toward southwest, being composed of early Miocene alternations of sandstone and shale.

Within and outside the campus, surficial cracks on the ground that may reflect slope sliding were observed and have developed gradually. To understand the sliding behavior of the dip-slope, monitoring systems, such as inclinometers and groundwater gauges in boreholes at the campus were set. The formers are to measure displacement amount of potential sliding surfaces with different depths underground and the latter are used to find correlation between groundwater table change and the displacement amount. In addition, a network of continuously operating GPS stations (including 3 dual-frequency reference stations and 12 single-frequency stations) has also been established since April in 2016.

Previous results acquired by the inclinometers reveal that creep of 2-3 mm of the dip-slope occurred monthly, and even 6-10 mm when precipitation exceeded 300 mm during typhoons' striking. Furthermore, recent findings by the GPS stations indicate obvious displacement, maximum 25 mm in horizontal and 10 mm in vertical, and the displacement is straightforwardly related to intense rainfall brought by the two typhoons Megi (2016.09.27) and Aere (2016.10.05). On the other hand, the displacement trends recorded are different from the individual GPS station, showing that the localized geological material and structures may play a role in controlling deformation behavior. To understand the phenomena observed, further study and more monitoring data are needed.

Slope deformation imaging of sandbox analogue models (LiDAR and InSAR)

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We investigate the potential of using a sandbox in the lab to (1) reproduce rapidly various types of movements (rotational and translational sliding, toppling, swelling, subsidence and strike-slip), (2) test tracking algorithm of surface deformation, (3) simulate InSAR fringes patterns for various geometries of acquisition. Kinetic sand, a commercial sand coated of a silicon-based organic polymer, is used as principal material in the sand box. During the deformation, the sand mass surface is periodically scanned by a high-resolution LiDAR (Minolta Vivid). These analogue models aim at imitate the geometries of various deformations, they do not pretend to be mechanically scaled relatively to real natural instabilities.

These models have proved to be particularly useful to help interpreting differential InSAR results (i.e. the fringes of an interferogram). Differential InSAR patterns of complex slope movements can be difficult to decipher because of unwrapping problems, loss of coherence or deformations due to radar images geometry. Moreover, results will change depending of the line of sight relatively to the surface displacement, the spatial baseline between the two acquisitions, and the radar wavelength. All these parameters can be easily changed and tested by simulations. Finally, LiDAR data from a real landslide (Lavalette in France) has also been used to compare simulated interferograms to real ones. It is also planned to use 3D printing of real topographies in order to reproduce historical cases of catastrophic events (the Randa rockfall for instance).

Seasonal fluctuations in pore-water pressures of a landslide in a seasonally snow-covered area

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Landslides in snowy regions are frequently triggered by increase in pore water pressure due to snow melting. It is known that the seasonal change in permeability in vadose zones may affect the pore water pressure fluctuation in a landslide. However, the mechanism responsible for the different fluctuations occurring in a landslide in the saturated and unsaturated zones, with or without snowpack, is unclear at present. This study focuses on the effect of moisture conditions in the vadose zone on the seasonal fluctuations of deep pore water pressure in a landslide in a snowy region.

The study site is located in a mountainous area in the Niigata Prefecture in northern Japan. The site is underlain by Neogene sedimentary rocks, and is a typical example of a reactivated landslide. The study site comprised a 300 m long and 50~70 m wide landslide that had occurred at an elevation of 550~650 m, with a mean inclination of 10~15° and sliding surface depth of 3–6 m. This region is characterized by the presence of abundant snow, with a maximum snow depth being over 5 m.

The shallow subsurface soil moisture was monitored over two seasons to observe the infiltration process. Sensors to register fluctuations in pore water pressure at deeper parts of the landslide body were installed at depths of 5.2 m (just above the sliding surface at 5.26 m) and 2.0 m below surface at the middle block. The data were simultaneously recorded with an identical logger at 5-minute intervals.

The results of the field observations indicate that fluctuations in pore water pressure changed seasonally. The measurements of volumetric water content show different seasonal fluctuations of soil moisture at each monitoring depth.

Deformation characteristics and surface monitoring of deep-seated gravitational slope deformation in the Tienchih area, southern Taiwan

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The deep-seated landslide located at the intersection of the Lalong Valley near Tienchih, Taiwan, has been the target of many previous investigations. In Taiwan, observations and analyses suggest those deep-seated landslides are mainly controlled by tectonic structures, which play a dominant role in the deformation of massif slopes. In this paper, LiDAR, GPS, TCP-InSAR, rain gauges and field observation data have been utilized to derive a kinematic constraint of the deep-seated gravitational slope deformation (DSGSD) process. The displacements observed by a continuous GPS site, TENC, shows a huge displacement of about 240 mm during typhoon Morakot in 2009. Considerable enhancement for the interpretation of morphological characteristics can be obtained by the integrated use of Airborne Light Detection And Ranging (LiDAR) technology. In order to extend the kinematic consideration, the TCP-InSAR technique has been specially applied to ALOS/PALSAR images from 2007- 201, obtain large-scale deformation data. On the other hand, continuous Global Positioning System (GPS) can easily measure surface deformation ranging from a few millimeters to several centimeters.

Our primary results demonstrate that valley erosion and DSGSD play key roles in the deformation of slate, indicating a block movement with shear concentration at the basal sliding surface. GPS data have shown that movements are correlated with the direction of slope and have a high correlation with rainfall. The cumulative rainfall is up to 2,700 mm over a period of 5 days during Typhoon Morakot; this is close to the annual average rainfall, which is 2,800 mm in this area. We find a nice correlation in the temporal variation of GPS displacement time series and rainfall with little time lag, suggesting that motion is possibly related to gravitational load related to overflow of water during the typhoon event.

Gravitational transpression folds formed in the large-scale sackung: an example from flysch Carpathians

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Recently emerged concept of “slope tectonic” suggests that gravitational mass movement might produce structures similar to extensional, strike-slip and compressional tectonic deformations. However, only some of these slope tectonic features were hitherto identified in the field and there is still lack of field evidence of specific structures, like those related to gravitational transpression. Here we present an example of large-scale sackung-type deep-seated gravitational slope deformation (DSGSD) of monoclinal ridge in the flysch Czech Outer Western Carpathians (Smrk Mt.). Sackung landforms involving synthetic and antithetic scarps are strongly related to transverse (NNW and NNE trending) inherited normal and strike-slip faults and mainly cross-cut general topography of the mountain ridge. Geomorphic mapping using high resolution LiDAR-derived topography supported by geophysical sounding (ERT and GPR) enabled identification of subtle landforms characteristic of slope tectonics, such as various types of scarps and gravitational folds. Although some of these folds originated as a product of buckling or compression in the distal parts of secondary landslides, pronounced concentration of folds along bended sackung lineaments suggests their transpressive origin. More specifically, we attribute genesis of these folds to the gravitational transpression originated due to the localized contraction between southward gravitationally sliding slab of sandstone flysch and bended sackung faults. It is for the first time, when field evidence suggests connection between DSGSDs kinematics and origin of transpressive structures excellently reflected in the topography. Our results suggest that geomorphic mapping based on LiDAR-derived topography could be useful tool for interpretation of slope tectonic features and inferring of DSGSDs kinematics, especially in soil-mantled forested mountain ranges with lack of outcrops.

Activity of large slope instabilities and denudation rate in the European Alps

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Large slope instabilities represent an important geological risk in relation with the deformation of large structures and infrastructures, and the damage of rock masses. Their movement, although slow, can continue for very long periods, producing large cumulative displacements and contributing to the denudation of the mountain range. Ground surface displacements typically range from a few millimeters to several centimeters per year, thus being within the detection limit of SAR (Synthetic Aperture Radar) interferometry. In this paper, permanent scatters (PS-InSAR) and Squee-SAR techniques are used to analyze the activity of 1224 Deep Seated Gravitational Deformations (DSGSD) and 1899 large landslides in the European Alps. For the estimation of state of activity and the displacement rate of the slope instabilities, different metrics have been used and evaluated. The control of climate, topography and tectonics on displacement rate has been assessed over the Alpine chain, showing a correlation of the displacement rate with local relief and the exhumation rate. The modern denudation rate due to large slope instabilities has been estimated by using a simple geometrical model of the instabilities, and compared with estimates available from the Alps. Large slope instabilities result to contribute nowadays only to a small percentage of the overall denudation rate at the Alpine scale, with some differences in different tectonic domains.

A Case Study on the comparison of Qlogging applied to Core Description with Well Logging Results in Potential Landslide Area

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One of the major methods for landslide investigation is geological boring. Geologists, geoengineers and related practitioners can assess the rock mass properties such as lithology in potential landslide area by core interpretation. The results of core interpretation provide important information for the understanding of landslide causes and triggering mechanisms.

Qualitative description is commonly adopted when recording core properties, however, it is not easy for data accumulation and statistical application. On the other hand, currently rock mass classification systems, Qlogging, a quantifying method, can consider various factors such as degree of crushing of core that can affect the rock strength.

This study had performed a series of geological investigation works, including geological boring, well logging and inclinometer observation in potential landslide area. Moreover, Qlogging method is utilized to assess the properties of borehole core. Results of Qlogging are compared with various well logging results and slope activity are discussing, attending to provide a methodology for the core and potential weak plane interpretation in landslide investigation.

An introductory, geostatistical and geomorphological review of the effects of geohazards and severe weather events as a retrospect throughout 2009/2010 in Norway

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Unforeseeable and severe weather events have been some of the reasons throughout 2009/2010 for natural processes which have caused catalytic events of a complex nature, such as rockfalls, landslides, small scale avalanches and flood. While the incidents took place, there was a need to set together overviews of the disasters distribution and the expected size of events at critical locations. Although, natural hazards today rarely take life in Norway - compared to some other parts of the World, there is no form of hazard which means more economically than natural hazards.

Certain railway lines will be studied in this work for showing how the harsh seasons severe weather and geohazards affected railway transport. These catalytic events have caused cessation of traffic on several railway lines. Owner and railway operators were unprepared for the extreme weather conditions. The response to weather challenges has been marked by improvised measures rather than pre-established routines and caused a shift of freight and passenger transport from rail to road where the conditions have been same in numerous situations.

In case of many of the most devastating events caused by certain climate conditions, can the source of the weather be far away from Norway. Also, some of these weather patterns are describe in the paper. Most of the events linked to geohazards have taken place during spring and summer time. The main incidents related to geohazards are caused by rockfalls, followed by debris flood and snow avalanches. The triggering factors are very often linked to slope tectonics and different weather events.

During so called “train chaos” 2009/2010 turned out that such information was time consuming and very difficult to obtain. This is partly the reason for this assessment, to gather knowledge in this paper, as the basis for handling of future disasters related to geohazards.

The response of catastrophic landslides to fluvial incision in the upstream of Minjiang River, Western Sichuan, China

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The intense river incision, caused by the strong tectonic uplifts during the orogenic activity of Longmenshan belt, could destabilize hillslopes and induce gravitational deformation and catastrophic failures. In our study area, many large landslides aligned along the trunk river of upstream of Minjiang, Sichuan, China were investigated by detailed geologic field survey and topographic analysis. The trunk river of Minjang has several knickpoints and a major one is exactly located upstream of a couple of large landslides including the largest one (Diexi landslide) along the trunk. The long-river profile analysis suggests that this major knickpoint was formed not by landslides but by tectonic activity and that they propagated upstream. We studied the typical examples of landslides in Diexi area responding to the river undercutting, mapped the widespread landslides along Minjiang River and reconstructed the fluvial incision history by investigating several series of knickpoints in trunk and tributary and corresponding slope breaks. Combined with the geologic and geomorphology characteristics of ancient landslides in Diexi, the distribution features of catastrophic landslides indicate that long-term incision by the Minjang River undercut the hillslopes with structural defects and finally caused large landslides under the context of long-term fluvial activity. The understanding of geological and fluvial history in hillslope processes could provide a conceptual model of geohazard prediction and mitigation in the Minjiang drainage basin.

The influence of tectonic agents on the activity of landslides on the west Caucasus area (Russia)

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The west offshoots of a Caucasus mountain range from the east Black sea coast. They present a tectonic and dynamic area with high seismic activity. In the history, this region experienced earthquakes with high intensity, resulted in the landslide formation (the Utrish sliding complex).

The main feature of West Caucasus geological structure is an involvement in tectonic movements. Yet one feature is crustal folding of terrigenous and calcite flysh. High-strength sandstones and limestones frequently interbedded with calcite and clayey marls. The last one type of rocks is characterized by low strength properties. It appears especially during water encroachment of beds. Interbedding, tectonic disintegration, steep angles of dip (from 15-35 degree to subvertical) in fold limbs influence greatly on the landslides formation in the region.

The sliding activity study was made on the coastal zone of the south part of Tsemes bay. Field investigation has shown the presence of a landslide on the slope under examination. The volume of landslide is 3.5 million m^3. The development on the deformations occurring on the slope surface of drunken forest (the woods age is above 20 years) and the electric power pylon indicates the modern landslide activity.

The assessment of landslide activity includes two stages. The effects of the tectonic fracturing and stratification on the slope stability were analyzed at first. As a result, the conclusion about probability offset development like sphenoid landslide. It was made because of slope's geological and structural features and possible conditional types of deformation zones formation. The results were used on the second during quantity stability assessment. It was organized with method of volume rock blocks.

Geological background of landslides induced by the 2016 Kumamoto earthquake in the Aso caldera with special reference to the weathering processes

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Landslides induced by the past earthquakes on tephra slopes caused enormous damage because of their high mobility. The Kumamoto earthquake occurred on 16th April 2016 with a moment magnitude of 7.0 and induced many landslides in the western part of the Aso caldera.

The basement of the survey area consists of lava flows and pyroclastic rocks with a wide range of chemistry from basalt to rhyolite (Ono and Watanabe, 1985). They are thickly covered by tephra, of which volcanic soil can be classified from color tone (Watanabe and Takada, 1990); we classified the volcanic soil into brown volcanic soil (Br), black volcanic soil (Bl), and blackish brown volcanic soil (BlBr).

One of the most devastating landslides induced by this earthquake occurred on tephra slopes, because they occurred on rather gentle slopes and ran out long distances. The landslides had three sliding surface each in the tephra layers; these are Kusasenrigahama pumice layer 30,000 years ago (Kpfa), black or blackish brown volcanic soil layer and brown volcanic soil layers which contained felsic lava block. These layers accommodating sliding surfaces had characters of high water content and halloysite clay mineral. Halloysite was formed by the weathering of the buried tephra layer. On the other hand, these landslides occurred on the unstable slope which lower part of tephra layer was cut. In this way, it was found that if tephra layers contain halloysite and is cut at the lower part of the slope, the layers likely will accommodate a sliding surface.

This study examined halloysite contents, water contents, and permeability of tephra, focusing on the weathering process of tephra layers and on the collapse mechanisms.

Dynamic movement history of the 2017 Iiyama landslide revealed from drone image and seismic data

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The Iiyama landslide occurred on May 19, early morning. A nearby resident found the downstream of the Idegawa river became muddy at 6AM on the day. The local government confirmed a large-scale hillside failure on the upstream of the river. The debris of the landslide run along the Idegawa river about 3 km and merged with Chikuma river.

We performed the field survey with a drone and analysis of seismic signal. The aerial photos taken by the drone enable us to create three-dimensional digital elevation model (3D DEM) with a modeling software (Pix4Dmapper). The 3D DEM revealed that there were two significant collapses in the landslide. The one was about 100m width and 300m length, and run from North to South direction. The horizontal displacement was about 100m, and the movement was terminated when the toe of the landslide reached the bottom of the valley. The other was about 100m width and 800m length, and run from West to East direction. The debris of this collapse run along the Idegawa river by a few kilometers.

In order to estimate the timing and dynamic movement history of the landslide, we analyzed the seismic waveforms provided by the NIED. The closest station (MAKH, about 7km north from the landslide) shows the long-period signal (0.1-0.01 Hz) preceding to the short-period signal (1-8 Hz) by about 40 seconds (at 6:37:35). The largest direction of the long-period signal is North-South component. This suggests the North-South collapse occurs prior to the East-West collapse. The seismic signal combining with drone aerial photos help us to understand the dynamic movement history of landslides.

Behavior of a gravitational deformation slope during earthquake shaking revealed by seismic observation

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A lot of cataclinal slopes experience gravitational deformation in the Shimanto accretionary complex in the Kii mountainous area, southwest Japan. In 2011, heavy rain due to the approach of Typhoon Talas induced lots of deep seated landslides here. One of the largest landslides (with the volume larger than one million cubic meter) was called Akadani landslide. Most volumes collapsed in 2011, however, there still remains unstable blocks on the top side of Akadani landslide.

Kii mountainous area also has a risk of earthquakes, because it is facing Nankai Trough where giant earthquakes occur every about 100 years. It is important to grasp how the slopes behave during strong earthquake motion. Since topography and heterogeneity in the landslide block make seismic waves rather complicated, seismic observation on the slope is essential.

We installed two seismometers inside and outside the unstable block. Ground velocity is continuously recorded with sampling frequency 100 Hz so that we can record small earthquakes which occur a few tens of kilometers distant from the seismometer. In order to estimate the response of the unstable block for the seismic wave input, waveform records from 30 earthquakes whose azimuths were widely distributed were collected. Horizontal components rotated by every five degrees was calculated each by each, from north-south and east-west components of the seismograms. Then, the spectral ratios of each horizontal component to the updown was estimated in the coda part where we could consider that seismic waves came from various directions. Finally, the direction where the amplification effect was the largest was detected. As a result, it was found that the unstable block tended to shake largest in the direction to the original position of the already failed block.

On the co-seismic responses of a deep-seated landslide: Insight by monitoring

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In recent years, earthquakes have triggered numerous landslides and a lot of researches on the earthquake triggered landslides had been implemented on different aspects. However, our understanding on the co-seismic response landslides especially to deep-seated landslides is still very poor. To better understand this issue, we then performed long-term seismic monitoring with five high-sensitivity seismometers on different locations of an ancient deep-seated landslide in Azue area, Tokushima prefecture, which were reactivated by heavily rainfall. By using these records, we analyzed the site responses, especially the amplification and polarization effects. The method of H/V spectral ratios on S-wave and Coda-wave durations (5s-duration) were applied to check the local amplifications in frequency domain (0.5-10Hz). The results in S-wave durations present that the low amplified factors appear in all frequency bands on bedrock areas with the amplified direction of N120°-160° but the high amplified factors appear in 5-7Hz on talus areas with the amplified direction of N105°-145°, meanwhile the moderate amplified factors in 3-4Hz on landslide blocks with the directions of N110°-130° which are perhaps along the previous sliding direction. The conditions from Coda-wave durations are similar to the them form S-wave durations. We also analyzed the polarization effects by means of TF wavelet method to learn the predominant shaking directions on different locations in landslide. The results prove that the polarization and amplification directions are almost the same on stable areas but there are intersection angles between the two directions on instable areas. Probably due to the assemblages from complex geological settings and/or ground water level, or other reasons probably, the seismic energy redistribute in landslide mass, which incorporate more complicated amplification effects rather than deposit areas or bedrock. Finally, multidisciplinary approaches will be adopted for analyzing the co-seismic responses on this landslide in the future.

Relationship between distance from active fault and scale of slope failure in Japan

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Japan belongs to the crustal movement zone and there are many active faults. Types of active fault are normal fault, reverse fault, strike slip fault. When the active fault moves, many slope failures occur around the active fault. The author studied many earthquake slope disasters in Japan. First, I studied three inland shallow direct hit earthquakes of the M7 class, the 2011 Iwaki Earthquake (normal fault), the 2014 Northern Nagano Earthquake (reverse fault) and the 2016 Kumamoto earthquake (strike slip fault). In addition, I studied the M8 class earthquake targeting the Median tectonic line of Shikoku and the 2011 Great east Japan earthquake (trench type) of M9 class. As the result, it was clarified that there is a logarithmic damping relationship between the scale of slope failures and distance from active faults.

Moreover, the tendency of the decay varies depending on the type of active fault. In addition, it became clear that the distance from the active fault increases as the magnitude of the earthquake increases.

Assessing rainfall threshold for large-scales landslide by exacting occurrence time of landslides from seismic records

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Understanding the rainfall condition which triggers mass moment on hillslope is the key to forecast rainfall-induced slope hazards, and the exact time of landslide occurrence is one of the basic information for rainfall statistics. In the study, we focused on large-scale landslides (LSLs) with disturbed area larger than 10 ha and conducted a string of studies including the recognition of landslide-induced ground motions and the analyses of different terms of rainfall thresholds. More than 10 heavy typhoons during the periods of 2005-2014 in Taiwan induced more than hundreds of LSLs and provided the opportunity to characterize the rainfall conditions which trigger LSLs. A total of 101 landslide-induced seismic signals were identified from the records of Taiwan seismic network. These signals exposed the occurrence time of landslide to assess rainfall conditions. Rainfall analyses showed that LSLs occurred when cumulative rainfall exceeded 500 mm. The results of rainfall-threshold analyses revealed that it is difficult to distinct LSLs from small-scale landslides (SSLs) by the I-D and R-D methods, but the I-R method can achieve the discrimination. Besides, an enhanced three-factor threshold considering deep water content was proposed as the rainfall threshold for LSLs.

Observations of pore-water pressure during failure in a moving landslide body

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In order to elucidate the mechanism of a coastal landslide, static and dynamic monitoring was conducted by the installation of displacement gauges, piezometers, and other sensors. Fluctuations in the pore-water pressure were monitored when a long-travelling landslide was induced by heavy rainfall from September 19 to 20, 2015. Observation results showed that pore-water pressure dropped rapidly just before landslide displacement occurred and high pore-water pressure was generated during the displacement and deformation of the moving landslide body.

The internal structure of Nagatono landslide dam and landsliding mechanism

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During Typhoon Talas, many large landslide dams had been formed and countermeasures have been performing on five large ones. Among them, the landslide dam occurring on Nagatono area is a well-controlled case by differing engineering methods, which enables us to conduct detailed survey on the internal structure of the dam. Using a surface-wave technique, we surveyed the Vs structure of surficial debris layers (depth <20 m). We used ERT to examine the internal structure of deeper layers. Based on these measured Vs and resistivity profiles and boring data, we analyzed the internal structure and then discuss the formation process of the landslide dam.

The Mont de La Saxe Landslide (Valle d'Aosta-Italy) - Evolution a large alpine landslide controlled by different hydrogeological components

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The Mont de La Saxe landslide is a large complex and active landslide. Its collapse threatens part of an important touristic resort of the western Italian Alps and important infrastructures such as the Mont Blanc A 5 Motorway that is one of the most important links between the industrial area of Northwestern Italy, France and Switzerland.

Since 2008, in the effort to mitigate the landslide collapse hazard, the Regione Autonoma Valle d'Aosta (RAVA) geological survey (RAVA-ATTGEO) undertook growing efforts to investigate geology, hydrogeology and monitoring the landslide.

The increasing acceleration of the phenomenon that began in 2012, forced the geological survey to further increase the hydrogeological investigations drilling long draining boreholes, performing geochemical analysis, and basin-scale surveys.

During the following years the geohydrological data collected, allowed the geologists to aim several long range sub-horizontal draining boreholes to the bottom (i.e.: the failure surface) of the landslide to reduce the periodic seasonal accelerations.

Furthermore, the hydrological and hydrogeological data sampled, conveniently collected in a multi-parametric warning and visualization tool expressly implemented for RAVA-GEO, today support the conclusion that the landslide is controlled by a two-stage snow melting mechanism, that triggers two hydrogeological impulses involving the landslide failure plan.

The results of the hydrogeological assessment show that the usual model employed for large scale Alpine landslides, controlled by spring activation snow cover fusion has actually to be refined taking into account the hydrogeological context at large scale and being supported by a comprehensive geological model.

The results obtained by this kind of integrated analysis method allowed a consistent remediation that, so far, has yielded a consistent slowing of the landslide velocity.

The investigation method elaborated, combining detailed geological investigation and deep water monitoring could be used for remediation of such phenomena and for calibrating, even avoiding, expensive remediation intervention.

Geological characteristics and multi-disciplinary observation in the active deep-seated slope deformation in slate in LuShan, Taiwan

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Underlain by Miocene slate, the large and deep-seated slope deformation has been recognized in LuShan, Taiwan. The 400-meter-high active rock slope extends 600m in width and 800m in length, with deepest sliding surface at 108m in depth. While groundwater table is always higher than 50m in depth, the slope deformation could be activated if accumulated rainfall exceeds 400mm.

Anisotropic sheeting cleavages with fair RQD often deformed as toppling, flexural folding, kinks with brittle shears in the slope. The regional steep-dipping (>50 degrees) cleavage and a vertical joint set constrain the active slope as an asymmetric wedge. By explication from borehole acoustic televiewer in A21-1 (120m) in central slope, inclination of cleavages in the deep (70-120m in depth) decrease to <20 degrees without modification of dipping direction but coupled with brittle-deformed kink bands. Since horizontal and overturned cleavages are only found near toe, it suggests that the basal incompetent layer of rockmass should ever shear off overlying steep-dipping cleavages, remove over long distance, then be held back by underlying drags in an intermediate stability nowadays.

During a torrential rainfall in June 2012, accumulated rainfall exceeded 1000mm in three days and led to 28cm displacement in the slope. When groundwater rose rapidly, a deeper then a shallower slope deformation occurred and lasted contemporaneously more than one month figured out by GPS, inclinometer, borehole extensometer and SAA. Multi-disciplinary observations also consistently illustrate that sliding at the specific plane (108m in depth) in central slope transforms into a broad shear zone (>60m) near toe. Although the mobility is partially locked at basal front, sufficient groundwater at toe might diminish resistance and re-activate the retrogressive deep-seated slope deformation.

The activity assessment of potential large-scale landslide by means of multi-staged images and data from aerial photographs

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In the present work, we used multi-stage DEM produce from LIDAR and aerial photographs (with time intervals from 10 to 30 years) to assess the activity of potential large-scale landslide sites. Landslide activity was classified according to the progress of geomorphological features identified from the aerial photographs in a chronological order. The failure modes of the assessed potential landslide sites include the plane slide in dip slopes and the non-planar slide in colluvium deposit. In some dip-slope landslide sites partially covered by colluvium, dual failure modes are possible. For the failure mode of plane slide in a dip slope, three factors for landslide activity assessment are considered: (1) the progress of main scarp, (2) the change in slope toe and (3) the weak-plane direction and daylight. For the failure mode of non-planar slide in colluvium, the following three factors for landslide activity assessment are considered: the change in (1) scarps, (2) gully erosion and (3) vegetation. For a dip slope possible for dual failure modes, the activity of both failure modes are assessed by means of the interpretation of the aerial photographs; the mode with a relatively higher activity class is regarded as the dominant failure mode. Each factor is assigned a score of 1, 2 or 3. The total score is the sum of the three considered factors. Thus, the lowest possible score is 3 and the highest possible score is 9. For a total score 3 or 4, the landslide activity is classified as “low active”. For a total score within 5 and 7, the landslide activity is classified as “medium active”. For a total score 8 or 9, the landslide activity is classified as “highly active”. We assessed 33 sites with the potential of large-scale landslide. Among these sites, 11 sites are highly active, 14 sites are medium active, and 8 sites are low active.

Geological background of Nagiso debris flow occurred on July 9 2014, in Nagano prefecture, central Japan

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Intensive rainfall promoted by Typhoon Neoguri induced slope failure and debris flow at Nagiso, Nagano Prefecture on July 9 2014. On the Nashizawa River, debris flow caused heavy damage on residential houses, railway tracks and national rout 19. Historically, there had been many debris flow disasters in this area. However serious damage caused by debris flow has not been recorded since 1976. The average annual precipitation was about 2,400 mm/year. In addition, about 1,600 mm is precipitated during the period from May to October.

The Nashizawa River is sited on the western foot of Mt. Nagiso, and flown into the Kiso River. Geology around the site is composed of Cretaceous granite. The mountain with the peak of 1679 m is surrounded by many faults. Magome-Toge fault is located in the northwestern foot of the mountain. The fault strikes N 40° E and its motion is right-lateral strike-slip. The fault also causes a displacement of several tens of meters in the river.

Meso-scale fractures which contain faults and joints are observed along the Nashizawa River. Meso-scale fault is shear fracture in which offset can be detected in the outcrops. Joint is opening fracture in which offset cannot be recognized. Meso-scale faults strike N 40° E parallel to the macro-scale Magome-Toge fault. In addition, some of them show right-lateral strike-slip. On the other hand, joint system has 3 joint groups. Each joint group is composed of parallel joints. And two of the groups are vertical and strike NS and EW, respectively. The other group is perpendicular to them and parallel to horizontal plane. The river mainly streams to EW direction, parallel to the most-frequent joint group. The joint system might contribute to the genesis of granitic boulders which were transported by debris flow. It might be a character of granite landforms.

Temperature and sound survey on steep tea farm area and salt pan site

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Wazuka town in Kyoto prefecture has the largest farmland for Uji green tea. In 1953, this area suffered from flood disaster due to the heavy rainfall along with the valley wind. After that, the steep hillsides were cultivated as tea farmland. In this area, diluvia, Osaka strata and granite are outcropped along the Wazuka fault, and many old landslides in small scale could be identified. The River Basin Control Bureau has an experimental site locating on Ishidera area in Wazuka, where there was a house that was built about 150 years ago, and the habitants migrated after the 1953 flood. This area was developed for lots and housing during the economic bubble years around 1990, but was abandoned due to the occurrence of a small landslide and the inclination of concrete wall. After that, some drainage wells and a pond for the collection of shallow ground stream water were constructed as the countermeasures to stabilize the slope.

To understand the distribution of ground water streams, 1m-depth-ground temperature survey method and sound survey method were used. It is noted that this sound survey method was developed jointely by Dr. Tada and Takuwa Corporation, and is a technique using very sensitive sensor for picking up the ground aeration sound resulting from seepage. Using these methods, ground water streams were detected at the Kizu river bank gate site, at salt pan site gate trail, and on Ishidera landslide observatory area. Based on the survey results, the construction sites of the wells for the drainage of ground water, as well as the steel-sheet piles were suggested for the river bank and area of the watergate for the salt field trails.

For those areas where the ground water stream was detected, pipes were buried to drainage the water and then to stabilize slope, and the bridges made by the local people before to crossing the stream holes had been monitored regularly.

Shear surfaces of simulated shear zones control mechanical behaviors of granular materials

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It is believed that the mechanical behaviors of granular materials provide fundamental insights into slope processes. Some previous experimental studies have pointed out that the mineralogy of constituent materials may play a first-order control on the transitions of mechanical behaviors, including sliding stability or instability. Moreover, other laboratory investigations have demonstrated the importance of shear rate as a primary control on the shear strength profiles, such as rate-strengthening or -weakening. Despite these efforts, however, neither the knowledge of general relationships among mechanical conditions, material properties and mechanical behavior nor the underlying processes are well known. Here we report on a suite of ring-shear experiments designed to investigate the possible influence of shear surfaces on mechanical behaviors in simulated shear zones over a wide range of shear rates. Samples, consisting of granular halite and mixtures of granular halite and silica sand, were sheared at room temperature and constant normal stress of 400 kPa, and we varied the proportions of halite by weight. The same loading procedures were adopted during each experiment, and the acoustic emissions (AEs) were synchronously monitored with a sampling rate of 1.0 MHz. We found that: (1) the pure halite sample shows stick-slip instability, but the pure silica sand sample exhibits stable-sliding; (2) inclusion a low concentration of halite is strongly to modify the mechanical behavior and specifically to reduce its ability to sustain stable-sliding for silica sand sample; (3) the stress drop and recurrence time of instability events increase with increasing halite contents, but the occurrence of plastic deformation increases the recurrence time; (4) the visual observations of shear zones show that the variations in halite content may form different shear surfaces which affect the mechanical behaviors in turn. Ultimately, we discussed the related energy dissipation process considering the released acoustic energy to evaluate the landslide mobility.

Normal faulting and gravitational slope deformation in the central range of Taiwan

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In recent decades, normal faulting has been identified to play an important role in mountain building processes affecting rock denudation and surface erosion. In the Central Range of Taiwan, Crespi et al. (1996) first showed the evidence of normal faulting from fault slickenside data along two major highways across Taiwan. Due to limited accuracy and resolution of terrain data, topographic evidence for normal faulting was not clearly identified or found at the time. With the progress of surveying technology, meter-scaled geomorphic features can be displayed and analytically studied using high-resolution DEMs. In this study, field investigation and geomorphic analysis were carried out using LiDAR-derived DEMs to explore the features of normal faulting or gravitational slope deformation in the Hsuehshan Range in central Taiwan. Our preliminary results both from the field investigation and topographic analysis show that the phenomena of gravitational slope deformation were common in the slate area of the Central Range. Three lineament sets with clear subsidence regions along the broad ridge-top areas of the Central Range can be identified from north to south of the Central Range. In comparison, the measured lineament directions were similar to those from the field observations of brittle normal faults reported by Crespi et al. (1996). The high-resolution topographic evidence of normal faulting presented by this study may further support the idea of normal faulting or gravitational slope deformation as one of the major operating mechanisms within the active Taiwan orogenic belt.

How deep-seated gravitational slope deformations are transformed into large-scale landslides: an example of 2009 Typhoon Morakot

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The Hsiaolin landslide incident caused by Typhoon Morakot highlights the importance of deep-seated gravitational slope deformations (DSGSD) studies. In recent years, the use of LiDAR to interpret deep-seated landslides has already shown an impressive result. However, as there are almost a thousand of deep-seated landslides that count an enormous surface in Taiwan, it is crucial to select those with great potential and high activity; secondly, as deep-seated landslides are identified according to their morphological features and most of them showed DSGSD, it is important to know whether they will become catastrophic collapse due to rapid movements. With DEM derived from LiDAR images taken in 2005 and 2010, and Formosat-2 satellite multiple time series images before and after Typhoon Morakot, DSGSD in the region are divided into potential deep-seated landslides and occurred deep-seated landslides (deep-seated landslides that were identified in 2005 and collapsed by 2010). Landslide affecting factors in the statistical analysis are aspect, dip slope, elevation, strength of rock, normalized difference vegetation index (NDVI), slope, distance to river and distance to fault. These factors, together with the weights-of-evidence method and catalogue of potential and occurred deep-seated landslides. That is, all potential deep-seated landslides identified in 2005 were classified into low-, medium- and high-risk groups according to their probability of landslide occurrence. The results indicate that the transformation rate for low-risk group is 10.9% (10.9% of low-risk DSGSD were transformed into a deep-seated landslide); the transformation rate for medium risk group is 36%; and that for high-risk group is 95.4%. The weights-of-evidence statistical analysis indicates that the landslide affecting factors can discriminate highly active deep-seated landslides. Finally, ALOS/PALSAR satellite images taken from 2007 to 2010 and the TCP-InSAR analysis are adopted to assess the relation between susceptibility and activity of deep-seated landslides.

The Kassen and Hakaneset rock slope instabilities along fjord lakes in Telemark, Southern Norway

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The Kassen and Hakaneset rock slope instabilities lie along fjord lakes. The Kassen instability lies at the tip of a plateau dipping steeply towards Bandak lake. The instability stretches 2.5 km E-W. It's up to 100-m-high steep back scarp separates undeformed crystalline bedrock from cracked rock mass breaking the slope in various compartments. In the central part a depression exists, that has descended an additional 25-50 m. Below that, bathymetric data reveal a 13.4-million m^3 large rock-avalanche deposit on the bottom of lake Bandak. Preliminary cosmogenic nuclide ages indicate that the top of the mountain melted out of the ice at 14.1 ka while the foot of the back scarp is 1.5 ka older. Differently the top of the Hakaneset rock slope instability lies mid slope but similarly the up to 75-m-high back scarp separates strongly deformed and cracked rock mass from stable rock mass. Bathymetric data of Tinnsjo lake reveal that the instability extends down to ~330 m below lake level. At the foot both a 20-m-high pressure ridge within a terrace and several generations of slide scars within this terrace suggest that the instability reaches down to the lake bottom.

Structural mapping reveal three steeply dipping and one shallow dipping joint set for the Kassen instability and four steeply dipping joint sets for the Hakanest instability. The schistosity is at both sites poorly developed and at Kassen parallel to one of the steep joints while at Hakaneset subhorizontal. Kinematic feasibility tests at both locations show that simple failure modes are only possible in the steepest slope parts but bi-planar sliding is feasible at both locations for larger compartments. Displacement rates determined by dGNSS show velocities below significance level (< 2mm/yr) for the past years suggesting that both rock slopes stabilized in comparison to the pronounced deformation.

Dynamic process analysis for the initiation time of the Aso-bridge co-seismic landslide

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Analyses of earthquake-induced landslides originate from an examination of slope stability, and the most well-known approach is based on pseudo-static analysis, which because of its simplicity, is frequently used to analyze slope stability problems under seismic loadings. Nevertheless, the method is limited to describing slope stability in terms of a factor of safety and is unable to reflect the behavior of a sliding block during a seismic loading. In fact, the mechanism of landslides is very complicated and having an appropriate initiation time of a landslide is key in understanding the mechanism of an earthquake-induced landslide.

In this study, a non-linear dynamic finite element software, was utilized to investigate the landslide initiation time triggered by an earthquake. The Aso-bridge landslide was selected to be the case of study. Note that the landslide was identified to be the largest one among the numerous landslides triggered by the main-shock of the 2016 Kumamoto earthquakes (Mw 7.3), which struck at a depth of 10km at 16:25 UTC on April 15 2016.

Based on the numerical simulations, the time history of the slope displacement on the critical sliding surface was realized, leading to the possibility of obtaining the landslide initiation time. To verify the appropriateness of the landslide initiation time obtained by the numerical method, comparisons were made against published results that were computed by other methods. Additional comparisons were made to examine the influence of incorporating the vertical seismic component on the numerical model. The results demonstrate the potential of using the numerical software for realistically obtaining the landslide initiation time induced by an earthquake.

Coupling fluvial processes and landslide distribution toward geomorphological hazard assessment: a case study in a transient landscape in Japan

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This study quantified the relationship among deep-seated gravitational slope deformations (DGSDs), landslides, and river rejuvenation in the upper reaches of the Kumano River in the Kii Mountains of Japan, an area of frequent bedrock landslides. River profiles and hillslope landforms were examined, and high-resolution digital elevation models (DEMs) were used to identify DGSDs and landslides. Many of the deep-seated landslides were associated with rainstorms in 1889 and 2011. Landslide volumes were related to landslide areas on the basis of 52 deep-seated landslides that failed during the 2011 rainfall, providing basic data for landscape denudation and sediment yield. River rejuvenation occurred stepwise, incising moderate-relief paleosurfaces and forming two series of knickpoints and V-shaped inner gorges that are up to 400 m deep. More than 65% of DGSDs and 75% of the landslides were located in association with the incised inner gorges along the peripheries of the paleosurfaces or were entirely contained within the inner gorges. DGSDs and landslides associated with the incised inner valley slopes tended to be larger than those developed within the paleosurfaces, and may be long-term transient hillslope responses to river incision. Hillslope undercutting caused by rejuvenated river incision may play an important role in long-term slope stability and the distribution of mass movements, and could serve as an indicator of landslide hazard.

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Gravitational deformation around Tokugo-toge Pass, Northern Japan Alps

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Totally over 10 km linear depressions and multiple ridges develop almost continuously from Mt Choga-take, Mt Otaki-yama to Tokugo-toge Pass, at the left bank of Azusa-gawa River, southern part of Hida Range known as Northern Japan Alps. At around Tokugo-toge Pass, micro-landforms such as ridge-top depression, multiple ridges and uphill-facing scarplet characterize ridges, not only on the main divide, but also on branch ridges. The main dividing ridge has asymmetrical profile i.e. NW-facing slope is gentler than SE-facing one. Arrangement of the micro-landforms indicates that the gravitational deformation process is active mainly in the northwest side. Laminated shale formations of the Jurassic accretionary complex trending NE-SW and dipping steeply to NW are important geologic cause of the sagging feature. Topographic features, geologic structure and loosening degree of rocks indicate that the tensile domain at the ridge part and compressive domain at spur part. The sagging bodies seem to differentiate into smaller bodies and collapse at last. Traces of deep-seated rapid landslides, $3x10^6$ m^3 at the maximum, are often remained. But slow-moving landslides are less developed. Analysis of sediment in the linear depressions shows the initial formation of the depressions may be after LGM.

A huge frontal bulge of the Horomoe landslide, Shiretoko Peninsula, Hokkaido, northern Japan

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The Horomoe landslide which occurred on April 24, 2015 at the southern coast of Shiretoko Peninsula, Hokkaido, northern Japan was accompanied by a characteristic bulge of ca. 380 m long, 40 m width and maximum 10 m high along the seacoast with landslide movement. The displacement body and the bulge consist of bedded mudstone and tuff of Miocene age. The formation mechanism of bulge is unique. The toe of displacement body was wedge-shape, which collided and intruded into a forehand mudstone constituting the wave-cut bench. Then lifted forehand mudstone was piled up on the wedge and transformed to the bulge on water surface. It is different manner from a thrust-bend fold of emplacement body on upslope-dipping slip surface. The bulge consists of left-laterally arranged five sub-bulges parallel to the strike of bedding plain. This arrangement corresponded to the strike direction of mudstone oblique to the direction of bedding-slip. The top of bulge was generally flat and both the seaward (downslope) and upslope sides were steep, which was harmonized with box-folds structure cropped out on a cross-cut section of bulge. The deformation mechanism of Horomoe landslide is not a specific case. Similar events appear in bedded soft sedimentary rocks located at a front of landsliding slope, especially in low-angle dip-slip beds constituting wave-cut bench or river beds.

Numerical study on influences of gravity and geometry to large-size landslides

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At huge rainfall, large-size landslides at which slide planes distributed in deep rock mass, sometimes will occur. Many studies for the occurrence conditions of these large-size landslides indicates reduction of effective stress at sliding plane by permeation of rain water. Many of these landslides, however, had the geomorphologic feature, which reveals deformation due to gravity, i.e. double ridges, before sliding. It seems, therefore, to be considered gravity to and geometry of slope as dominant factors causing these large-size landslides. This report will show the results of numerical experiments on influences of gravity on and geometry of slope to large-size landslides occurrences.

The gravity influences were inspected as increase of empty weight of slope due to rain water permeation. The results of calculation show that the strain at bottom of layer into which rain water will permeate, becomes larger as the empty weight of that layer becomes larger. This result seems to correspond to reduction of slope stability due to rain water permeation. If we can convert increment of empty weight into volume of permeation, the criteria value of rainfall at specific slope will be able to set, because the permeation volume will be estimated from rainfall volume and the permeability of slope material.

Parametric calculations on slope angles and on mechanical properties of slope materials, on the other hand, will give us the geometrical conditions of slope causing to large-size landslide occurrences. If the conditions will be clear, we will be able to detect the slopes which are in unstable for gravitational deformation.

Gravitational slope deformation and its transformation into catastrophic landslides during earthquakes in a slate area

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Japan is now expecting next gigantic earthquakes in Tokai and Tonankai regions along the Nankai trough, which earthquakes likely induce catastrophic landslides. In order to mitigate landslide disaster, clarifying the occurrence mechanism and predicting the potential locations of landslides are essentially important. The purpose of study is to characterize the geomorphological and geological features of gravitational slope deformation of slate in the southern Akaishi Mountains, and to understand the mechanism of their transformation into catastrophic failure during earthquakes based on historic records of landslides.

The study area is the Abe River catchment, where slate of the Paleogene Setogawa Group is distributed and a large landslide, Oya kuzure, was induced by the 1707 Hoei Earthquake, one of the largest earthquakes in Japan. Also during the 1854 Ansei Tokai Earthquake, many landslides were induced and landslide dams were made, which were recorded on a map.

The slate in the study area has well developed cleavage, and commonly toppled or buckled in a flexural manner near the slope surface. Such deformations appear on slope surfaces as linear depressions, convex bulge, and down-hill facing scarps. In particular, large scale linear depressions aligned parallel to ridge tops are inferred to have been developed by shearing along a wide crush zone of faults during toppling. A crush zone is generally impermeable across it, so the deformed rock mass may be affected not only by earthquakes but also by heavy rainstorms. On the other hand, the gravitationally deformed rocks without it have many openings and highly permeable, so they are vulnerable to earthquake shaking rather than rainstorms. Gravitational buckling deformation is also susceptible to earthquake shaking.

Distribution of highly saline groundwater in the areas with many landslides in the southern Niigata Prefecture

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Numerous numbers of landslides have occurred in the areas of Neogene sedimentary rocks in the southern Niigata Prefecture along the Japan Sea coast. They have been called Tertiary type landslides and their occurrence has been attributed to the weakness of those rocks, but recent studies have found highly saline groundwaters beneath some landslides and suggested those groundwaters may be related to landslide activity. However, distribution of highly saline groundwater in wide areas is not known and the actual relationship between highly saline groundwater and landslides has not been elucidated. We have conducted geological surveys, geochemical surveys and the CSAMT geophysical exploration in and around the Nagakurayama anticline, where many landslides and gravitational slope deformations are recognized.

The Nagakurayama anticline consists of Neogene massive tuff, mudstone, and alternation of sandstone and mudstone beds, which are folded with an axis trending NNE-SSW and plunging to the north and the south. There are many landslide units on both wings of the anticline, and there are linear depressions along the ridge. Other anticlines and synclines are aligned subparallel to the Nagakurayama anticline in the Higasi-kubiki hills, Niigata.

Our CSAMT survey showed that the surveyed area is widely underlain by zones of low resistivities (<10 Ωm) generally deeper than about 100 m and that much higher resistivity areas are present shallower than the level. Low resistivity zones extend much deeper just beneath the linear depression. Comparing with the results with geological cross sections, higher resistivity zones may correspond to tuff and the linear depression. The interstitial water of mudstone may be highly saline water in the depth and might be replaced by fresh water at shallower zones. The replacement could deteriorate rocks and likely be a basic cause of landslide occurrence.

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Deformation measurement of slow velocity landslide by analysis of three-dimension point clouds

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In recent years, there is an increasing risk of occurrence of various landslides such as slope collapses of deep-seated landslide and shallow depth slides, but it is difficult to predict the occurrence of slope failures. Landslides are monitored after geological surveying and consideration of countermeasures if interpretation of aerial photograph or laser measuring indicates their activity. However, if characteristic landslide features are found only locally or their activity is not obvious, it is difficult to decide to make a further investigation.

To catch slow velocity landslides is necessary for landslide prediction, but it is too costly to carry out real-time observations with invar wire extensometers or borehole inclinometers on every place that shows a specific land feature. In recent years topographic data have been acquired by using laser measurement, which has developed rapidly, and as a result of that high-dense three-dimensional point cloud data have been accumulated.

In this study, we have developed the discriminating method of the evaluating method of landslide variation amount using a laser point group at the position shifted from the ground with an arbitrary distance. Our proposed method is an application of DEM data processing, in which detailed topography can be extracted using only the laser data set from below a certain height from the ground surface. Next, we compute the accurate displacement vector of the slope by matching the processing for the laser data image. We describe the result that it is possible to predict the movement of slow velocity landslide using the method we developed. We discuss the results of an experiment in an actual slow velocity landslide and report the applicability of our proposed method.

Effects of geological division on geomorphic parameters in Japan based on the spatial analysis of the seamless geological map of Japan

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Quantitative analysis with DEMs based on GIS (Geographic Information System) is a valid method to prove relationships among slope angle, altitude and bedrock geology. Altitude distribution, altitude dispersion, slope distribution, and curvature for each of rock varieties have been measured as a popular method for quantitative assessments of rock types. Such topographical measurements have been applied to various rocks since the 1930s in Japan. Over the past few decades, a considerable number of studies have been conducted on topographical measurements with high-resolution DEM based on GIS. Although studies have been made on the spatial analysis with DEMs in large area, there is little study of spatial analysis with digital geological map in large area. Due to the relatively large time for the field survey requirement, compiling geological maps are limited only in small area. This study contributes spatial analysis with DEMs and seamless geological map of Japan at the scale of 1:200,000. The average altitude, average slope angle and altitude-slope relationship of each geological unit was examined. Based on the initial results of the spatial analysis, the terrains underlain by some specific rocks, however, are highly susceptible to slow gravitational landslides and thus have markedly reduced slope angles than other terrains with similar altitudes. Topographical measurements covering landslide areas and non-landslide areas disclosed that slopes of geological formations concentrated by landslides are 10 to 20 % less than those of the remaining formations.

A risk evaluation method for deep-seated landslides based on stream water chemistry

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Topographic features related to bedrock creep are considered to be effective signals for detecting and evaluating potential landslide areas (PLAs) for deep-seated catastrophic landslides, for which the high-resolution DEM based on airborne laser scanner is a quite powerful tool. In addition, as a supporting index for screening and evaluating the PLAs, water chemical analysis data of stream or spring water could be also useful, based on the assumption that the changing of groundwater flow pathways accompanied by a development of potential slip plane (bedrock deterioration) significantly influences on not only water discharge amount but also water quality from slopes. There is a possibility that the concentrations of mineral derived solutes (such as Ca^{2+}, Na^{+}, SO_4^{2-}, HCO^{3-}, and Si) or electric conductivity (EC; corresponding to the total concentration of ions in solution) of stream water becomes higher, reflecting on increasing degree of contribution of bedrock groundwater flow passing through potential slip plane with high water permeability due to a development of potential slip plane. In this study, we examined availability of that water quality index by comparing spatial distribution of PLAs detected based on topographic and geological features with water chemical analysis data collected at multiple points in southern Taiwan. In Chaochou formation (underlain by argillite and/or slate intercalated with sandstone lentils) where PLAs are especially concentrated, a certain correlation was found between the occupancy ratio of PLAs to the catchment area corresponding to each water sampling point and the index combining Si concentration and EC of stream water.

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Sorting out landslide topography in Japan by knick line distribution, and geological signs of landslide occurrence

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The mountains in Japan have been continuously influenced by upheaval force under the tectonic movement since the quaternary era. Scoring and erosion frequently occur on river banks and slopes due to heavy rains and river flows, which form so-called “knick lines” in terms of geomorphology. Rock mass on slopes also becomes fragile due to weathering over the long period. These specific geological and geomorphological features in Japan, in couple with wet climate conditions, accelerate erosion on the river basins and mass movement such as landslide and failure.

This paper describes several phenomena of erosion process including river capture in the neighboring basins, and gravitational deformation of rock slopes which may indicate signs of landslides. Around the gentle slopes above the knick lines, linear depression in the upper portion, gentler slope in the mountain side, time-dependent rock mass loosening, and weathering result from gravitational deformations. If the collapse in the toe portion, where usually supports loosening slope upwards by compressive strength or geotechnical supporting structure, occurs due to such as river erosion, inundation, heavy rainfall or earthquake, new larger landslide in the upper portion could be triggered. Deformations in rock mass induced by loosening occur not only in the dip slope such as slides on discontinuities and buckling folds at the toe portion, but also in the escarpment of opposite dip slope such as kinking, bending, block toppling, and shear failure changing discontinuities. Rock mass plasticity due to loosening may become lager in the slope consisting of ductile rocks totally or partially in the toe portion where the concentration of stress occurs. Where rock mass loosening has increased by the river erosion, they may result not only in lower density, larger permeability, and smaller seismic velocity in rock mass, but also decrease in rock strength and lowering ground water level.

Structural features and formative processes of a sliding zone of a large rockslide

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Brittle fracturing of rocks develops a sliding zone of a rockslide during gravitational slope deformation and therefore the structure of a sliding zone likely records its formative processes. We investigated a sliding zone of a 60-m thick rockslide at an excavated trench in a rockslide of mudstone, green stone, sandstone, and chert in an accretionary complex, central Japan. The sliding zone is a crush zone with a maximum thickness of 5 m and dip of 15° downslope parallel to the bedding plane. The boundary between the hanging wall and the crush zone is irregularly undulating and had no well-defined planar shear structures like Y-shear and P-shear. The crush zone is made in mudstone and the hanging wall consists of green stone and chert, which are separated into blocks by fractures; the blocks are displaced and rotated to each other to form openings, where the crushed materials is thrusted into. These structural features strongly suggest that this crush zone has a gravitational origin at a shallow depth. The crush zone has 10-cm thick clayey zone in its upper middle, in which we found a few slickensides with striations. Only this clayey zone has consistent shear surfaces and the other portions of the crush zone has chaotic mixtures of rock fragments and fine matrix. Grain size distributions showed that the grain sizes are the smallest in the clayey layer and get larger upward and downward away from it. The rock fragments in the crush zone become more spherical and rounded toward the clayey layer. These morphological features suggest that brittle deformation during the gravitational slope deformation became localized in the upper middle of the crush zone, where pulverization, attrition, and shearing concentrated.

Bell-shape index indicating top-heavy profile of high relief mountain and gravitational deformation

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Double ridges or up-hill facing scarplets distributed on mountain ridges of high relief are empirically known as indicators that the mountain bodies are slowly undergoing gravitational creep deformation and are known as signs of landslides of large scale. Such micro topographies on top ridges in Japan Alps have developed since 30 ka before. That is presumably attributed to the para-glacial phenomena and they have intermittently developed in a time scale of 10000 year. However, it is quite gradual movement. It is very difficult to distinguish which mountain slopes are critical to collapse soon. Dense distribution of the up-hill facing scarplets is not always a pre-cautious sign of sudden collapse of the mountain body in near future, though the earthquake tremor will affect the stability of high relief mountains.

Other causative factors to induce landslide for hazard susceptibility mapping are required. We analyzed topographic features of mountain ridges in Akaishi and Hida Ranges (Southern and Northern Japan Alps), using DEM of 10m grid scale and considering those of the surrounding slopes and ridge scale over the study area, where gentle and round ridge top fringed by distinct break of slopes develop. The authors propose bell-shape index. Profiles in high relief mountainous are sometimes show high contrast between steep lower slope and gentle ridge tops are similar to a bell-shaped. Bell index is defined as area ratio of a mountain profile per a subterranean aperture area from a ridge top, averaging those of eight directions from the top. In another word, the bell-shaped index is one kind of the convexity of ridge as a whole. The authors think bell-shape index is a good criterion of gravitational rock creep and a subsequent deformation of mountains.

Integrated landslide survey using UAV-SfM and geophysical technologies: a case study in Rikubetsu, Hokkaido, Japan

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We show a case of integrated landslide survey by using sophisticated technologies including unmanned aerial vehicle (UAV) photogrammetry, digital terrain modeling by structure from motion (SfM), and ground-penetrating radar (GPR) and surface wave (SW) tomographies. The studied landslide was found in Rikubetsu, Hokkaido, Japan, in April 2016 due to the appearance of a terminal bulge on a flat grassland. The dimension of the landslide is up to 370 m long and 100 m wide, and that of the bulge is about 3 m high and 20 m wide. As the bulge is formed on the grassland and landslide motion is slow but active, we could observe detailed change of the topography especially at the terminal bulge by UAV-SfM technique. Digital terrain models produced by UAV-SfM show that the bulge expanded and its height rose from 3.1 m in April 2016 to 3.7 m in May 2017. GPR and SW profiles exhibit thrust-like structures at 3-4 m depth beneath the surface of the terminal bulge. The landslide shows a valley-like topography, and some landslide blocks are distributed in the valley bottom. A landslide block is incised by the 5-m wide river behind the bulge, indicating that the landslide mass mostly consists of unconsolidated valley-filled sediment originated from volcanic activity. As the rupture surface is not observed on the exposed cliff, it would pass under the riverbed and thrust up beneath the grassland. An old tephra fills in a 1-m wide crack on the exposed cliff, implying that the landslide activity has been continuing for several hundred to several thousand years.

Locations and ages of large mass movements in a high-relief mountainous area underlain by accretionary complex: a case of the Katsuragawa Valley along the Hanaore Fault, central Japan

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This study conducted exposure dating of landslide deposits and topographic and geologic analysis using a geographic information system for revealing controlling factors of temporal frequency and spatial distribution of largescale mass movements in a high-relief mountains area underlain by accretionary complex. The study site is the Katsuragawa Valley located between the Hira Range and Tanba Mountains in central Japan. High-relief hillslopes characterize the topography in this area with elevation ranging from 300 to 1000 m, forming deeply-incised V-shaped valley along an active strike-slip fault, Hanaore Fault System. Bedrock in this area consists of Jurassic accretionary complex, composed of chert, sandstone and mudstone, and Cretaceous porphyrite and granite intruding into the sedimentary rocks. Large-scale gravitational deformation of hillslopes and catastrophic bedrock landslides have occurred with paleo heavy rainfall events and earthquakes; some of the landslide debris had probably blocked the trunk river and tributaries. We mapped landslide scars and deformation scarplets, bedding attitudes of the bedrocks, and lineaments formed by tectonic faulting, to examine the relationships between topography, geologic structures, and occurrence of the mass movements. Samples for exposure dating were collected from the outcropping boulders on several landslide deposits to measure cosmogenic 10Be accumulated in quartz. The results of the spatial analysis indicate that mass movements tend to occur at conditions of high-relief, steep dip slope, with high angle faulting. The exposure ages indicate that several landslides occurred at 6 ka and 2 ka. The older age corresponds to the timing of the known latest large event of the Hanaore Fault. A sub-fault cuts the landslide deposit, making a right-lateral offset of a incising channel of 20~25 m, indicating a displacement rate of 3.3~2.2 m/kyr. This fast slip rate implies high activity of the Hanaore Fault System in late Holocene.

Characteristics of soil layers on shallow landslides triggered by rainfall at Izu Oshima, Japan

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On October 15th to 16th, 2013, periodic heavy rainfall associated with the typhoon affected the eastern part of Japan, including Tokyo and Izu islands. The intensity of rainfall in Izu Oshima island exceeded 400 mm. Based on 30 years of record (1981-2010) from the Japan Meteorological Agency (JMA), the mean rainfall in October is 329 mm. Heavy rainfall in this island triggered landslides and lahar disaster in this area.

The most landslides at Izu Oshima rapidly transformed into lahars and flowed down along stream channels. Most of the landslides in this area occurred on slopes which was steeper than 20° were mostly higher than 200 m elevation (Miyabuchi et al., 2015). Large-scale landslides concentrated to Okanezawa at the upper area of Motomachi area which have many populations.

The rainfall activity triggered the shallow landslides. The rainfall activity induced the water content value increase at this location. Soil properties (at the slippage plane) may affect the occurrence of this shallow landslide. Rainfall activity increases the value of water content and can influence the landslides. Furthermore, clay fraction content will increase in the slippage plane. Soils and clay characteristics at slippage plane may have an effect at this location.

Interpretation of L-band InSAR images to detect landslide surface deformation along Minjiang River, Western Sichuan, China

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1933 Diexi Earthquake (M7.3) triggered large landslides along Minjian River. Synthetic Aperture Radar (SAR) is a promising tool to detect slight surface deformation not only by tectonic but also by landslide movement. Especially, L-band microwave (wave length: ca. 24cm) SAR is more suitable to detect surface deformation in forest area such as monsoon SE Asia than C-band (wave length: ca 6cm), because C-band microwave is tend to be scattered on the surface of forest. In this study, InSAR images were produced from L-band SAR data, i.e., ALOS/PALSAR and ALOS-2/PALSAR-2 data to detect slight landslide surface deformation. The observation period is from Jan 2007 to Dec 2016, and six pairs of the InSAR images were produced in this period. As a result of InSAR images interpretation, for example, two suspected deformation areas were detected; one is at 103.936587 deg E and 32.04462 deg N, another is at 103.674754 deg E and 31.852838 N. Other pairs of InSAR images are now under production and more deformation candidate sites will be detected and more precise discussion will be given in the meeting.

Evaluation of secondary slope failure susceptibility using detailed topographic data

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At slope disaster sites, such as slope failure and a debris flow, in order to carry out safe search and relief activity, we have to take the danger of secondary slope failure into consideration. However, it was very difficult to acquire sufficient information for carrying out safe activity at the time of the disaster first action, and we had to carry out the old relief activity for depending on few information. In this research, I collect the disaster examples by secondary slope failure which occurred in the past, analyze the feature of the secondary slope failure, and clarify information required at the time of the disaster first action for safe search and relief activity. In particular, I collect and measure the detailed topographic data immediately after slope disaster generating (before secondary slope failure occurring), and evaluate the secondary slope failure susceptibility using the detailed topographic data.

The subjects of the research are the slope failure and the debris flow in the Hiroshima heavy rain disaster which occurred in August, 2014, Japan. I aimed at clarifying the features of the slope failure and debris flow. And, by the detail topographic data measured by the airborne laser scanner (LiDAR), and aerial photograph taken by drone which were acquired after the disaster, I estimated the secondary slope failure susceptibility. The slope failure and debris flow are mostly shallow landslides with a shallow head less than 1 m. The cause of the sedimentary soils which attacked human activity was based on the erosion of the flow part. Therefore, in order to consider the susceptibility, it proved that it is necessary to observed not only the slope failure head but the secondary sedimentation of a flow part. It is noted that this work was supported by JSPS KAKENHI Grant Number JP16K16382.

Geotechnical study on fluidized landslide at Aso Volcanological Laboratory in the 2016 Kumamoto earthquake

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In the 2016 Kumamoto earthquake, various landslide disasters occurred in the Aso caldera. It seems that the strong ground motion and the geomorphology, geology and soil mechanics peculiar to the volcanic area are the main causes.

We focus on the fluidized landslide in Takanoobane lava dome of Aso volcanological laboratory. A landslide in the tephra layer occurred from the hillside to the foot of the lava dome, and nearly 600 m of volcanic soils flowed, struck the Takanodai, and 5 people died.

The height of the sliding section of this landslide's scar is about 8 m. The slope of the sliding surface exposed at the middle of the landslide is gentle slope, about 10 to 15 degrees. This inclination is almost equal to the inclination of the surface slope before the landslide occurred.

Since it was considered that the slippage surface from the field survey was the Kusasenrigahama pumice (Kpfa; 30ka), the undisturbed samples of this layer were sampled, and carried out various soil mechanical tests, permeability test, density test, direct shear test and cyclic triaxial test (scheduled). From these test results, we will consider geotechnical consideration of fluidized landslides.

Breaking-off of hanging glaciers at Mt. Langtang Lirung, Nepal Himalaya

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On 25 April 2015, a big earthquake (M7.8) occurred at Gurkha region located northwest of Kathmandu, the capital of Nepal. On 12 May, an earthquake of M 7.3 also occurred. In Langtang valley, located north of Kathmandu, twice catastrophic snow-rock avalanches (6.81×10^6 and 0.84×10^6 m^3) triggered by the earthquake caused serious damages such as more than 350 victims at Langtang village (Kargel et al., 2015; Fujita et al., 2016). The ice-rock avalanches dammed up liver in the bottom of valley, caused air blasts, and destroyed the greater part of Langtang village. It is thought that triggers of the slope failure are ice avalanche from hanging glacier on steep mountain slope and snow avalanche from massive snow fall during winter. In this study, we verified influence of hanging glacier directed at southwest and east face of Mt. Langtang Lirung to face Langtang valley, and created a distribution map of hanging glacier by using the digital aerial images acquired in the field survey in the September 2015 and SfM software (Agisoft, Photoscan). We extracted failure point and size of hanging glaciers using Google Earth and digital aerial images before and after the earthquake, and found failure of 12 breaking-off and new clack points on hanging glaciers. The failure points are located on the steep slope of 20°-60° between 5500 m and 6700 m asl. The biggest ice failure was roughly 150 m × 110 m × 30 m on southeast face of Mt. Langtang Lirung. In addition, we also compared aerial images on September 2015 and April 2017, to detect the features of breaking-off at hanging glaciers.

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The study of rockfall and topographical change in Shirouma-Daisekkei, the Northern Japanese Alps

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Shirouma-Daisekkei is one of the three largest snow patches in the Japanese Alps. More than 10,000 climbers pass on the Shirouma-Daisekkei to climb Mt. Shirouma every summer. At the Shirouma-Daisekkei which has steep rock-wall on both sides, the rockfall accidents occur every year. As recent remarkable accidents, two rock slips at the rock wall caused several victims in August 2005 and 2008 (Kariya et al., 2008). We investigated the current condition of rockfall and rock slip, and topographic change around Shirouma-Daisekkei in 2014-2017. To investigate the source area of rockfall, erosion zones were extracted using airborne laser DEM of plural years. Felsic rock area is a linear erosion type along stream line on the steep rock-wall. While, the ultramafic rock and the felsic tuff areas are point erosion type. The erosion pattern on the steep rock-wall differed in geology. These results show the timing of rockfall at a linear erosion type delays in the year with many snowfalls. Comparing the two ortho images taken at the same time using UAV, the number of boulders in the year with many snowfalls (2015) was also smaller than that in the year with small snowfalls (2016) on the Shirouma-Daisseki. Focusing on the surface inclination angle obtained from the 50-cm resolution DSM produced, the gentle and steep slopes are alternately present in the Shirouma-Daisekkei main stream, and re-rolling and re-sliding of many boulders were confirmed from the interval imaging to the steep slope. In addition, we investigated the internal structure of the Shirouma-Daisseki using ground penetration radar (GPR) and distribution of crevasses. We found a huge ice tunnel has developed along a stream line at the bottom of the snow patch. Our following survey shows ice tunnel still remains in May 2017. The ice tunnel might cause snow collapse in this summer.

Time-dependent analysis of a complex rockslide constrained by geomorphic markers

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This study focuses on the time-dependent analysis of a large rockslide in the headwater sector of the Bidente River (Northern Apennines, Italy). Several landslides affect this area, thus testifying for the intense gravitational morphogenesis. One of the most significant in terms of dimension and complexity involves the left (south-facing) valley-side, where a village and some sparse buildings are settled. Aim of this study is double: characterizing the landslide in terms of mechanism and depth, as well as understanding its evolution from the onset to present, considering the slope-to-channel evolutionary context.

Geological and geomorphological surveys allowed us to classify the slope deformation as a slow-moving, structurally-controlled, compound rockslide that affects the hanging-wall of a major thrust fault, thus representing its gravitational, reverse re-activation. Morphological evidence suggests that the movement began as a huge, unique slide successively dissected in three separate lobes by two left tributaries of the Bidente River.

The geological model of the slope is featured by an alternation of sandstone and marlstone layers arranged with a dip-slope attitude. The engineering-geological model of the slope arises from the transposition of equivalent continuum parameters derived from in-situ investigations and laboratory tests to the geological model.

The position and chronology of Quaternary strata terrace levels and their correlation with stream long-profile knickpoints, as well as the application of time-dependent catchment-scale metrics, provided useful constraints for the reconstruction of the late Quaternary slope-to-channel morpho-evolutionary stages. The latter, have been put into a finite difference stress-strain model, starting from a reconstructed original morphology and considering the time-dependent behavior of the rock mass by a creep rheology.

As a result, it was possible to assess i) the sensitivity of the slope system to rock mass creep parameters, ii) the actual depth of the sliding surface, iii) the present evolutionary stage of the gravitational process.

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Nucleation and kinematic significance of deformational structures in earth flows

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Surface mapping, geophysical surveys, mechanical modeling, GPS surveys and strain analysis were used to study the spatial distribution, the conditions of nucleation and the kinematic significance of deformational structures along the Mount Pizzuto earth flow in southern Italy. The earth flow reactivated in 2014 and, as consequence of its movement, many deformational structures marking the upslope and the downslope ends of kinematic zones, formed along its length. Mechanical models, developed on the basis of field data, were used to analyze the transitional slopes between steep (riser) and gently (tread) sloping, driving and resisting, elements forming kinematic zones and vice versa.

Field observations, data, and mechanical modeling indicate that in the case of the riser-to-tread transition, the earth flow decelerates and compressive structures form at the change in slope to accommodate the decrease in velocity. Similarly, in the case of the tread-to-riser transition, the earth flow accelerates and extensional structures form. Additionally, the relative velocity between the riser and the tread controls the geometry of the compressive structures in the riser-to-tread transition. If the velocity drop between the riser and tread is large, a downslope vergent thrust and associated fold resembling a fault-propagation-folds form. On the other hand, if the velocity drop between the riser and tread is small, the longitudinal shortening is accommodated by a smaller, upslope vergent backthrust and associated fold/pressure ridge. In the case of a tread-to-riser transitional slope, similar extensional structures are generated regardless if the tread is stable or not. Multiple reactivations and long-term creep translate downslope the structures as relatively coherent units, changing their position along the earth flow channel and possibly their geometry. 2D strain along the surface of the earth flow indicates the presence of zones of positive and negative dilatation consistent with the structures geometry and position.

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Time-dependent modelling of a mountain front retreat due to a fold-to-fault controlled lateral spreading

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The Eastern Betic Cordillera (Spain), shows at the Sierra de Aitana an impressive example of lateral spreading involving a mountain anticline ridge dislodged by a post-orogenic extensional tectonic. The 40 m deep and 20 m opened trenches testify the ongoing gravitational slope deformation featured by a rock mass lateral spreading.

The Sierra de Aitana anticline ridge was dislodged along a normal fault line which generated a scarp with a kilometric lateral continuity. Due to the geological setting where Eocene limestone overlays calcareous Eocene marls and marly clays a lateral spreading originated, isolating huge prismatic blocks.

This phenomenon had a continuous evolution over time. The mechanical properties of the materials were inferred through both field and laboratory tests which allowed to constrain an engineering-geological model of the Sierra de Aitana ridge based on equivalent-continuum approach. A stress-strain sequential numerical modelling, aimed at reproducing the morpho-structural evolution of the Sierra de Aitana anticline was carried out by a back-analysis of the front retreat. A time-dependent solution was approached by assuming a creep configuration of the modelling.

A parametric solution was adopted to calibrate rock mass rheology also taking into account: i) tectonic displacement due to the Aitana normal fault system by simulating these element as interfaces in the discretized domain; ii) influence of pre-existing joint sets by assuming a main anisotropy in the elasto-plastic failure solution; iii) admissible variations of the regional stress-field related to compressive and extensional phases; iv) generalised visco-plastic behaviour representing the ductile marls. The numerical modelling outputs that the lateral spreading mainly evolved as a creep driven process while stress-release induced by tectonic activity is not sufficient to justify the observed landforms. The obtained results highlight the relevant role of inherited structural elements for regulating the time evolution of the ongoing gravitational process at the Sierra the Aitana.

Dynamic responses of the intact and remodeled loess slopes under the coupling effect of earthquake and rainfall: Insights from shaking table model tests

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In order to examine the dynamic response of loess slopes with different formation backgrounds to earthquakes with preceding rainfall, a serious of shaking table model tests were conducted in this study. A natural relatively homogeneous Malan loess slope (Q3), which is located on Shanzidun Village, Xicha Town of Lanzhou city, was selected as prototype of this study, and intact specimens of the loess mass sized 2 m × 1 m × 1 m was cut from the slope and was used as the model slopes in the tests. Reconstructed model with the same size was also adopted by remodeling the loess taken from the tests on those intact specimens. By analyzing the acceleration, soil pressure and pore water pressure that were monitored at different locations of the specimen slope model, we examined the dynamic responses of the slopes that were subjected to a rainfall of 100mm before the introduction of shaking with different shaking intensities. The deformation and failure characteristics of the slopes were presented and analyzed. Finally, we summarized the failure mechanism of the intact and remodeled loess slopes under the coupling effect of earthquake and rainfall, and also discussed the possible influences of loess structure on the dynamic responses of the slopes.

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Landslide history in post-caldera central cones of Aso volcano, Japan

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Aso volcano is a composite volcanic system comprising Aso caldera and post caldera central cones. Post-caldera central cones were formed soon after the last caldera-forming eruption (90ka) and have produced large amounts of tephra fall deposits that thickly cover their slopes. In such a setting, landslide is primary cause of tephra erosion, therefore its frequency and magnitude strongly affect regional denudation rate and sediment yield. Here, we present two case studies on landslide history in post-caldera central cones of Aso volcano: rainfall-induced landslides on steep slopes of Takadake volcano and earthquake-induced landslides on gentle slopes of the Takanoobane lava dome. At Takadake volcano, rainfall-induced landslide events repeatedly occurred almost every decade (1990, 2001, and 2012 in the last 30 years). Moreover, presence/absence of key marker beds, Ojodake scoria (OjS; 3.6ka) and Nakadake N2 scoria (N2S; 1.5ka), indicates timing and extent of major landslide events during the last 3,600 years. At Takanoobane lava dome, several landslides were induced by the 2016 Kumamoto earthquake. The largest one formed slip surface in Kusasenrigahama pumice (Kpfa; 30ka), resulting in erosion of tephra accumulated during the last 30,000 years. We also found an old landslide scar adjacent to the landslide. Field observation revealed that tephra accumulated during the past 23,000 years (from the 30ka Kpfa eruption to the 7.3ka Kikai-Akahoya ash (K-Ah) eruption) has been eroded at the scar, while the erosional surface was buried under soil developed during the last 7,200-7,000 years. This finding indicates the possibility that strong earthquake(s) struck this area soon after the K-Ah eruption and induced large landslides as same as the 2016 Kumamoto earthquake.

Geomorphological control on distribution and development of wetlands on large-scale landslides in Ou Mountain Range, NE Japan

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Quaternary volcanoes of the Ou Mountains, in the northeastern Japan, are occasionally dissected by large-scale landslides with their areas greater than 1 km^2. Within these landslide masses various-size and -type (lake, fen, bog) wetlands have been formed in the landslide depressions and contribute to creating mosaic landscapes and biodiversity of landslide areas. This study examines geomorphological controls on the distribution and development stage of wetlands on large-scale landslides in the Ou Mountains. We mapped in detail the microtopography of the landslides and identified wetlands using color aerial photographs and digital elevation models. We selected two rotational slides in the Hachimantai Volcanic Groups, two translational slides in the Funagata Volcanic Groups and one multiple slide in the Kurikoma volcano.

Landslide movements determine the topography of the landslide masses including the scale and distribution of depressions. Whether the depressions become wetlands or not depends on the local groundwater table. In the case of the rotational landslides, many large wetlands are on the blocky structure areas of the upper part of landslide bodies. In the middle and lower part of the landslides, a few small wetlands tend to be due to fragmented topography, whereas large wetlands could occur in depressions behind transverse pressure ridges in the zone of accumulation. In the case of translational slides, the wetlands stand in the depressions between the scarps and in cracks widely scattered over the landslide masses. All landslides in this study contain both lakes and peatlands, as different development stages. Sediment accumulation, drainage-channel development, and shortage of water recharge are major factors to develop wetlands from lakes to forests via peat bogs. In contrast, secondary landslides create younger lakes to rejuvenate wetland diversity in landslides.

History of mass movements and paleolake formation revealed by depression-filling sediment records in a tectonically active mountainous area: a case study in Mt. Kushigata, Koma Range, central Japan

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Landslide hazard assessment in tectonically-active regions requires comprehensive understanding of the history of mass movements, which is possibly recorded as sediments in the depressions formed by paleo-events. This study reconstructed the activity of landslides and duration for persistence of paleolakes using depression-filling sediment records in a high-relief mountain range nearby an active thrust fault. The study area is Mt. Kushigata, northern Koma Range, bounded its eastern margin by Ichonose Fault, located in Southern Japanese Alps. A zone of aligned depressions lies on the eastern side of the Mt. Kushigata. We mapped the depressions and surrounding landslides, and conducted field-investigation for sediments in the depressions, and analyzed pollen and tephra layers. The basement material beneath the depression zone is a thick landslide debris. Lacustrine overlays the landslide deposits, suggesting the formation of lakes after the initial events. The lacustrine outcrops at several localities with different altitudes within an elevation range of ~70 m. Some of the lacustrine beds are thicker than 10 m, bearing two pumice layers: 9~50 cm of On-In (90 ka) and ~100 cm of On-Pm1 (100 ka), erupted from Ontake Volcano, 90 km west from the study site. The analysis of pollen included in the lacustrine revealed that the lakes were formed initially during Marine Isotope Stage 6 to 5d (185-110 ka) and had persisted as long as a few tens of thousands of years. These sediments were buried by subsequent landslides to form the present land surface. The vertical succession of the sediments and its localized distribution suggest that episodic landslides contributed to the emergence and disappearance of the paleolakes, although further researches are left for exploring detailed mechanisms and processes in relevance to the gravitational slope deformation of Mt. Kushigata and the activity of the Ichinose Fault.

Slope deformation problem in Quaternary volcanics by the 2016 Kumamoto Earthquake

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Many slope movements have occurred by the 2016 Kumamoto Earthquake. These slopes were mainly composed of Quaternary volcanic rocks (mainly auto-breccia and massive lava) and volcanic ashes (mainly tephra). As those new volcanics are soft and easily deformed, not only landslides but also various slope deformations were observed in slopes that remained after the earthquake. The amounts of displacement by the deformation vary from several millimeters to 5 meters and over. Topographically, those slope deformations are divided into 2 types, A: shoulder of cliff, and B: other slopes. Type A has appeared in all Quaternary volcanics, and type B has appeared in volcanic ashes and auto-breccia. Geologically and mechanically, those slope deformations are divided into seven types, 1: shallow soil creep and ductile deformation of soft volcanics (volcanic ashes and auto-breccia), 2: shallow sliding/gliding with many open cracks of soft volcanics (volcanic ashes and auto-breccia), 3: toppling of volcanic rock mass (columnar jointed lava), 4: in-situ rolling of volcanic rock mass (columnar and block jointed lava), 5: deep-seated sliding/gliding of volcanics (volcanic ashes, auto-breccia), 6: active fault or tectonic deformation (all strata), 7: mixture of slope deformation and tectonic deformation (soft strata). Those slope deformations have induced many problems on civil engineering structures such as roads, railways and waterways. Especially for bridges, the displacement of foundations by the deformation should be limited within very small so that bridge body would not suffer devastating damages. Then the Japanese Ministry of Land, Infrastructure and Transport and Tourism has informed, after the earthquake, a new government notification on the geological investigation and resilient design of bridges for slope deformation by earthquakes.

An application of the MIBSA to slow moving landslides

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Large rockslides are characterized by complex spatial and temporal evolution, with non-linear displacement trends and significant effects of seasonal or occasional events. Forecasting landslide motion and collapse is a fundamental task for hazard zonation and the design of risk mitigation structures. Consequently, the analysis and modeling of the involved phenomena are very important. In order to forecast the landslide evolution in terms of displacement and natural risk it is necessary to simulate their mechanical behavior. For this reason, an evolution of the mathematical model MIBSA (Multi Interacting Block for Slope Analysis; Crosta et al. 2014; Dattola et al. 2016), consisting in a set of independent and interacting rigid blocks together with a viscous-plastic model based Perzyna's approach, is here proposed. Block motion derives by solving the first momentum equation in which forces considered come from the interaction of blocks and the slip surfaces (shear band).

The mathematical model for the shear was initially developed and calibrated on the experimental results on the sample from the Mont de La Saxe and obtained by means of the dynamic-loading ring-shear apparatus (DPRI-5, Sassa et al., 1997). This laboratory-testing machine has been used to simulate the entire process of failure.

This model is applied to simulate three case studies: the Mont de La Saxe (Italy), Ruinon (Italy), and other large landslides under different boundary conditions. Since in the landslide case studies, the mass movement is strongly conditioned by the seasonal trends of the groundwater table, their piezometric surfaces are reconstructed by the previous in situ measurements using an interpolation tool directly implemented in the numerical code.

Finally, the simulations give insight about the progressive failure mechanism involved in the evolution of the rockslide. The numerical simulations give the evolution of the kinematic variables (displacement, velocity and acceleration) of each block as well as global and local safety factor to provide a basic tool for the prevision of local and/or global instabilities.

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