589       November 18, 2020         591       The debris avalanche in Donghekon area triggered by the 2008 Wenchuan (M8.0) earthquake: features and possible transportation mechanisms         592       Gonghui Wang <sup>1</sup> , Fanyu Zhang <sup>2</sup> , Gen Furuya <sup>3</sup> , Koichi Hayashi <sup>a</sup> , Wei Hu <sup>3</sup> , Mauri McSaveney <sup>5,6</sup> , Runqiu Huang <sup>5</sup> )         593       Addresses of authors:         594       Disaster Prevention Research Institute         695       Gonghui Wang (Corresponding author)         596       Disaster Prevention Research Institute         697       Gókasho, Uji, 611-0011, Japan         698       Tet: (+81)774-384100; Fax, (+81)774-384105         698       Email: wang.gonghui.3r@kyoto-u.ac.jp         697       Disaster Prevention Research Institute         698       MOK Key Laboratory of Mechanics on Disaster and Environment in Western China         699       Lanzhou Taiouo, China         600       Email: Mang Mol, Caucduen         611       Email: Glouya@u-toyama.ac.jp         612       Generuruya         613       Toyama Prefectural University         614       Kurokawa S180, Imizu-shi, Toyama 939-0398, Japan         615       Email: gluruya@u-toyama.ac.jp         616       Kurukawa S180, Imizu-shi, Toyama 939-0398, Japan         617       4       Koichi Hayashi@geometrics.com	588	Sub	mitted to <i>Engineering Geology</i> for possible publication
590         The debris avalanche in Donghekou area triggered by the 2008 Wenchuan (M8.0) earthquake:	589		November 18, 2020
The debris avalanche in Donghekou area triggered by the 2008 Wenchuan (M8.0) earthquake:           features and possible transportation mechanisms           Gonghui Wang <sup>1</sup> , Fanyu Zhang <sup>2</sup> , Gen Furuya <sup>3</sup> , Koichi Hayashi <sup>4</sup> , Wei Hu <sup>5</sup> , Mauri McSaveney <sup>5,6</sup> , Runqiu Huang <sup>5</sup> )           Addresses of authors:           In         Gonghui Wang (Corresponding author)           Disaster Prevention Research Institute         Koichi Hayashi <sup>4</sup> , Wei Hu <sup>5</sup> , Mauri McSaveney <sup>5,6</sup> , Runqiu Huang <sup>5</sup> )           Cockasho, Uji, 611-0011, Japan         Gokasho, Uji, 611-0011, Japan           The (+81)774.384100; Fax:(+81)774.384105         Fanal: wang.gonghui.3r@kyoto-u.ac.jp           Mol         Key Laboratory of Mechanics on Disaster and Environment in Western China           Department of Goological Engineering         Lanzhou University           Lanzhou University         Lanzhou University           Gen Furuya         Toyama Prelectural University           Kuokawa 5180, Unizz-shi, Toyama 939-0398, Japan           Email: gfuruya@pu-toyama.ac.jp           Mat         Karokawa 5180, Unizz-shi, Toyama 939-0398, Japan           Email: gfuruya@pu-toyama.ac.jp           Mat         Koichi Hayashi           Geometric Ltd.         San Francisco, California, United States           Email: Stargery         State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection           Chengdu University of Technolo	590		
502features and possible transportation mechanisms503Gonghui Wang <sup>10</sup> , Fanyu Zhang <sup>21</sup> , Gen Furuya <sup>10</sup> , Koichi Hayashi <sup>40</sup> , Wei Hu <sup>50</sup> , Mauri McSaveney <sup>5,60</sup> , Runqiu Huang <sup>10</sup> 504Addresses of authors:507Addresses of authors:508I)Gonghui Wang (Corresponding author)509Disaster Prevention Research Institute600Kyoto University601Gokasho, Uji, 611-0011, Japan602Tei: (+81774-384100; Fax:(+81774-384105603Email: wang.gonghui.3r@kyoto-u.ac.jp604MOK Key Laboratory of Mechanics on Disaster and Environment in Western China607Department of Goological Engineering608Lanzhou University609Lanzhou University610Gon Furuya621Toguma Prefectural University622Gen Furuya633Toguma Prefectural University644Karokawa 5180, Imizu-shi, Toguma 939-0398, Japan655Email: gfuruya@pu-toguma.c.jp676Wei Hu6774)678Goometric Ltd.679San Francisco, California, United States670Chengdu University of Technology671Chengdu University of Geo-hazard Prevention and Geo-environment Protection672State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection673Mauri McSaveney674Mauri McSaveney675Mauri McSaveney676Chengdu University of Technology677Chengdu University of Technology <t< th=""><td>591</td><td>T</td><td>he debris avalanche in Donghekou area triggered by the 2008 Wenchuan (M8.0) earthquake:</td></t<>	591	T	he debris avalanche in Donghekou area triggered by the 2008 Wenchuan (M8.0) earthquake:
<ul> <li>Gonghui Wang<sup>1</sup>, Fanyu Zhang<sup>2</sup>, Gen Furuya<sup>3</sup>, Koichi Hayashi<sup>4</sup>, Wei Hu<sup>5</sup>, Mauri McSaveney<sup>5,6</sup>, Runqiu Huang<sup>4</sup>)</li> <li>Gonghui Wang (Corresponding author)</li> <li>Disster Prevention Research Institute</li> <li>Kyoto University</li> <li>Gokasho, Uji, 611-0011, Japan</li> <li>Tcl: (+81)774-384100; Fax: (+81)774-384105</li> <li>Email: Wang, gonghui.3fr@kyoto-u.ac.jp</li> <li>MOE Key Laboratory of Mechanics on Disaster and Environment in Western China</li> <li>Department of Geological Engineering</li> <li>Lanzhou University</li> <li>Lanzhou University</li> <li>Gen Furuya</li> <li>Toyama Prefectual University</li> <li>Gen Furuya</li> <li>Toyama Prefectual University</li> <li>Gen Furuya</li> <li>Toyama Prefectual University</li> <li>Kurokawa 5180, Inizu-shi, Toyama 939-0398, Japan</li> <li>Email: gluruya@pu-toyama.ac.jp</li> <li>Kurokawa 5180, Inizu-shi, Toyama 939-0398, Japan</li> <li>Email: gluruya@pu-toyama.ac.jp</li> <li>Wei Hu</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: 513933225@qq.com</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: M.McSaveney</li> <li>Gistate Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: M.McSaveney</li> <li>Gistate Key Laboratory of Geo-hazard Prevent</li></ul>	592		features and possible transportation mechanisms
994       Gonghui Wang <sup>11</sup> , Fanyu Zhang <sup>21</sup> , Gen Furuya <sup>3</sup> , Koichi Hayashi <sup>41</sup> , Wei Hu <sup>41</sup> , Mauri McSaveney <sup>5,61</sup> , Runqiu Huang <sup>11</sup> 997       Addresses of authors:         917       Gonghui Wang <sup>11</sup> , Groresponding author)         928       Disaster Prevention Research Institute         939       Disaster Prevention Research Institute         940       Kyoto University         941       Gokasho, Uji, 611-0011, Japan         942       Tel: (+81)774-384100; Fax:(+81)774-384105         943       Tel: (+81)774-384100; Fax:(+81)774-384105         944       Earabu         945       Panyu Zhang         946       MOE Key Laboratory of Mechanics on Disaster and Environment in Western China         947       Lanzbou University         948       Lanzbou University         949       Lanzbou University         941       Kurokawa 5180, Imizu-sehi, Toyama 939-0398, Japan         945       Email: ginquya@u-uogama.ac.jp         946       Fanali Ki Jayashi@geometrics.com         947       N koichi Hayashi         948       Geometric Ltd.         949       San Francisco, California, United States         940       Email: KHayashi@geometrics.com         941       State Key Laboratory of Geo-hazard Prevention and Geo-environment P	593		
Gonghui Wang <sup>1</sup> , Fanyu Zhang <sup>2</sup> , Gen Furuya <sup>3</sup> , Koichi Hayashi <sup>4</sup> , Wei Hu <sup>5</sup> , Mauri McSaveney <sup>5,0</sup> , Runqiu Huang <sup>2</sup> )         Addresses of authors:       1)         Gonghui Wang (Corresponding author)       Disaster Prevention Research Institute         600       Kyoto University         611       Gokasho, Uji, 611-0011, Japan         622       Fanyu Zhang         632       Email: wang gonghui 3r@kyoto-u.ac.jp         633       Email: wang gonghui 3r@kyoto-u.ac.jp         644       Department of Geological Engineering         635       Lanzhou University         636       Email: Zhangfw@lzu.edu.en         641       Toyana Prefectural University         642       Toyana Prefectural University         643       Toyana Prefectural University         644       Kurokawa 5180, Imizu.eshi, Toyana 939-0398, Japan         655       Email: gluruya@pu-toyama.ac.jp         666       Koichi Hayashi         67       4)         67       4)         68       Email: gluruya@pu-toyama.ac.jp         616       Email: gluruya@pu-toyama.ac.jp         617       4)       Koichi Hayashi         618       Geometric Ltd.         629       San Francisco, California, United States <t< th=""><td>594</td><td></td><td></td></t<>	594		
Addresses of authors:         1)       Gonghui Wang (Corresponding author)         Disaster Prevention Research Institute         Kyoto University         61       Gokasho, Uji, 611-001, Japan         62       Fanil: wang.gonghui.37@kyoto-u.a.cjp         63       Fanil: wang.gonghui.37@kyoto-u.a.cjp         64       Fory Zhang         66       MOE Key Laboratory of Mechanics on Disaster and Environment in Western China         67       Department of Geologial Engineering         68       Lanzhou University         69       Lanzhou Virversity         60       Email: Zhangfy@lzu.edu.en         611       3)       Gen Furuya         70yama Prefectural University       Kurokawa 5180, Imizu-shi, Toyama 939-0398, Japan         616       Fanil: gfuruya@pu-toyama.ac.jp         617       4)       Koichi Hayashi         620       Email: KHayashi@geometrics.com         621       San Francisco, California, United States         622       Swith Hu         631       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         642       Chengdu, Sichuan 610059, P.R. China         653       Email: 51393225@qq.com         654       Mauri McSaveney         655<	595	Goı	nghui Wang <sup>1</sup> ), Fanyu Zhang <sup>2</sup> ), Gen Furuya <sup>3</sup> ), Koichi Hayashi <sup>4</sup> ), Wei Hu <sup>5</sup> ), Mauri McSaveney <sup>5,6</sup> ), Runqiu Huang <sup>5</sup> )
597       Addresses of authors:         598       1) Gonghui Wang (Corresponding author)         598       Disaster Prevention Research Institute         600       Kyoto University         601       Gokasho, Uji, Gi, 10-001, Japan         602       Tel: (+81)774-384100; Fax:(+81)774-384105         603       Email: wang gonghui.3r@kyoto-u.ac.jp         604       MOE Key Laboratory of Mechanics on Disaster and Environment in Western China         605       2) Fanyu Zhang         606       Lanzhou University         607       Department of Geological Engineering         608       Lanzhou University         619       Email: Zhangfy@lzu.edu.en         611       Email: Zhangfy@lzu.edu.en         612       J Gen Furuya         613       Toyama Prefectural University         614       Kurokawa S180, Imizu-shi, Toyama 39-0398, Japan         615       Email: gfuruya@pu-toyama.ac.jp         616       Email: gfuruya@pu-toyama.ac.jp         617       4) Koichi Hayashi         618       Geometric Ltd.         619       San Francisco, California, United States         620       Email: Sflavashi@geometrics.com         621       5) Wei Hu         623       State Ke	596		
598       1)       Gonghui Wang (Corresponding author)         599       Disaster Prevention Research Institute         600       Kyoto University         611       Gokasho, Uji, 611-0011, Japan         622       Fanyu Zhang         636       MOE Key Laboratory of Mechanics on Disaster and Environment in Western China         637       Department of Geological Engineering         638       Lanzhou University         639       Earzhou University         649       Lanzhou University         659       Lanzhou University         669       Lanzhou University         670       Earzhou University         671       Yoyama Prefectural University         673       Toyama Prefectural University         674       Kurokawa 5180, Imizu-shi, Toyama 939-0398, Japan         675       Email: gfuruya@pu-toyama.ac.jp         676       Email: gfuruya@pu-toyama.ac.jp         677       4)       Koichi Hayashi         678       Geometric Ltd.         679       Email: KHayashi@geometrics.com         621       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         624       Chengdu University of Technology         635       Mauri McSaveney <t< th=""><td>597</td><td>Ad</td><td>dresses of authors:</td></t<>	597	Ad	dresses of authors:
599       Disaster Prevention Research Institute         600       Kyoto University         601       Gokasho, Uji, Sol I-0011, Japan         602       Tel: (+81)774-384100; Fax:(+81)774-384105         603       Email: wang.gonghui.3r@kyoto-u.ac.jp         604       OK Exy Laboratory of Mechanics on Disaster and Environment in Western China         605       2)       Fanyu Zhang         606       MOE Key Laboratory of Mechanics on Disaster and Environment in Western China         607       Department of Geological Engineering         618       Lanzhou 730000, China         619       Eanzhou 730000, China         610       Email: Zhangfy@lzu.edu.en         611       Farili Zhangfy@lzu.edu.en         612       3)       Gen Furuya         613       Toyama Prefectural University         614       Kucikui Hayashi         615       Email: gfuruya@pu-toyama.ac.jp         616       Email: gfuruya@pu-toyama.ac.jp         617       4)       Koichi Hayashi         618       Geometric Ltd.         619       San Francisco, California, United States         620       Email: KHayashi@geometrics.com         621       Swith Hu         623       State Key Laboratory of Geo-	598	1)	Gonghui Wang (Corresponding author)
600       Kyoto University         601       Gokasho, Uji, 611-0011, Japan         602       Tel; (+81)774-384100; Fax;(+81)774-384105         603       Email: wang.gonghui.3r@kyoto-u.ac.jp         604       MOE Key Laboratory of Mechanics on Disaster and Environment in Western China         607       Department of Geological Engineering         608       Lanzhou University         609       Email: Zhangfy@lzu.edu.en         611       Email: Zhangfy@lzu.edu.en         612       3)       Gen Furuya         613       Toyama Prefectural University         614       Kurokawa 5180, Imizu.shi, Toyama 939-0398, Japan         615       Email: gfuruya@pu-toyama.ac.jp         616       Geometric Ltd.         617       4)       Koichi Hayashi         618       Geometric Ltd.         619       San Francisco, California, United States         620       Email: KHayashi@geometrics.com         621       5)       Wei Hu         622       5)       Wei Hu         623       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         624       Email: S1393322@gq.com         625       Chengdu University of Technology         636       Kate Key	599	,	Disaster Prevention Research Institute
601       Gokasho, Uji, 611-0011, Japan         602       Tel: (+81)774-384100; Fax:(+81)774-384105         603       Email: wang.gonghui.37@kyoto-u.ac.jp         604       MOE Key Laboratory of Mechanics on Disaster and Environment in Western China         605       2)       Fanyu Zhang         606       MOE Key Laboratory of Mechanics on Disaster and Environment in Western China         607       Department of Geological Engineering         608       Lanzhou 730000, China         609       Lanzhou 730000, China         610       Email: Zhangfy@lzu.edu.en         611       Toyama Prefectural University         612       3)       Gen Furuya         613       Toyama Prefectural University         614       Kurokawa 5180, Imizu-shi, Toyama 939-0398, Japan         615       Email: gfuruy@pu-toyama.ac.jp         616       Email: gfuruy@pu-toyama.ac.jp         617       4)       Koichi Hayashi         618       Geometric Ld.         619       San Francisco, California, United States         620       Email: KHayashi@geometrics.com         621       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         626       Email: S13933225@qq.com         627       Shart McSave	600		Kyoto University
602       Tel: (+81)774-384100; Fax:(+81)774-384105         603       Email: wang.gonghui.3 <i>r@kyoto-u.ac.jp</i> 604       MOE Key Laboratory of Mechanics on Disaster and Environment in Western China         605       2)       Fanyu Zhang         606       Lanzhou University         607       Department of Geological Engineering         608       Lanzhou University         609       Lanzhou 730000, China         610       Email: Zhangfy@lzu.edu.en         611       Toyama Prefectural University         612       3)       Gen Furuya         613       Toyama Prefectural University         614       Kurokawa 5180, Imizu-shi, Toyama 939-0398, Japan         615       Email: Effavashi@genetrics.com         616       Geometric Ltd.         617       4)       Koichi Hayashi         628       5)       Wei Hu         639       San Francisco, California, United States         640       Email: KHayashi@geometrics.com         621       5)       Wei Hu         622       5)       Wei Hu         63       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         64       Chengdu, Sichuan 610059, P.R. China         65	601		Gokasho, Uji, 611-0011, Japan
603       Email: wang.gonghui.3r@kyoto-u.ac.jp         604       MOE Key Laboratory of Mechanics on Disaster and Environment in Western China         606       MOE Key Laboratory of Mechanics on Disaster and Environment in Western China         607       Department of Geological Engineering         608       Lanzhou University         609       Lanzhou University         609       Lanzhou University         610       Email: Zhangfy@lzu.edu.en         611       Famail: Zhangfy@lzu.edu.en         612       3)       Gen Furuya         613       Toyama Prefectural University         614       Kurokawa S180, Imizu.shi, Toyama 939-0398, Japan         615       Email: gfuruya@pu-toyama.ac.jp         616	602		Tel: (+81)774-384100; Fax:(+81)774-384105
604       Use of the transmission of transmismission of transmission of transmission of transmissi	603		Email: wang.gonghui.3r@kyoto-u.ac.jp
605       2) Fanyu Zhang         606       MOE Key Laboratory of Mechanics on Disaster and Environment in Western China         607       Department of Geological Engineering         608       Lanzhou University         609       Lanzhou 730000, China         610       Email: Zhangfy@lzu.edu.cn         611       Email: Zhangfy@lzu.edu.cn         612       3) Gen Furuya         613       Toyama Prefectural University         614       Kurokawa 5180, Imizu-shi, Toyama 939-0398, Japan         615       Email: gfuruya@pu-toyama.ac.jp         616       Geometric Ltd.         617       4) Koichi Hayashi         618       Geometric Ltd.         619       San Francisco, California, United States         620       Email: KHayashi@geometrics.com         621       5) Wei Hu         622       5) Wei Hu         623       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         624       Chengdu University of Technology         625       Chengdu University of Technology         626       Email: 51393225@qq.com         627       Mauri McSaveney         638       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection <t< th=""><td>604</td><td></td><td></td></t<>	604		
<ul> <li>MÖE Key Laboratory of Mechanics on Disaster and Environment in Western China</li> <li>Department of Geological Engineering</li> <li>Lanzhou University</li> <li>Lanzhou Juiversity</li> <li>Lanzhou Juiversity</li> <li>Gen Furuya</li> <li>Toyama Prefectural University</li> <li>Kurokawa 5180, Imizu-shi, Toyama 939-0398, Japan</li> <li>Email: gfuruya@pu-toyama.ac.jp</li> <li>Koichi Hayashi</li> <li>Geometric Ltd.</li> <li>San Francisco, California, United States</li> <li>Email: KHayashi@geometrics.com</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: 51393225@qq.com</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: mesaveney@xtra.co.nz</li> <li>Mauri McSaveney</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: S1393225@qq.com</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: S13934225@qq.com</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: M.McSaveney</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: M.McSaveney</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: M.McSaveney</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: M.McSaveney</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Liversity of Technology</li> <li>Chengdu, Liversity of Technology</li> <li>Chengdu, Liversity of Technology</li></ul>	605	2)	Fanyu Zhang
607       Department of Geological Engineering         608       Lanzhou University         609       Lanzhou 730000, China         610       Email: Zhangfy@lzu.edu.en         611       Imail: Zhangfy@lzu.edu.en         612       3)       Gen Furuya         613       Toyama Prefectural University         614       Kurokawa 5180, Imizu-shi, Toyama 939-0398, Japan         615       Email: Eduruya@pu-toyama.ac.jp         616       Imail: Geometric Ltd.         617       4)       Koichi Hayashi         618       Geometric Ltd.         619       San Francisco, California, United States         620       Email: KHayashi@geometrics.com         621       Imail: KHayashi@geometrics.com         622       5)       Wei Hu         623       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         626       Email: S1393225@qq.com         627       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         638       S       Mauri McSaveney         639       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         640       Chengdu University of Technology         651       Mauri McSaveney       Gin Science,	606	,	MOE Key Laboratory of Mechanics on Disaster and Environment in Western China
608       Lanzhou University         609       Lanzhou 730000, China         610       Email: Zhangfy@lzu.edu.cn         611         612       3)         613       Toyama Prefectural University         614       Kurokawa 5180, Imizu-shi, Toyama 939-0398, Japan         615       Email: gfuruya@pu-toyama.ac.jp         616       6         617       4)         618       Geometric Ltd.         619       San Francisco, California, United States         620       Email: KHayashi@geometrics.com         621       6         622       5)         63       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         64       Chengdu University of Technology         65       Chengdu University of Technology         66       6         67       6         68       5)         69       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         60       Chengdu University of Technology         61       Geometric State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         62       Chengdu, Sichuan 610059, P.R. China         63       Chengdu, Sichuan 610059, P.R. China </th <td>607</td> <td></td> <td>Department of Geological Engineering</td>	607		Department of Geological Engineering
<ul> <li>Lanzhou 730000, China</li> <li>Email: Zhangfy@lzu.edu.cn</li> <li>Toyama Prefectural University</li> <li>Kurokawa 5180, Imizu-shi, Toyama 939-0398, Japan</li> <li>Email: gfuruya@u-toyama.ac.jp</li> <li>Koichi Hayashi</li> <li>Geometric Ltd.</li> <li>San Francisco, California, United States</li> <li>Email: KHayashi@geometrics.com</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>Chengdu University of Technology</li> <li>Chengdu University of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>GNS Science, Lower Hutt, New Zealand</li> <li>Email: M.McSaveney</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>GNS Science, Lower Hutt, New Zealand</li> <li>Email: M.McSaveney@gns.cri.nz</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>Chengdu University of Technology</li> </ul>	608		Lanzhou University
610       Email: Zhangfy@lzu.edu.en         611       Toyama Prefectural University         613       Toyama Prefectural University         614       Kurokawa 5180, Imizu-shi, Toyama 939-0398, Japan         615       Email: gfuruya@pu-toyama.ac.jp         616       Email: Geometric Ltd.         617       4)       Koichi Hayashi         618       Geometric Ltd.         619       San Francisco, California, United States         620       Email: KHayashi@geometrics.com         621       5)       Wei Hu         622       5)       Wei Hu         623       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         624       Chengdu, Sichuan 610059, P.R. China         625       Chengdu, Sichuan 610059, P.R. China         626       Email: 513933225@qq.com         637       Kate Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         638       Chengdu, Sichuan 610059, P.R. China         639       Kater Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         630       Chengdu, Sichuan 610059, P.R. China         631       Chengdu, Sichuan 610059, P.R. China         632       GNS Science, Lower Hutt, New Zealand         634       M	609		Lanzhou 730000, China
611       0         612       3)       Gen Furuya         613       Toyama Prefectural University         614       Kurokawa 5180, Imizu-shi, Toyama 939-0398, Japan         615       Email: gfuruya@pu-toyama.ac.jp         616       6         617       4)       Koichi Hayashi         618       Geometric Ltd.         619       San Francisco, California, United States         620       Email: KHayashi@geometrics.com         621       6         622       5)         63       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         64       Chengdu University of Technology         65       Chengdu University of Technology         66       Email: 513933225@qq.com         67       6         68       5)         69       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         60       Chengdu University of Technology         611       Chengdu University of Technology         622       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         63       Chengdu University of Technology         64       6         65       Mauri McSaveney	610		Email: Zhangfy@lzu.edu.cn
612       3)       Gen Furuya         613       Toyama Prefectural University         614       Kurokawa 5180, Imizu-shi, Toyama 939-0398, Japan         615       Email: gfuruya@pu-toyama.ac.jp         616       Famali: gfuruya@pu-toyama.ac.jp         617       4)       Koichi Hayashi         618       Geometric Ltd.         619       San Francisco, California, United States         620       Email: KHayashi@geometrics.com         621       6         622       5)         63       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         64       Chengdu University of Technology         65       Chengdu, Sichuan 610059, P.R. China         66       Email: 513933225@qq.com         67       6         68       5)         69       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         61       Chengdu University of Technology         62       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         63       Chengdu, Sichuan 610059, P.R. China         64       Mauri McSaveney         65       GNS Science, Lower Hutt, New Zealand         64       Mauri McSaveney@gns.cri.nz	611		
613       Toyama Prefectural University         614       Kurokawa 5180, Imizu-shi, Toyama 939-0398, Japan         615       Email: gfuruya@pu-toyama.ac.jp         616       Formal: gfuruya@pu-toyama.ac.jp         617       4)       Koichi Hayashi         618       Geometric Ltd.         619       San Francisco, California, United States         620       Email: KHayashi@geometrics.com         621	612	3)	Gen Furuya
614       Kurokawa 5180, Imizu-shi, Toyama 939-0398, Japan         615       Email: gfuruya@pu-toyama.ac.jp         616	613		Toyama Prefectural University
615       Email: gfuruya@pu-toyama.ac.jp         616         617       4)         618       Geometric Ltd.         619       San Francisco, California, United States         620       Email: KHayashi@geometrics.com         621       6         622       5)         63       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         64       Chengdu University of Technology         65       Chengdu, Sichuan 610059, P.R. China         66       Email: 513933225@qq.com         67       6         68       5)         69       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         60       Chengdu University of Technology         61       6         62       Email: 513933225@qq.com         63       5)       Mauri McSaveney         64       6)       Mauri McSaveney         65       GNS Science, Lower Hutt, New Zealand         66       Email: M.McSaveney@gns.cri.nz         67       6         68       5)       Runqiu Huang         69       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         61       Geo-hazard Prevention	614		Kurokawa 5180, Imizu-shi, Toyama 939-0398, Japan
<ul> <li>Koichi Hayashi</li> <li>Geometric Ltd.</li> <li>San Francisco, California, United States</li> <li>Email: KHayashi@geometrics.com</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: 513933225@qq.com</li> <li>Mauri McSaveney</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: 513933225@qq.com</li> <li>Si Mauri McSaveney</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: mesaveney@xtra.co.nz</li> <li>6 Mauri McSaveney</li> <li>GNS Science, Lower Hutt, New Zealand</li> <li>Email: M.McSaveney@gns.cri.nz</li> <li>S Runqiu Huang</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Geo-hazard Prevention and Geo-environment Protection</li> </ul>	615		Email: gfuruya@pu-toyama.ac.jp
<ul> <li>4) Koichi Hayashi</li> <li>Geometric Ltd.</li> <li>San Francisco, California, United States</li> <li>Email: KHayashi@geometrics.com</li> <li>Wei Hu</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: S13933225@qq.com</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: S13933225@qq.com</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: mcsaveney@xtra.co.nz</li> <li>GNS Science, Lower Hutt, New Zealand</li> <li>Email: M.McSaveney@gns.cri.nz</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chungiu Huang</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> </ul>	616		
618       Geometric Ltd.         619       San Francisco, California, United States         620       Email: KHayashi@geometrics.com         621       6         622       5)         623       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         624       Chengdu University of Technology         625       Chengdu, Sichuan 610059, P.R. China         626       Email: 513933225@qq.com         627       6         628       5)         629       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         630       Chengdu University of Technology         631       Chengdu University of Geo-hazard Prevention and Geo-environment Protection         630       Chengdu, Sichuan 610059, P.R. China         631       Chengdu, Sichuan 610059, P.R. China         632       Email: mcsaveney@xtra.co.nz         633       6)       Mauri McSaveney         634       6)       Mauri McSaveney         635       GNS Science, Lower Hutt, New Zealand         636       Email: M.McSaveney@gns.cri.nz         637       6         638       5)         639       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection	617	4)	Koichi Hayashi
619       San Francisco, California, United States         620       Email: KHayashi@geometrics.com         621       621         622       5)       Wei Hu         623       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         624       Chengdu University of Technology         625       Chengdu, Sichuan 610059, P.R. China         626       Email: 513933225@qq.com         627       628         628       5)         629       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         630       Chengdu University of Technology         631       Chengdu, Sichuan 610059, P.R. China         632       Email: mcsaveney@xtra.co.nz         633       6)       Mauri McSaveney         634       6)       Mauri McSaveney         635       GNS Science, Lower Hutt, New Zealand         636       Email: M.McSaveney@gns.cri.nz         637       6       Runqiu Huang         638       5)       Runqiu Huang         639       State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection         640       Chura du Laboratory of Geo-hazard Prevention and Geo-environment Protection	618		Geometric Ltd.
620Email: KHayashi@geometrics.com6216225)Wei Hu623State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection624Chengdu University of Technology625Chengdu, Sichuan 610059, P.R. China626Email: 513933225@qq.com62766285)629State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection630Chengdu, Sichuan 610059, P.R. China631Chengdu, Sichuan 610059, P.R. China632Email: mcsaveney@xtra.co.nz6336)6346)635GNS Science, Lower Hutt, New Zealand636Email: M.McSaveney@gns.cri.nz63766385)639516395163951639516395163960-hazard Prevention and Geo-environment Protection63961639516395163960-hazard Prevention and Geo-environment Protection63951639516395163960-hazard Prevention and Geo-environment Protection639616395163961639516396163961640616416164161641616416164161641641 <td< th=""><td>619</td><td></td><td>San Francisco, California, United States</td></td<>	619		San Francisco, California, United States
<ul> <li>621</li> <li>622 5) Wei Hu</li> <li>623 State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>624 Chengdu University of Technology</li> <li>625 Chengdu, Sichuan 610059, P.R. China</li> <li>626 Email: 513933225@qq.com</li> <li>627</li> <li>628 5) Mauri McSaveney</li> <li>629 State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>630 Chengdu University of Technology</li> <li>631 Chengdu, Sichuan 610059, P.R. China</li> <li>632 Email: mcsaveney@xtra.co.nz</li> <li>633</li> <li>634 6) Mauri McSaveney</li> <li>635 GNS Science, Lower Hutt, New Zealand</li> <li>636 Email: M.McSaveney@gns.cri.nz</li> <li>637</li> <li>638 5) Runqiu Huang</li> <li>639 State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> </ul>	620		Email: KHayashi@geometrics.com
<ul> <li>5) Wei Hu</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: 513933225@qq.com</li> <li>state Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>Chengdu University of Technology</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: 513933225@qq.com</li> <li>Chengdu University of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: mcsaveney@xtra.co.nz</li> <li>GNS Science, Lower Hutt, New Zealand</li> <li>Email: M.McSaveney@gns.cri.nz</li> <li>Runqiu Huang</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> </ul>	621		
623State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection624Chengdu University of Technology625Chengdu, Sichuan 610059, P.R. China626Email: 513933225@qq.com6276286285)629State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection630Chengdu University of Technology631Chengdu, Sichuan 610059, P.R. China632Email: mcsaveney@xtra.co.nz6336)6346)635GNS Science, Lower Hutt, New Zealand636Email: M.McSaveney@gns.cri.nz6376386385)639State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection	622	5)	Wei Hu
<ul> <li>Chengdu University of Technology</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: 513933225@qq.com</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: mcsaveney@xtra.co.nz</li> <li>Email: mcsaveney@xtra.co.nz</li> <li>GNS Science, Lower Hutt, New Zealand</li> <li>Email: M.McSaveney@gns.cri.nz</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> </ul>	623		State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection
<ul> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: 513933225@qq.com</li> <li>5) Mauri McSaveney</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: mcsaveney@xtra.co.nz</li> <li>6) Mauri McSaveney</li> <li>GNS Science, Lower Hutt, New Zealand</li> <li>Email: M.McSaveney@gns.cri.nz</li> <li>5) Runqiu Huang</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> </ul>	624		Chengdu University of Technology
<ul> <li>Email: 513933225@qq.com</li> <li>5) Mauri McSaveney</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: mcsaveney@xtra.co.nz</li> <li>63</li> <li>6) Mauri McSaveney</li> <li>GNS Science, Lower Hutt, New Zealand</li> <li>Email: M.McSaveney@gns.cri.nz</li> <li>5) Runqiu Huang</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> </ul>	625		Chengdu, Sichuan 610059, P.R. China
<ul> <li>627</li> <li>628 5) Mauri McSaveney</li> <li>629 State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>630 Chengdu University of Technology</li> <li>631 Chengdu, Sichuan 610059, P.R. China</li> <li>632 Email: mcsaveney@xtra.co.nz</li> <li>633</li> <li>6) Mauri McSaveney</li> <li>635 GNS Science, Lower Hutt, New Zealand</li> <li>636 Email: M.McSaveney@gns.cri.nz</li> <li>637</li> <li>638 5) Runqiu Huang</li> <li>639 State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> </ul>	626		Email: 513933225@qq.com
<ul> <li>5) Mauri McSaveney</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: mcsaveney@xtra.co.nz</li> <li>GNS Science, Lower Hutt, New Zealand</li> <li>Email: M.McSaveney@gns.cri.nz</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> </ul>	627		
<ul> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Chengdu University of Technology</li> <li>Chengdu, Sichuan 610059, P.R. China</li> <li>Email: mcsaveney@xtra.co.nz</li> <li>63</li> <li>6) Mauri McSaveney</li> <li>635 GNS Science, Lower Hutt, New Zealand</li> <li>Email: M.McSaveney@gns.cri.nz</li> <li>636</li> <li>5) Runqiu Huang</li> <li>639 State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> </ul>	628	5)	Mauri McSaveney
<ul> <li>630 Chengdu University of Technology</li> <li>631 Chengdu, Sichuan 610059, P.R. China</li> <li>632 Email: mcsaveney@xtra.co.nz</li> <li>633</li> <li>634 6) Mauri McSaveney</li> <li>635 GNS Science, Lower Hutt, New Zealand</li> <li>636 Email: M.McSaveney@gns.cri.nz</li> <li>637</li> <li>638 5) Runqiu Huang</li> <li>639 State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> </ul>	629		State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection
<ul> <li>631 Chengdu, Sichuan 610059, P.R. China</li> <li>632 Email: mcsaveney@xtra.co.nz</li> <li>633</li> <li>634 6) Mauri McSaveney</li> <li>635 GNS Science, Lower Hutt, New Zealand</li> <li>636 Email: M.McSaveney@gns.cri.nz</li> <li>637</li> <li>638 5) Runqiu Huang</li> <li>639 State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> </ul>	630		Chengdu University of Technology
<ul> <li>Email: mcsaveney@xtra.co.nz</li> <li>633</li> <li>6) Mauri McSaveney</li> <li>635 GNS Science, Lower Hutt, New Zealand</li> <li>636 Email: M.McSaveney@gns.cri.nz</li> <li>637</li> <li>638 5) Runqiu Huang</li> <li>639 State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>640 Charache University of Technology</li> </ul>	631		Chengdu, Sichuan 610059, P.R. China
<ul> <li>633</li> <li>634 6) Mauri McSaveney</li> <li>635 GNS Science, Lower Hutt, New Zealand</li> <li>636 Email: M.McSaveney@gns.cri.nz</li> <li>637</li> <li>638 5) Runqiu Huang</li> <li>639 State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>640 Charachy University of Technology</li> </ul>	632		Email: mcsaveney@xtra.co.nz
<ul> <li>634 6) Mauri McSaveney</li> <li>635 GNS Science, Lower Hutt, New Zealand</li> <li>636 Email: M.McSaveney@gns.cri.nz</li> <li>637</li> <li>638 5) Runqiu Huang</li> <li>639 State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>640 Charache University of Technology</li> </ul>	633		
<ul> <li>GNS Science, Lower Hutt, New Zealand</li> <li>Email: M.McSaveney@gns.cri.nz</li> <li>5) Runqiu Huang</li> <li>State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>Charache University of Technology</li> </ul>	634	6)	Mauri McSaveney
<ul> <li>Email: M.McSaveney@gns.cri.nz</li> <li>637</li> <li>638 5) Runqiu Huang</li> <li>639 State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>640 Charache University of Technology</li> </ul>	635		GNS Science, Lower Hutt, New Zealand
<ul> <li>637</li> <li>638 5) Runqiu Huang</li> <li>639 State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>640 Charachy University of Technology</li> </ul>	636		Email: M.McSaveney@gns.cri.nz
<ul> <li>638 5) Runqiu Huang</li> <li>639 State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection</li> <li>640 Charachy University of Technology</li> </ul>	637		
639 State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection	638	5)	Runqiu Huang
(1) Change du University of Teachandle and	639		State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection
640 Chengdu University of Technology	640		Chengdu University of Technology
641 Chengdu, Sichuan 610059, P.R. China	641		Chengdu, Sichuan 610059, P.R. China
642 Email: 706618681@qq.com	642		Email: 706618681@qq.com

- The debris avalanche in Donghekou area triggered by the 2008 Wenchuan (M8.0) earthquake: features
   and possible transportation mechanisms
- 645

# 646 Gonghui Wang<sup>1</sup>, Fanyu Zhang<sup>2</sup>, Gen Furuya<sup>3</sup>, Koichi Hayashi<sup>4</sup>, Wei Hu<sup>5</sup>, Mauri McSaveney<sup>5,6</sup>, Runqiu Huang<sup>5</sup>

- <sup>648</sup> <sup>1)</sup>Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto, Japan (E-mail: wang.gonghui.3r@kyoto-
- 649 u.ac.jp; Tel: 81-774384100; Fax: 81-774-384105)

<sup>2)</sup> MOE Key Laboratory of Mechanics on Disaster and Environment in Western China, Department of Geological

- 651 Engineering, Lanzhou University, Lanzhou 730000, China
- <sup>3)</sup> Toyama Prefectural University, Kurokawa 5180, Imizu-shi, Toyama 939-0398, Japan
- <sup>4)</sup>Geometric Ltd., San Francisco, California, United States
- <sup>5)</sup> State Key Laboratory of Geo-hazard Prevention and Geo-environment Protection, Chengdu University of
- 655 Technology, Chengdu, P.R. China
- <sup>656</sup> <sup>6)</sup>GNS Science, Lower Hutt, New Zealand
- 657 ABSTRACT:

In 2008, the Wenchuan earthquake triggered many large landslides with rapid movement and long runouts, 658 659 resulting in a great number of casualties. Although there have been many studies of the geographical features and initiation mechanisms of some catastrophic landslides, the movement mechanisms for many remain unclear. In 660 this paper, we present a case study of a large landslide (debris avalanche) triggered by the 2008 Wenchuan 661 earthquake in the Donghekou area, Sichuan Province, China. We made detailed field surveys of the geographical 662 features of the landslide and carried out subsurface investigations of the landslide deposits using microtremor array 663 measurement and electrical resistivity tomography (ERT). Based on the observed surficial features, shear-wave 664 velocity (Vs) profiles and 2D electrical resistivity profiles of the landslide deposits, we estimated the possible 665 thickness of landslide deposits at different locations, and also analyzed the possible landsliding mechanisms. We 666 inferred that this landslide resulted from retrogressive failures on the source area, and the displaced landslide 667 materials underwent transitional spreading with further entrainment of debris along the travel path. Multiple mud 668 waves might have been formed in the substrate soil layers along the travel path due to the entraining of landsliding 669 materials, and the landsliding materials might have presented channelized movements, indicating that different 670 parts may have moved at different speeds. This kind of transportation mechanism may provide information for 671 elevating the numerical simulation of landsliding, and also for reuse of deposit area of large landslides. 672

674 Keywords: Wenchuan earthquake, debris avalanche, internal structure, landslide deposits, movement mechanism

675 **1. Introduction** 

Rock or debris avalanches are normally characterized by large volumes, rapid movement and long runouts, and 676 677 thus are usually catastrophic (e.g., Heim, 1932; McSaveney, 1978; Evans and Clague, 1999; Strom and 678 Adbrakhmatov, 2018). They can be triggered by rainfall, earthquakes, and human activities, and some by unknown factors. To prevent or at least to mitigate the hazards resulting from different types of avalanches, numerous studies 679 had been carried out to better understand their long runout mechanisms (McSaveney et al., 1992; Hungr et al., 680 2001; Davies and McSaveney, 2002; Hancox et al., 2005; Crosta et al., 2007; Schulz et al., 2008). It has been 681 assumed that the avalanches move as a fluid (e.g. Heim, 1932; Kent, 1966; Hsu, 1975; Voight et al., 1983), as 682 disintegrating rock blocks (McSaveney, 1978), or as sliding blocks riding on thin but ductile basal layers or air 683 cushions (Kent, 1966; Shreve, 1968; Aharonov and Anders, 2006). Statistical data indicate that the mobility of an 684 avalanche is directly related to its volume (Heim, 1932; Scheidegger; 1973), while several physical models, such 685 as fluidization, air cushion, self-lubrication, debris entrainment, dynamic fragmentation, and hydrothermal 686 overpressuring, have been proposed to explain their long runout movement (Kent, 1966; Shreve, 1968; McSaveney, 687 1978; Davies and McSaveney, 2002; Voight et al., 1983; Anders et al., 2000; Erismann and Abele, 2001; Collins 688 and Melosh, 2003; Goren et al., 2010; Hu et al., 2018). Although these models sound reasonable, most of them are 689 derived from field observation on the surficial features of their deposits with less information on the internal 690 691 structure of the landslide deposits. This is understandable, because it is normally difficult to conduct detailed surveys on the avalanche deposits with large areas. Nevertheless, understanding the internal structure of the 692 avalanche deposits is important for clarifying the movement mechanism and then validating the suitability of these 693 models mentioned above. 694

To unravel the internal structure of deposits of debris avalanches, and improve our understanding of long runout 695 696 movement of displaced materials, we described a debris avalanche triggering by the 2008 Wenchuan earthquake in the Donghekou area (hereinafter termed the Donghekou landslide), Qingchuan County, Sichuan Province, China. 697 Because Donghekou landslide is one of the most catastrophic landslides triggered by the 2008 Wenchuan 698 earthquake and featured by long runout and great number of casualties, immediately after the earthquake, we 699 conducted field survey on the landslide phenomena, investigated the features of the surficial layers of the landslide 700 deposits and examined the shear behavior of landsliding materials for better understanding the possible sliding 701 mechanism (Wang et al., 2014). It is also noted that soon after the earthquake, Donghekou landslide area was 702 designated an earthquake ruins park. This enabled us to conduct further subsurface investigations of the landslide 703

deposits using multiple geophysical approaches, including microtremor array measurement and electrical resistivity topography (ERT). In this paper, we present those newly obtained results. Based on these data we analyze the transportation mechanism of Donghekou landslide, and discuss its implication for understanding the movement mechanisms of other debris avalanches.

708

# 709 2. The 2008 Wenchuan earthquake and Donghekou landslide

The 2008 Wenchuan earthquake ( $M_w$ 8.3) occurred on 12 May, 2008, at 14:28 local time. The epicenter, with a depth of about 19 km, is in Wenchuan County (Fig. 1) (Huang, 2009), which is 80 km west-northwest of Chengdu City in Sichuan Province, China. The fault rupture resulted in several meters of surface displacements and propagated from the epicenter for about 240 km along the Longmenshan thrust zone. This earthquake caused huge losses in both built infrastructure and human lives. According to the International Strategy for Disaster Reduction (ISDR), more than 87,400 people were confirmed dead, and 459,000 injured (Qi et al., 2010).

More than 60,000 landslides were triggered by the earthquake (Huang and Li, 2009; Dai et al., 2011a; Gorum et al., 2011). The main landslide types include shallow landslides, rock falls, deep-seated landslides, and rock/debris avalanches (Dai et al., 2011b). Although most of the landslides are shallow ones, there were also many catastrophic large landslides, which resulted in severe casualties. One was the Donghekou landslide (Figs. 2 and 3).

The Donghekou landslide is located on the junction zone between Hongguang Town and Guanzhuang Town, Qingchuan County, about 250 km northeast of Chengdu, the capital city of Sichuan Province. It originated from a slope along the confluence of the Qingzhu River and its tributary, the Hongshi River (Fig. 2). The mountains in this area normally reach elevations of more than 1000 m, with an altitude difference (above the river bed) of about 500 m, and have steep upper slopes and gentle lower slopes.

Donghekou landslide is a rockslide-debris avalanche (as defined by Hungr and Evans, 2004) with the runout path material entrained by the impact of rock debris (e.g., Wang et al., 2014; Dai et al., 2011b; Yin et al., 2009, 2011; Xu and Tang, 2009). A bout  $1 \times 10^7$  m<sup>3</sup> of landslide materials displaced from the source area and descended a vertical distance of about 500 m over a horizontal distance of about 2 km. The landslide material buried the residential areas and the rice paddy on the downstream, and blocked both rivers, resulting in the formation of a dam. It is noted that although the resultant impounding water overflowed a few days late and caused partial collapse of the dam, no further casualties were triggered to the downstream villages due to proper countermeasure.

There were four villages in the Donghekou area before the earthquake. Figs. 3a and 3b present views of the

Donghekou area before and after the earthquake, respectively. There were many houses located on the toe part of the mountains before the earthquake (Fig. 3a). However, almost all these houses were destroyed and the villages buried completely by the displaced landslide materials (Fig. 3b). As a result, about 780 people were killed. The dashed circles (Fig. 3a, b) show the one-story house that survived during the earthquake, while the river shown in Fig. 3b is the breached Qingzhu River.

According to the local geological map (Fig. 4), the exposed strata of the research area consist of Sinian, 739 Cambrian, Silurian and Quaternary systems, and each stratum presents a stripped distribution along the tectonic 740 line. The Sinian system can be divided into three members, i.e., the Third  $(Zy^3)$ , the Second  $(Zy^2)$  and the First 741  $(Zy^1)$  members, based on their age from oldest to most recent.  $Zy^3$  mainly consists of dolomitic limestone, grey 742 blocky dolomite, and dark blocky siliceous dolomite.  $Zy^2$  mainly consists of calcareous sericite phyllite, thin layer 743 of crystalline limestone, and lenticular dolomite. Zy<sup>1</sup> mainly consists of siliceous banded dolomite and siliceous 744 dolomite. The Cambrian system consists of the Youfang Formation ( $\notin$ y) and Qiujiahe Formation ( $\notin$ q).  $\notin$ y mainly 745 consists of calcareous tuffaceous sandstone, and tuffaceous sericite phyllite; while  $\epsilon$ q consists of carbonaceous 746 siliceous slate and siliceous rock, with low-grade Mn ore. The Quaternary strata (Qh) are mainly distributed in the 747 valley of the landslide deposit area, and consisted of alluvial or alluvial deposits (riverbed sand, gravel, silt and 748 clay) of the Holocene Series. The lithology changes greatly, and the thickness of the siliceous dolomite interlayer 749 is also different. The bottom is a carbonaceous siliceous slate sandwiched with thin layer of siliceous dolomite, 750 751 partially lumpy siliceous dolomite. The Sinian system mainly crops out on the middle-upper part of the landslide slope, and the Donghekou landslide originated mainly in this stratum. The Cambrian Youfang and Oiujiahe 752 Formations are found on the right side of the landslide body and the middle and lower part of the slope body. A 753 fault (Hongkan Fault) passing through the source area has been identified (Xu and Tang, 2009; Yu et al., 2010; 754 among others). Large extension cracks had been identified to the left side of the source area before the earthquake, 755 and the residents were made aware of slope instability, so evacuation was enforced during heavy rainfall events. 756

As reported by Wang et al (2014), six months after the earthquake, fumaroles with sulfur smell appeared on the middle part of the landslide (as shown in Fig. 5). Wang et al. (2014) carried out long-term monitoring of the ground temperature around the fumarole opening and reported that the ground temperature was measured as 65°C in highest value. They also conducted chemical analyses of the liquid and gas collected from the vents of the fumaroles, and concluded that the fumaroles resulted from the weathering of underlying landslide materials and bedrock (carbonaceous siliceous slate).

### 764 **3. Methods**

To unravel the internal structure of the landslide deposits, Wang et al (2014) measured the 2D shear-wave 765 velocity  $(V_s)$  profile of the landslide deposits by using the active multichannel analysis of surface waves (MASW) 766 method. Details for the principles of MASW method can be referred to Park et al. (1998), Miller et al. (1999), 767 Hayashi and Suzuki (2004), and Hayashi et al. (2008). Due to the limitation in the surveying depth (usually in the 768 range of 10-20 m) through this active MASW method, Wang et al (2014) failed to obtain the Vs information for 769 the layers of the landslide deposits deeper than 20 m, such that the formation of the sliding surface remains unclear. 770 Therefore, in this study we employed a passive MASW method (microtremor array measurement) (Park et al., 771 2005), in which ten geophones with a natural frequency of 2 Hz for each were placed in an equilateral triangle (as 772 illustrated in Fig. 6). According to Okada (2003), the detection depth through this kind of observation array for the 773 passive MASW method is practically about three to four times of the observation radius (the distance between G2 774 and G11 as shown in Fig. 6). Therefore, by employing the observation array shown in Fig. 6, a detection depth of 775 about 80 m beneath the central point (G2) of the triangle could be expected. It is noted that in both the active and 776 passive MASW methods, we employed the instrument of McSEIS-SXW (OYO Corporation) for data acquisition, 777 and used SeisImager/SW software (OYO Corporation) for the raw data process and analysis. 778

Passive MASW surveys were carried out at two locations (M1 and M2 in Fig. 7) on the landslide deposit area 779 in the early morning (around 5:00 AM) of November 22, 2009, to avoid strong anthropogenic noise from cars, 780 781 trucks, and other machines. At each location, altogether 27 records were measured without changing the geophone array, and each record was sampled at a frequency of 500 Hz with a data length of 16384. It is noted that Wang et 782 al (2014) conducted active MASW survey along three survey lines on the landslide deposit area, and their locations 783 (L1-L3) are also presented in Fig. 7. Fig. 8 shows an example of one record acquired at location M2. Using the 784 SeisImager/SW software, a file list was at first constructed by reading all the 27 records acquired by the McSEIS-785 786 SXW, which was followed by the setup of array geometry and calculation of 2D spatial autocorrelation. Thereafter, a phase velocity image in frequency domain was obtained through the phase velocity-frequency transformation in 787 which a maximum velocity and a maximum frequency were set as 1000 m/s and 16 Hz, respectively. Basing on 788 the phase velocity image, phase velocities were picked automatically at the mathematical maximum amplitude for 789 each frequency by setting up the minimum frequency as 2 Hz. Because the passive MASW data do not include 790 shallow depth information (less than 5~10 m), we used the active data that were obtained along L3 and presented 791 in Wang et al (2014) through location projection, and conducted similar analyses to get the phase velocity image. 792 Based on these phase velocity images, the dispersion curve was extracted. Based on the dispersion curve, an initial 793

model for the 1-D shear wave velocity (Vs) profile was constructed by simple depth transformation, which includes calculating the wavelength ( $\lambda$ ) from frequency and phase-velocity, inferring the depth that is defined as  $\lambda/3$ , and plotting the phase-velocity on depth-velocity chart. Finally, the 1-D shear wave velocity (Vs) profile was estimated by fitting the observed and the theoretical phase velocities through inversion. It is noted that non-linear least square method was employed in the inversion with number of iterations = 5, scaling factor = 0.15, acceleration factor = 2.0, and damping factor = 0.01. More details on the data acquisition and analysis for both the active and passive surface wave methods could be obtained in SeisImager/SW<sup>TM</sup> Manual (Geometrics, Inc., 2009).

We also used Electrical Resistivity Tomography (ERT) to measure the 2D images of the distribution of electrical resistivity in the landslide deposits. ERT surveys enable identification of resistivity contrasts that may result from both the lithological nature of the deposits and variation in water content. Due to its effectiveness, ERT had been widely used in landslide studies (Perrone et al., 2014).

An ERT survey was conducted in March 2018, in which measurements were carried out using the Wenner method. All ERT data were processed using 2D inversion with the RES2Dinv software, which is based on a technique proposed by Loke and Barker (1996). Three lines (E3-E5) were arranged along the transverse direction of the deposit area, while two lines (E1 and E2) were individually set along the longitudinal direction, due to the spillway along Hongshi River. The locations of ERT survey lines E1-E5 are superimposed in Fig. 7, where a zoomed view (based on the Google Earth image shot on October 30, 2019) of the window shown in Fig. 2a is used.

811

## 812 **4. Results**

#### 813 **4.1 Shear velocity profile**

The analyzed results obtained from the measurements at M2 are summarized in Fig. 9, where Figs. 9a and 9b 814 815 present the phase velocity images in frequency domain obtained from active and positive MASW methods, respectively. The dispersion curve extracted from Fig. 9a (for the data with frequency being ranging from 8~40 816 Hz) and 9b (for the data with frequency being less than 8 Hz) is depicted in Fig. 9c, where wavelengths calculated 817 from the phase velocity and frequency are also presented. Fig. 9d plots the inverted 1-D Vs profile together with 818 the original picked phase velocities (presented by red points) whose depths were estimated following the 819 one-third-wavelength approximation. In Figs. 9a and 9b, the error between the observed coherences and the 820 theoretical Bessel functions is displayed by different colors: magenta indicates large error and blue presents 821 small error. The red dots indicating the phase velocities with minimum-error at each frequency are picked for 822 the construction of observed dispersion curves, and plotted in Fig. 9c. The observed dispersion curve shown 823

in Fig. 9c enabled the analysis of  $V_s$  to a depth of about 80 m (as shown in Fig. 9d). In Fig. 9d, the darker grey marks the valid range of the inversion, while the light grey is not based on data. From Fig. 9d, it is seen that the  $V_s$  for the surficial layer (0~5.4 m in depth) is less than 230 m/s, and increases to 270 m/s approximately for the layer in the depth of 5.4 ~ 12.3 m. The soil layers between the depth of 12.3 m and 20.8 m have their  $V_s$  being 440~590 m/s approximately, while all the soil layers deeper than 20.8 m show Vs values greater than 700 m/s.

Fig. 10 presents the phase-velocity images in frequency domain, dispersion curve and the 1-D Vs profile for the measurements at M1. Similar to M2, both the active and passive data show clear dispersion curve, and enable the analysis of Vs to a depth of about 73 m. However, it is worth noting that at M1, Vs shows a sharp change from 426 m/s to 700 m/s approximately at the depth of 25.6 m. After that, Vs increases to 740 m/s at the depth of 36.3 m and further to 810 m/s at the depth of 42.3 m, and finally does not show remarkable change with further increase of depth.

835

## 836 **4.2 ERT profile**

Figs. 11a and 11b show the electrical resistivity tomographies measured along the E1 and E2 survey lines, respectively. In Fig. 11a, the domain in the upper stream area (zone D4) and surficial soil layers (0 – 10 m deep) show high resistivity (>255 ohm·m) in general, with an exception for the surficial layer ranging from 255 m to 305 m along the profile; there the resistivities are smaller than 150 ohm·m. Three zones (D1, D2 and D3) show remarkably low resistivities. In zone D1 the resistivities range from about 16–25 ohm·m; while the resistivities in D2 and D3 are <15 ohm·m.

In Fig. 11b, the surficial soil layers upstream of survey line E2 ( $10 \sim 210$  m) have a high resistivity (>255 ohm·m), while downstream they show relatively low resistivity. Underneath the surficial soil layer, the resistivity lowers to a small value (about 8 ohm·m at a minimum) in most area. However, the resistivity increased with further increases of depth, presenting a clear contrast with the two clusters of high resistivities. It is also noticed that the domain (D5) located between 170–200 m in HD and at 630–590 m in elevation shows lower resistivities (< 127 ohm.m).

Figure 12 presents the electrical resistivity tomographies measured along the E3, E4 and E5 lines, respectively. Due to a limitation on available survey cable lengths, the span of survey Lines E3 and E4 are less than 140 m, while E5 spanned 295 m. In all the survey lines, the start (zero) point indicates the right margin (looking downslope) of the landslide deposits. In Line E5 (Fig. 12a), the surficial layer (about 10 m thick) shows higher resistivities, except for the domain of 100 ~135 m in horizontal distance, while the deeper domains showed clear

contrasts in resistivity structure, and the zone having approximately the same values in resistivity inclined leftward 854 with increase of depth in general. For the survey line E4 (Fig. 12b), the surficial layer (about 6 m deep) shows high 855 resistivity, and underneath the surficial layer there are several separated domains with low resistivity, and these 856 857 domains are approximately horizontal. In Fig. 12b, it can be seen that some of the domains are underlain by layers with higher resistivity. The surficial layer in survey line E3 (Fig. 12c) does not show distinguishable contrast 858 within the deeper soil layer. However, a domain of relatively high resistivities located at the surficial distance of 859 40-45 m inclined rightward with increase of depth, while another domain (starting from 95 to 105 m on the 860 surficial layer) inclined leftward with increase of depth, and the area between these two domains presents low 861 resistivities. 862

863

#### 864 **5. Discussion**

By now, several interpretations have been proposed to explain the long runout movement of Donghekou landslide (Xu and Tang, 2009; Yin et al., 2009, 2011; Wang, et al., 2014). Some studies emphasized the effect of strong seismic motion on the possible sliding velocity of landslide materials when they slid from the source area (Zhou et al., 2013; Zhang et al., 2015), while others examined the effect of entrainment of debris on the mobility along the transport path (Yuan et al., 2014; Wang et al., 2014).

Numerical simulations using different approaches have been carried out to simulate the processes of 870 871 transportation and deposition of landslide materials (Li et al., 2012; Zhang et al., 2013, 2015; Huang et al., 2012a, among others). For example, Li et al. (2012) simulated the kinematic behavior and concluded that a low friction 872 coefficient (about 0.1) is required to justify its mobility. Yuan et al. (2014), using 2-D DEM analysis, concluded 873 that the landslide in the source area began as a push-type and then changed to a retrogressive one, and the 874 entrainment of sliding path materials slightly elevated the mobility. Zhang et al. (2015) analyzed the mobility of 875 876 the Donghekou landslide using a seismic discontinuous deformation analysis (DDA) approach and concluded that seismic loading on the displaced landslide materials could be a factor helping increase the mobility of the 877 Donghekou landslide. Huang et al. (2012b) concluded that Donghekou landslide may have several flow stages 878 879 with long sliding distances. Nevertheless, most of these studies are based on surficial examination of the landslide deposits without information on their internal structure. As pointed out by Strom (2006), developing reliable 880 models for predicting the movement and deposition processes of a landslide mass needs to intercorporate the 881 topographical, structural and depositional features, which should be regarded as constraints for checking the 882 reliability of the numerical model. However, for Donghekou landslide, the internal features of the landslide 883

deposits and the basal sliding surface have not been clarified, so that the numerical simulations can only use the deposit area of the landslide materials as the constraint for model calibration. This may be the reason why different failure models for the landslide materials from the crown were adopted in different simulations.

887 The thickness of the landslide deposits on Donghekou area seems to be an unsolved issue. For example, the descriptive texts on some guide plates erected on the ruins park tell indicate that some areas of the landslide 888 deposits damming these rivers have a thickness of more than 100 m. On the other hand, Zhang et al (2011) reported 889 that the thickness of the landslide deposits varies from several meters to dozens of meters, while Xu and Tang 890 (2009) reported that the landslide dams on Hongshi River and Qingzhu River are about 50 m and 20 m in height, 891 respectively. Further, Li et al (2012) stated that the landslide dam on Qingzhu River is about 25 m in maximum 892 thickness. From Figs. 10d, it is noticed that  $V_s$  of the soil layer changes from 460 m/s to 700 m/s at the depth of 893 about 25.6 m. Considering that  $V_s = 700$  m/s had been widely used for defining the engineering bedrock (Miller 894 et al., 1999; Santamarina et al., 2001), we infer that the soil layer deeper than 25.6 m with  $V_s > 700$  m/s be the 895 bedrock of the original ground, and the overlaid soil layers be the landslide deposits, and then the landslide deposits 896 at location M1 may have a thickness of about 25.6 m. This inference is supported by the ERT results shown in Fig. 897 898 11d, where the electrical resistivities of soil layers show significant contrast at the depth of about 26 m. By comparing Figs. 9d and 11b, we further infer that the thickness of landslide deposits at location M2 be about 21 899 m. It is noted that these inferred thicknesses show good consistency with the maximum thickness of 25 m reported 900 by Li et al (2012), although they did not provide any evidence for the estimation of this value. In this sense, our 901 result for the possible thickness of landslide deposits provides reliable evidence, because previous estimates for 902 the thickness of the landslide deposits in the Donghekou area were based on a DEM with a 10-m-contour, which 903 904 was the only available one for this area before the earthquake.

905 According to Dunning and Armitage (2011), rock-avalanche deposits commonly have three sedimentary facies: a carapace facies, a body facies, and a basal facies. The carapace facies represents the coarsest unit composing the 906 surface and near surface, the body facies is the main body of the rock-avalanche deposit, while the basal facies 907 indicates the base of the rock-avalanche deposit. By employing the active MASW method, Wang et al. (2013b) 908 examined  $V_s$  values of the deposits of a landslide that was triggered by the same earthquake in the Tianchi area, 909 Sichuan. They identify a clear boundary between the basal facies and the body facies, and suggest that the 910 superficial layer (carapace facies) and the bottom layer (basal facies with a thickness of about 2-3 m) have 911 relatively smaller shear-wave velocities. 912

For Donghekou landslide, Wang et al (2014) conducted active MASW survey along three survey lines (L1-L3)

on the landslide deposit area. Fig.13 summarizes the Vs profiles along these survey lines. As reported in Wang et 914 al (2014), L1 and L2 are laid along the drainage channel on the right and left banks, respectively, and are 70 m 915 apart. The Vs profile along L2 (Fig. 13a) showed that the upper layers are weaker, with Vs values ranging from 916 917 250–300 m/s. This weak layer is about 12 m thick near the zero point at the horizontal distance (HD) and becomes 918 thicker when the HD becomes greater. For L1, the upper weaker layers with Vs values ranging from 250-300 m/s are thin and their thickness increases also when HD becomes greater (Fig. 13b). The shear-wave velocity along 919 L3 showed that the superficial soil layers have small V<sub>s</sub> values (ranging from 180–270 m/s) (Fig. 13c). From Figs. 920 9, 10 and 13, it is inferred that the most upper layers of landslide deposits with small Vs values may present the 921 carapace facies. The existence of carapace facies can also be inferred from the ERT profile shown in Fig. 11. The 922 vertical distribution of resistivity at Location M2 (shown in Fig. 11b) indicates the existence of three main layers, 923 namely, surficial layer (about 5 m thick) with resistivity being greater than 100 ohm.m, middle layer (about 10 m 924 thick) with the resistivity being among 60~100 ohm.m, and the bottom layer locating above the dashed line (about 925 4 m thick) with resistivity being among 100-127. It is understood that the resistivity of a soil layer could be changed 926 with variation of soil moisture. However, the high resistivities in Fig. 11b are distributed along the superficial 927 layers at different elevation (say from 0 to 200 m in HD), it will be reasonable to infer that the high resistivity of 928 the superficial layers results from loose soil structure, which may result in small Vs value, corresponding to the 929 930 carapace facies.

It is also noted that the basal facies consisting of thin layers with smaller Vs values had not been identified through these  $V_s$  profiles presented in Figs. 9, 10 and 13, probably because the basal faces is located in a depth to which the active MASW method failed to reach, while the basal faces is too thin such that the passive MASW method failed to individuate it, i.e., the thickness of the basal faces is out of the resolution of the passive MASW method. Therefore, further survey, such as drilling, will be necessary to delineate the basal facies in the landslide deposits of Donghekou area.

As pointed out by Hungr et al. (2001), in debris avalanches, multiple surges are not common, but may occur as a result of retrogressive failures from the crown or slides off the source scar. The ERT results (Fig. 11a) indicate the presences of several domains with diagonally forward isopleth resistivity. This phenomenon might result from progressive failures occurring on the source area. As reported by Wang et al. (2014), the colluvium in the valley on area B1 (Fig. 3) started its movement almost at the same time as the landsliding originating on the upper slope (area B2), which was followed by the downslope movement of the "mountain" on area B3. Further failures on a smaller scale on the source area continued for two days. Zones D2 and D3 (Fig. 11a) mainly consist of slate rocks, where rapid chemical weathering (biological oxidation of pyrite) caused the appearance of fumes (as shown in Fig.
5) and resulted in an increase in ground temperature for some years after the earthquake (Wang et al., 2014). The
domain with high resistivity upstream of D4 may present the deposits of fragmented dolomite limestone
originating from the uppermost source area.

Landslide materials originating from a source area often may entrain debris along the sliding path, increasing 948 the landslide mobility and destructiveness (Sassa, 1985; Hungr and Evans, 2004; McDougall and Hungr, 2005; 949 Wang et al., 2003, 2013a, 2014; Crosta et al., 2009; Mangeney et al., 2010; Berger et al., 2011; Dufresne, 2012; 950 Zhou et al., 2016). Although entrainment has also been incorporated in some numerical landslide simulations, the 951 interaction between the sliding debris and the original ground along the sliding path remains unclear. Hungr and 952 Evans (2004) presented a hypothetical mechanism of a flow with entrainment of liquefiable materials and provided 953 a schematic illustration for the interaction between the moving rock mass and the substrate along the travel path 954 (Fig. 14). In this model, the landsliding materials from the source area may trigger liquefaction through impact on 955 a liquefiable substrate layer (Fig. 14b). As the result, a mud wave could be formed and then projected forward (Fig. 956 14c), and finally the rock mass may be deposited on the mud wave with long travel (Fig. 14d). For the Donghekou 957 landslide, the electrical resistivity topography profiles presented in Fig. 11b suggest that the landsliding of those 958 long-traveled materials might have involved multiple surges resulting from different failure stages. The contour 959 lines (dashed lines) for the resistivities of 127-200 ohm.m in the domain starting from HD 75 to 135 m are 960 961 approximately horizontal, and then shift to an uphill inclination with further increase in HD (from HD 135 to 170 m). A similar phenomenon can be observed for the domain from HD 200 to 310 m. As mentioned above, we infer 962 that the soil layers underneath the soil layer (with resistivities of 127-200 ohm.m) are the former ground surface 963 before the earthquake, and the ground underwent shear failures at different locations along the travel path during 964 the landsliding, resulting in the formation of multiple mud waves, as shown in Fig. 11. 965

966 Through comparing the V<sub>s</sub> profile along L2 and the ERT profile along E5 (Fig. 15), we found that channelized sliding may also have occurred within the landsliding materials during the emplacement. As shown in Fig. 15a, 967 the boundaries showing greater V<sub>s</sub> values (marked by dashed lines at points of P and P') are approximately in good 968 agreement with those revealed by the ERT profile (as presented by points of Y and Y' in Fig. 15b). Similar 969 phenomena can also be identified in the ERT profile shown in Fig. 12c, where the locations of the boundaries are 970 marked by R and R', and in the Vs profiles shown in Figs.13a and b (locations are marked by T and T'). We 971 interpret these boundaries as longitudinal ridges, which channelized the emplacement of sliding material. As 972 pointed out in other studies, longitudinal ridges are a frequently occurring topographical feature on rock avalanches 973

deposits (Dufresne and Davies, 2009; Dufresne et al., 2010, 2019; Dunning et al., 2015; Shugar and Clague, 2011), and could be in the form of ridges, flowbands or aligned hummocks that are characterized by differences in texture. Although shearing within the moving debris has been inferred as one reason for these kinds of ridges or flowbands, details on their formation remain unclear (Dufresne et al., 2019). Therefore, the V<sub>s</sub> and ERT profiles (Figs. 12 and 15) provide evidence for better understanding the internal structures of these ridges or flowbands. The lower resistivities (< 127 ohm.m) in the domain D5 shown in Fig. 11b may suggest the existence of a fault

that had not been identified yet. Based on the topography and location of an old landslide located on the slope on the right side of the landslide deposit area, we infer that a fault (see Fig. 7) may exist. Nevertheless, concerning this inference, further surveys will be necessary and will be conducted in the near future.

983

#### 984 6. Conclusions

During the 2008 Wenchuan earthquake (M8.0), a catastrophic landslide occurred in the Donghekou area. The landslide had a total volume of about  $1 \times 10^7$  m<sup>3</sup> and a travel distance of about 2.0 km, with an elevation drop of about 500 m. Four villages were buried by the landslide materials, and more than 780 people were killed. The displaced landslide materials also dammed two rivers, threatening people downstream immediately after the earthquake. Field investigations and geophysical surveys using different approaches suggest the following conclusions.

Donghekou landslide can be classified as a debris avalanche. The landslide materials originating from the
 source area involved retrogressive failures, resulting in the formation of a landslide deposit with differing
 internal structures at different locations.

The landslide materials deposited in the upper stream area of the valley (immediately below the toe of the
 landslide slope) showed complex structures. Two domains showed very low resistivities, representing
 deposits of slate rocks from the landslide source area and weathered quickly after being outcropped.

997 3. Combined analyses of both passive and active surface waves enabled the pickup of dispersion curve in an
998 extended frequency range, and then enabled the estimation of Vs for the soil layers to a depth of about 80
999 m. The Vs and ERT profiles provided more reliable evidence for estimating the thickness of landslide
1000 deposits, and also provided information for understanding the carapace facies formed in the landslide
1001 deposits.

4. The ERT profiles suggest that the landsliding materials may have involved at least two main surges, which
 resulted in the formation of mud waves in the substrate soil layers along the slide path.

- 5. The  $V_s$  and ERT profiles along lines traversing the landslide deposits reveal that channelized sliding may have occurred within the landsliding materials. The structure of the channelized sliding provides evidence for understanding the formation of ridges within landslide materials during their emplacement.
- 1007

Finally, it is noted that all these inferences mentioned above are based on the MASW and ERT data. Considering the limitation of these geophysical survey methods, further survey (such as borehole drilling) will be needed to elevate the accuracy of these inferences. Applying these methods to some landslides in Japan are also in operation for better understanding the internal structures of landslide deposits resulting from different types of landslides triggered by rainfall and/or earthquake.

1013

### 1014 Acknowledgement

This research was supported by the Open Fund of the State Key Laboratory of Geohazard Prevention and 1015 Geoenvironment Protection (Chengdu University of Technology) (Nos. GZ2009-02 and SKLGP2018K006), 1016 scientific research grants from the MEXT of Japan (Grant No. 18380094, 19310124, and 19KK0121), and 1017 International Collaborative Research (2020W-01) funded by the Disaster Prevention Research Institute, Kyoto 1018 University. We thank Prof. Oliver Korup in Potsdam University, Dr. Johannes Weidinger in Erkudok 1019 Institute/Museum of Gmunden, and Dr. Chris Massey in GNS Sciences, New Zealand, for their valuable 1020 1021 discussions in the field trips to this landslide; Dr. Issei Doi at Disaster Prevention Research Institute, Kyoto University, for his valuable discussion in the Microtremor analysis; Mr. Yongqing Liu, Mr. Xishan Lin, and Mr. 1022 Hailin An, for their help in the ERT survey; Mr. Xianggui He for his logistical help in the field work. Valuable 1023 English editing by Dr. Eileen McSaveney (GNS Science, New Zealand) is appreciated. Finally, the editor-in-chief, 1024 Dr. Janusz Wasowski, and two reviewers of this paper are greatly thanked for their valuable comments that led to 1025 1026 substantial improvement of this paper.

1027

## 1028 References

- Aaron, J., McDougall, S., 2019. Rock avalanche mobility: The role of path material. Engineering Geology 257,
   1030 105126.
- Aharonov, E., Anders, M.H., 2006. Hot water: a solution to the Heart Mountain detachment problem. Geology 34,
   165–168.
- Anders, M.H., Aharonov, E., Walsh J.J., 2000. Stratified granular media beneath large slide blocks: implications
   for mode of emplacement. Geology 28, 971–974.
- 1035 Berger, C., McArdell, B.W., Schlunegger, F., 2011. Direct measurement of channel erosion by debris flows,

- 1036 Illgraben, Switzerland. Journal of Geophysical Research 116(F1), pp. 93–104.
- Collins, G.S., Melosh, H.J., 2003. Acoustic fluidization and the extraordinary mobility of sturzstroms. J. Geophys.
   Res. 108 (B10), 2473.
- Crosta, G.B., Frattini, P., Fusi, N., 2007. Fragmentation in the Val Pola rock avalanche, Italian Alps. J. Geophys.
   Res. 112, F01006.
- 1041 Crosta, G.B., Imposimato, S., Roddeman, D., 2009. Numerical modelling of entrainment/deposition in rock and
   1042 debris-avalanches. Engineering Geology 109(1-2), 135–145.
- Dai, F.C., Tu, X.B., Xu, C., Gong, Q.M., Yao, X., 2011b. Rock avalanches triggered by oblique-thrusting during
   the 12 May 2008 Ms 8.0 Wenchuan earthquake, China. Geomorphology 132(3-4), 300–318.
- Dai, F.C., Xu, C., Yao, X., Xu, L., Tu, X.B., Gong, Q.M., 2011a. Spatial distribution of landslides triggered by the
   2008 Ms 8.0 Wenchuan earthquake, China. Journal of Asian Earth Sciences 40, 883–895.
- Davies, T.R., McSaveney, M.J., 2002. Dynamic simulation of the motion of fragmenting rock avalanches.
  Canadian Geotechnical Journal 39(4), 789–798.
- Dufresne, A., 2012. Granular flow experiments on the interaction with stationary runout path materials and comparison to rock avalanche events. Earth Surface Processes and Landforms 37(14), 1527–1541.
- 1051 Dufresne, A., Davies, T.R., 2009. Longitudinal ridges in mass movement deposits. Geomorphology 105:171–181
- Dufresne, A., Davies, T.R., McSaveney, M.J., 2010. Influence of runout-path material on emplacement of the
   round top rock avalanche, New Zealand. Earth Surface Processes and Landforms 35, 190-201.
- Dufresne, A., Wolken, G.J., Hibert C., Bessette-Kirton, E. K., Coe, J.A., Geertsema, M., Ekström, G., 2019. The
   2016 Lamplugh rock avalanche, Alaska: deposit structures and emplacement dynamics. Landslides 16, 2301–
   2319.
- Dunning, S.A., Almitage, P.J., 2011. The grain-size distribution of rock-avalanche deposits: implication for natural
   dam stability. In: Evans, S.G., Hermanns, R., Scarascia-Mugnozza, G., Strom, A.L. (eds), Natural and
   Artificial Rockslide dams, 133. Lecture Notes in Earth Sciences, pp.479–498.
- Dunning, S.A., Rosser, N.J., McColl, S.T., Reznichenko, N.V., 2015. Rapid sequestration of rock avalanche
   deposits within glaciers. Nature Communications 6(7964), 7
- Erismann, T.H., Abele G., 2001. Dynamics of Rockslides and Rockfalls. 3-540-67198-6, Springer-Verlag, Berlin,
   Heidelberg, 316 pp.
- Evans, S.G., Clague, J.J., 1999. Rock avalanches on glaciers in the Coast and St. Elias Mountains, British
   Columbia. In: Proceedings of the 13<sup>th</sup> Annual Vancouver Geotechnical Society Symposium, Vancouver, pp.
   115–123.
- 1067Geometrics,Inc.,2009.SeisImager/SWTMManual.314p.https://geometrics.com/wp-1068content/uploads/2019/04/SeisImagerSW\_Manual\_v3.0.pdf (accessed on September 15, 2020)
- Goren, L., Aharonov, R., Anders M.H., 2010. The long runout of the Heart Mountain landslide: heating,
   pressurization, and carbonate decomposition. J. Geophys. Res., Solid Earth 115 (B10), Article B10210.
- Gorum, T., Fan, X.M., van Westen, C.J., Huang, R.Q., Xu, Q., Tang, C., Wang, G., 2011. Distribution pattern of
  earthquake-induced landslides triggered by the 12 May 2008 Wenchuan earthquake. Geomorphology 133(34), 152–167.
- Hancox, G.T., McSaveney, M.J., Manville, V.R., Davies, T.R., 2005. The October 1999 Mt Adams rock avalanche
   and subsequent landslide dam-break flood and effects in Poerua River, Westland, New Zealand. New Zealand

- 1076 Journal of Geology and Geophysics 48(4), 683–705.
- Hayashi, K., Hirade, T., Iiba, M., Inazaki, T., Takahashi. H., 2008. Site investigation by surface-wave method and
  micro-tremor array measurements at central Anamizu, Ishikawa Prefecture. Butsuri-Tansa (Geophys. Explor.)
  61, 483–498 (in Japanese with English abstract).
- Hayashi, K., Suzuki, H., 2004. CMP cross-correlation analysis of multi-channel surface-wave data. Exploration
   Geophysics 35, 7–13.
- 1082 Heim, A., 1932. Bergsturz und Menschenleben. Fretz and Wasmuth, Zurich. 218 pp.
- Hsu, K.J., 1975. Catastrophic debris streams (Sturzstroms) generated by rockfalls. Geol. Soc. Am. Bull. 86, 129–
   1084 140
- Hu, W., Huang, R.Q., McSaveney, M., Zhang, X.H., Yao, L., Shimamoto, T., 2018. Mineral changes quantify
   frictional heating during a large low-friction landslide. Geology 46 (3), 223–226.
- 1087 Huang, R.Q., 2009. Geohazard assessment of the Wenchuan Earthquake. Science Press, 944P (in Chinese).
- Huang, R.Q., Li, W.L., 2009. Analysis of the geo-hazards triggered by the 12 May 2008 Wenchuan Earthquake,
   China. Bulletin of Engineering Geology and the Environment 68, 363–371.
- Huang, R.Q., Pei, X.J., Fan, X.M., Zhang, W.F., Li, S.G., Li B.L., 2012. The characteristics and failure mechanism
  of the largest landslide triggered by the Wenchuan earthquake, May 12, 2008, China. Landslides 9(1), 131–
  142.
- Huang, Y., Zhang W.J., Xu, Q., Xie, P., Hao, L., 2012b. Run-out analysis of flow-like landslides triggered by the
   Ms 8.0 2008 Wenchuan earthquake using smoothed particle hydrodynamics. Landslides 9, 275–283.
- Hungr, O., Evans, S.G., 2004. Entrainment of debris in rock avalanches: An analysis of a long run-out mechanism.
  Geological Society of America Bulletin 116(9), 1240–1252.
- Hungr, O., Evans, S.G., Bovis, M.J., Hutchinson, J.N., 2001. A review of the classification of landslides of the
   flow type. Environmental & Engineering Geoscience 7(3), 221–238.
- 1099 Kent, P.E., 1966. The transport mechanism in catastrophic rock falls. J. Geol., 74 (1966), pp. 79–83.
- Li, X.P., He, S.M., Luo, Y., Wu Y., 2012. Simulation of the sliding process of Donghekou landslide triggered by
   the Wenchuan earthquake using a distinct element method. Environmental Earth Sciences 65: 1049–1054.
- Loke, M.H., Barker, R.D., 1996. Rapid least-squares inversion of apparent resistivity pseudo-sections using quasi Newton method. Geophysical Prospecting 48, 181–152.
- Mangeney, A., Roche, O., Hungr, O., Mangold, N., Faccanoni, G., Lucas, A., (2010. Erosion and mobility in
  granular collapse over sloping beds. Journal of Geophysical Research 115(F3), 1–21.
- McDougall, S., Hungr, O., 2005. Dynamic modelling of entrainment in rapid landslide. Canadian Geotechnical
   Journal 42(5), 1437–1448.
- McSaveney, M.J., 1978. Sherman Glacier rock avalanche, Alaska, USA. B. Voight (Ed.), Rockslides and
   Avalanche, Elsevier, Amsterdam, Netherlands. pp. 197–258.
- McSaveney, M.J., Chinn, T.J., Hancox, G.T., 1992. Rock Avalanches of 14 December 1991, New Zealand.
  Landslide News 6, 32–34.
- Miller, R.D., Xia, J., Park, C.B., Ivanov, J.M., 1999. Multichannel analysis of surface waves to map bedrock. The
   Leading Edge 18, 1392–1396.
- 1114 Okada, H., 2003. The Microtremor Survey Method, Geophysical Monograph, Vol. 12, Society of Exploration
- 1115 Geophysicists, Tulsa, OK.

- Park, C.B., Miller, R.D., Ryden, N., Xia, J., Ivanov, J., 2005. Combined use of active and passive surface waves.
  Journal of Environmental and Engineering Geophysics 10, 323–334.
- Park, C.B., Miller, R.D., Xia, J., 1998. Imaging dispersion curves of surface waves on multi-channel record. 68th
  Annual International Meeting, SEG, Expanded Abstracts, 1377–1380.
- Perrone, A., Lapenna, V., Piscitelli, S., 2014. Electrical resistivity tomography technique for landslide
   investigation A review. Earth-Science Reviews 135, 65–82.
- Qi, S.W., Xu, Q., Lan, H.X., Zhang, B., Liu, J.Y., 2010. Spatial distribution analysis of landslides triggered by
   2008.5.12 Wenchuan Earthquake, China. Engineering Geology 116(1–2), 95–108.
- 1124 Santamarina, J.C., Klein, K.A., Fam, M.A., 2001. Soil and Waves. John Wiley & Sons Inc, New York.
- Sassa, K. (1985). The mechanism of debris flows. In: Proceeding of the XI International Conference on Soil
   Mechanics and Foundation Engineering, San Francisco, pp. 1173–1176.
- Schulz, W.H., Harp, E.L., Jibson, R.W., 2008. Characteristics of large rock avalanches triggered by the November
   3, 2002 Denali Fault earthquake, Alaska, USA. Proceedings of 10<sup>th</sup> International Symposium on Landslides
   and Engineered Slopes, Xi'an, China, June 30 ~ July 4, 2008
- Sheidegger, A.E., 1973. On the prediction of the reach and velocity of catastrophic landslides. Rock Mechanics 5,
  231-236.
- Shreve, R.L., 1968. Leakage and fluidization in air-layer lubricated avalanches. Geol. Soc. Am. Bull. 79 (5), 653–
  658.
- Shugar, D.H., Clague, J.J., 2011. The sedimentology and geomorphology of rock avalanche deposits on
   glaciers. SLAS Faculty Publication, 336, 44 p.
- Strom, A.L., 2006. Morphology and internal structure of rockslides and rock avalanches: grounds and constraints
  for their modelling. In: Evans, S.G., Scarascia Mugnozza, G., Strom, A., Hermanns, R.L. (eds), Landslides
  from Massive Rock Slope Failure. NATO Science Series: IV: Earth and Environmental Sciences 49, 305–328.
- 1139 Strom, A., Abdrakhmatov, K. (2018). Rockslides and rock avalanches of Central Asia. Elsevier, 449p.
- Tang, C., Zhu, J., Qi, X., Ding, J., 2011. Landslides induced by the Wenchuan earthquake and the subsequent
  strong rainfall event: A case study in the Beichuan area of China. *Engineering Geology* 122(1-2): 22–33.
- Voight, B., Janda, R.J., Glicken, H., Douglass, P.M., 1983. Nature and mechanics of the Mount St. Helens rock
  slide-avalanche of 18 May 1980. Géotechnique 33, 243–273.
- Wang, G., Huang, R.Q., Chigira, M., Wu, X.Y., Lourenço S.D.N., 2013a. Landslide amplification by liquefaction
  of runout path material after the 2008 Wenchuan (M8.0) earthquake, China. Earth Surface Processes and
  Landforms 38, 265–274.
- Wang, G., Huang, R.Q., Kamai, T., Zhang F.Y., 2013b. The internal structure of a rockslide dam induced by the
  2008 Wenchuan (M<sub>w</sub>7.9) earthquake, China. Engineering Geology 156, 28–36.
- Wang, G., Huang, R.Q., Lourenço, S.D.N., Kamai, T., 2014. A large landslide triggered by the 2008 Wenchuan
  (M8.0) earthquake in Donghekou area: phenomena and mechanisms. Engineering Geology 182(Part B), 148–
  151 157.
- Wang, G., Sassa, K., Fukuoka, H., 2003. Downslope volume enlargement of a debris slide-debris flow in the 1999
   Hiroshima, Japan, rainstorm. Engineering Geology 69(3-4), 309–330.
- 1154 Xu, Q., Tang, M.G., 2009. Donghekou landslide, Qingchuan. In (Xu et al. eds): Large-scale landslides induced by
- the Wenchuan Earthquake, Science Press, Beijing, pp 221–263

- Yin, Y.P., 2008. Researches on the Geo-hazards triggered by Wenchuan Earthquake, Sichuan. Journal of
   Engineering Geology 16, 433–444 (in Chinese).
- Yin, Y.P., Wang, F.W., Sun, P., 2009. Landslide hazards triggered by the 2008 Wenchuan earthquake, Sichuan,
  China. Landslides 6(2), 139–152.
- Yin, Y.P., Zheng, W.M., Li, X.C., Sun, P., Li, B., 2011. Catastrophic landslides associated with the M8.0
  Wenchuan earthquake. Bulletin of Engineering Geology and the Environment 70, 15–32.
- 1162 Yu, G.H., Xu, X.W., Klinger, Y., Diao, G.L., Chen, G.H., Feng, X.D., Li, C.X., Zhu, A.L., Yuan, R.M., Guo, T.T.,
- Sun, X.Z., Tan, X.B., An, Y.F., 2010. Fault-Scarp Features and Cascading-Rupture Model for the Wenchuan
  Earthquake (Mw 7.9), Eastern Tibetan Plateau, China. Bulletin of the Seismological Society of America,
  100(5B), 2590–2614, doi: 10.1785/0120090255.
- Yuan, R.M., Tang, C.L., Hu, J.C., Xu, X.W., 2014. Mechanism of the Donghekou landslide triggered by the 2008
  Wenchuan Earthquake revealed by discrete element modeling. Natural Hazards and Earth System Sciences
  14, 1195–1205.
- Zhang, L.M., Xu, Y., Huang, R.Q., Chang, D.S., 2011. Particle flow and segregation in a giant landslide event
   triggered by the 2008 Wenchuan earthquake, Sichuan, China. Natural Hazards and Earth System Science 11,
   1153–1162.
- Zhang, Y.B., Chen, G.Q., Zheng, L., Li, Y.G., Wu, J., 2013. Effects of near-fault seismic loadings on run-out of
   large-scale landslide: A case study. Engineering Geology 166, 216–236.
- Zhang, Y.B., Wang, J.M., Xu, Q., Chen, G.Q., Zhao, J.X., Zheng, L., Han, Z., Yu, P.C., 2015. DDA validation of
   the mobility of earthquake-induced landslides. Engineering Geology 194, 38–51.
- Zhou, J.W., Cui, P., Hao, M.H., 2016. Comprehensive analyses of the initiation and entrainment processes of the
   2000 Yigong catastrophic landslide in Tibet, China. Landslides 13(1), 39–54.
- Zhou, J.W., Cui, P., Yang, X.G., 2013. Dynamic process analysis for the initiation and movement of the
   Donghekou landslide-debris flow triggered by the Wenchuan earthquake. Journal of Asian Earth Sciences 76,
   70–84.
- 1181 1182



Fig. 1. Epicenter of Sichuan earthquake, distribution of landslides, and location of Donghekou landslide (after Huang, 2009).



**Fig. 2.** Donghekou landslide: (a) oblique aerial view; (b) Longitudinal section along the main sliding path (after Yin, 2008). L1, L2, L3: S-wave survey lines presented in Wang et al. (2014), and the arrows in L1~L3 present the extending direction of the survey lines.



Fig. 3. Views of Donghekou area towards S-W before (a) and after (b) the earthquake, respectively (after Wang et al., 2014). B1: toe part of the valley where the material started to move almost at the same time as the earthquake. B2: location of middle slope; B3: main source area. Photo in (b) was taken on 7 July 2018. The dashed cycles in both views mark the location of a one-stored building that was not destroyed during the earthquake.



Fig. 4. Geological map of Donghekou landslide area (after Xu and Tang, 2009)



Fig. 5. Fumes rising from the landslide deposits near location B1 in Fig. 3a (taken on March 6, 2009)



Fig. 6. Layout of geophones in triangular array for microtremor method (passive SPAC method).



**Fig. 7.** layout of ERT lines (E1-E5), S-wave survey lines (L1, L2, L3), and locations of microtremor monitoring (M1, M2) (Google Earth image shot on October 30, 2019).

1449																			
1450										Ti	me (s	5)							
1451			0 2	2 4	1	6	81	0 1	2 1	4 10	5 18	32	0 2	2 2	24 2	26 2	8 30	32	34
1452		G2	槲槲	milledinini	h h h h h h h h h h h h h h h h h h h	unnahana MA	hlinguyyhy	llun der Hern		ll www.	ntal-virtained	NALAMAN	ntall completion	hishafilatiwi	₩MMMM	WWWWWWWWW	laidy 10 14 for the sec	www.	-
1453		<u></u>	เม่นสายเม	ار میشد. اندانانی	Waamaan	الانامير بدمه	linhar	مىلمەر مەللا	n.a	' dhi wanini da	المانية الماميا	t Mutantica	المراقب بيعالين	Nu kalisatirati	kannadal	nta. Ulubaat	։ այսինիներին է	, anailatai ikad	ŀ
1454		Go	ad the hold of the	andhadhada	edibilitativan.	adali daga kali	MANAN ANYA	dilykeddiaddad	and in all all a	hliachtidadh	hotelev helev helev h	Munddun	anditatan dala	ntestalladiead	hududadah	natuhahaha	avalikilikan kova	oli Miniku Miniku	
1455		G4	how	nuhnlhhnl	4. Hillonaalaan	uvuluuluul	nikinkikinkin	na han han han han han han han han han h	W-##	Marrid Mart	ullun veraim	hender	u-philiperical philesis	hahillana	www.	www.halland	NAM MANYA	william	-
1457	e	~	and a solution	u dhana aa		.a. 111a	u katakata	n Acardedea	haa aaab	1՝ մես շահեն	lan, taat di	lita intara	terre tabali	ու լու Ամեները	յլ է թե հետուն	hi alla ai		n in the second s	-
1458	nbe	G5	<b>ann an t</b> ailtean.	edhallanda	ad dala ana kana kana kana kana kana kana ka	novinavyvili	urvinanlahvad	Invininihidad	Mullewilleille	NVFY&~ININAN	hallikavidasivadi	ulana kata da	duraudinda	nerhiniwa	ana haafaa ha	ne adama ang ang ang ang ang ang ang ang ang an	ee-dillinger	with the state	
1459	nu	G6	hollowing	windalawi	MANNING I	-loopsille	WALLAN	lo lli mine	liphywwyliph)	mandia	WWWWWWW	hand	WWWWWWW		hummu	<b>N</b> ation and N	hall population		-
1460	Station 1	~		ndun an			"] 	ան է։ Դերելու	alliar at	64 II		e at indeal		առեւս առողիվ	n i se i se e e e e e e e e e e e e e e e	nutre ne	ne ne generalizati		-
1461		G/	- Minika Minika	(W) provinsky	kenerati (Ali	(vernedirect)	enderheimen	red Williamsterred	WIMP+Iww	ed Morrid Herry	VIndillinio-arrianted	Qeedine(AMPAN)	politer and a	ad di Madial	n www.	allinh linna	and the second second	wwwww	
1462		G8	International	Ministration	an likalan	municular	unanan	linensi	hypowellowith	Mr. Monadam	Winewilliahumil	Alian Mahama	alision Vacionilian	u hallullulu	alihimuyula	Winterford	nadadaa ay yaa kaa kaa kaa kaa kaa kaa kaa ka	-tuillonlottal II	-
1463			- 10 - 10					li a thas d	hn		h.,	n pr De teo	اس ان	بيبين شيد اليون	ութ. օր մին, ստում	and the la		alu adda	-
1464		G9	-184/14/1-mHaile	liviahamilat	na ana ang ang ang ang ang ang ang ang a	nihimini (1944)	hhannahhh	allivilli llivad	a nanari	de Alander William A	(Note-Alteria)	hirinnana	ND-WARNIN	WWW	All working	WWWWWWWW	wikan Kilakwai	WHY WAR	ľ
1465		G10	- Millelworked	h hand hand hand hand hand hand hand han	www.www.autor	human	a himilyer barbard	il with the with	millionations	- hannen Maan Maan Maan Maan Maan Maan Maan	phylocal	kalinyidraatii	hourse-bille	ullinianiami	Nutranut	ndindlik wiede	Mandhallinanana	wilwilwilwi	-
1466								,							11.11	n . 'n . 'n	ւրուս։ Խ. քիշնը, է է է	a líti a líti	-
146/		G11	hillinhalpen	livilareviljeviljev	WAMMAN	nnh-hunn-hu	www.	all	ww.lylulidi	WANNAMANA	~kwalaniny.H	nNNNNN	b Milennine (Milen	human manager and a second	(WW)(Inff))	phenenen (	heaver Will Will Will An Article	anter Milling	ŀ
1468																			
1470																			
1471	Fig	<b>2. 8.</b> 4	An exa	mple	of the	record	d of pa	assive	MAS	W mea	asuren	nent at	t surve	y poir	nt M2.				
1472	,	,		1			1							. 1					
1473																			
1474																			
1475																			
1476																			
1477																			
1478																			
1479																			
1480																			
1481																			
1462																			
1484																			
1485																			
1486																			
1487																			
1488																			
1489																			
1490																			
1491																			
1492																			
1493																			
1494																			
1495																			
1496																			
149/ 1408																			
1470																			
1500																			
1501																			
1502																			
1503																			



Fig. 9. Vs profile for Point M2. (a), (b) Phase-velocity images in frequency domain obtained by active and passive methods, respectively; red dots indicate the picked phase-velocity; (c) Dispersion curve obtained from (a) and (b); (d) Inverted shear-wave velocity ( $V_s$ ) profile together with the original picked phase velocities (presented by red points) whose depths were estimated following the one-third-wavelength approximation.

- 1556
- 1557
- 1558 1559



Fig. 10. Vs profile for Point M1. (a), (b) Phase-velocity images in frequency domain obtained by active and passive methods, respectively, there the red dots indicate the picked phase-velocity; (c) Dispersion curve obtained from (a) and (b); (d) Inverted shear-wave velocity  $(V_s)$  profile together with the original picked phase velocities (presented by red points) whose depths were estimated following the one-third-wavelength approximation.



Fig. 11. Electrical resistivity topography (ERT) profiles along survey lines E1 and E2; the locations of cross section survey lines E3-E4 and microtremor measurement sites
 M1 and M2 are marked.



Fig. 12. Electrical resistivity tomography (ERT) profiles along survey line E5 (a), E4 (b), and E3 (c) on the landslide deposits. The arrow shows the location of intersection of two survey lines. Dashed lines mark the boundaries of channelized sliding.



**Fig. 13.** Shear-wave velocity (Vs) profiles along traverse line L2 (a), L1 (b), and L3 (c), respectively (After Wang et al., 2014).



Fig. 14. Schematic illustration of interaction between moving rock mass and liquefiable substrate (after Hungr and Evans, 2004). (a) rock mass moving towards the substrate layer; (b) deformed substrate with overriding rock mass;
(c) mud wave projected forward, (d) mud wave and rock mass deposit.





## 1775 Captions:

1782

1787

1789

1791

1793

1796

1798

Fig. 1. Epicenter of Sichuan earthquake, distribution of landslides, and location of Donghekou landslide (after
 Huang, 2009).

Fig. 2. Donghekou landslide: (a) oblique aerial view; (b) Longitudinal section along the main sliding path (after Yin, 2008). L1, L2, L3: S-wave survey lines presented in Wang et al. (2014), and the arrows in L1~L3 present the extending direction of the survey lines.

Fig. 3. Views of Donghekou area towards S-W before (a) and after (b) the earthquake, respectively (after Wang et al., 2014). B1: toe part of the valley where the material started to move almost at the same time as the earthquake.
B2: location of middle slope; B3: main source area. Photo in (b) was taken on 7 July 2018. The dashed cycles in both views mark the location of a one-stored building that was not destroyed during the earthquake.

- 1788 Fig. 4. Geological map of Donghekou landslide area (after Xu and Tang, 2009)
- 1790 **Fig. 5.** Fumes rising from the landslide deposits near location B1 in Fig. 3a (taken on March 6, 2009)
- 1792 Fig. 6. Layout of geophones in triangular array for microtremor method (passive SPAC method).

Fig. 7. layout of ERT lines (E1-E5), S-wave survey lines (L1, L2, L3), and locations of microtremor monitoring
 (M1, M2) (Google Earth image shot on October 30, 2019).

1797 Fig. 8. An example of the record of passive MASW measurement at survey location M2.

Fig. 9. Vs profile for Point M2. (a), (b) Phase-velocity images in frequency domain obtained by active and passive methods, respectively; red dots indicate the picked phase-velocity; (c) Dispersion curve obtained from (a) and (b);
(d) Inverted shear-wave velocity (V<sub>s</sub>) profile together with the original picked phase velocities (presented by red points) whose depths were estimated following the one-third-wavelength approximation.

1803 1804

1810

1813

1817

1820

Fig. 10. Vs profile for Point M1. (a), (b) Phase-velocity images in frequency domain obtained by active and passive methods, respectively, there the red dots indicate the picked phase-velocity; (c) Dispersion curve obtained from (a) and (b); (d) Inverted shear-wave velocity ( $V_s$ ) profile together with the original picked phase velocities (presented by red points) whose depths were estimated following the one-third-wavelength approximation.

Fig. 11. Electrical resistivity topography (ERT) profiles along survey lines E1 and E2; the locations of cross section
 survey lines E3-E4 and microtremor measurement locations M1 and M2 are marked.

Fig. 12. Electrical resistivity tomography (ERT) profiles along survey line E5 (a), E4 (b), and E3 (c) on the landslide deposits. The arrow shows the location of intersection of two survey lines. Dashed lines mark the boundaries of channelized sliding.

Fig. 13. Shear-wave velocity (Vs) profiles along traverse line L2 (a), L1 (b), and L3 (c), respectively (After Wang
et al., 2014).

Fig. 14. Schematic illustration of interaction between moving rock mass and liquefiable substrate (after Hungr and
 Evans, 2004). (a) rock mass moving towards the substrate layer; (b) deformed substrate with overriding rock mass;
 (c) mud wave projected forward, (d) mud wave and rock mass deposit.

1824

Fig. 15. Comparison between the shear-wave velocity  $(V_s)$  profile along L2 (after Wang et al., 2014) and electrical resistivity tomography (ERT) profile along E5. Dashed lines mark the possible boundaries of channelized sliding.