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# GEOGRAFIA FISICA E DINAMICA QUATERNARIA

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# DOWNSTREAM VARIABILITY OF CHANNEL MORPHOLOGY AND BED MATERIAL IN THE BRAIDED KELLER RIVER, JAMES ROSS ISLAND, ANTARCTICA

**ABSTRACT:** ONDRÁČKOVÁ L., SURIAN N., NÝVLT D & STUCHLÍK R., *Downstream variability of channel morphology and bed material in the braided Keller River, James Ross Island, Antarctica.* (IT ISSN 0391-9838, 2020).

Changes in sediment supply and water availability in rivers are associated with ongoing climate change and glacier melting. The processes connected with increasing temperatures largely determine braidplain activity within glacier forefields. This work focuses on downstream changes in channel morphology (i.e., channel width and braiding intensity) and bed material (i.e., petrological types and clast roundness), as well as possible controlling factors (i.e., sediment sources and sediment connectivity). The study area is the Keller River catchment located on the James Ross Island (JRI), Antarctica. This paper describes the 8.6 km-long Keller River in terms of morphology, including river braidplains, sediment sources and connectivity within the catchment. Eight sediment sources and three types were identified: one moraine sediment source, four debris-flow-dominated sediment sources and three fluvial-flow-dominated sediment sources. Along with high sediment connectivity, the occurrence of lateral sediment sources from tributaries significantly impacted downstream changes in channel morphology and processes. Channel width and braiding intensity showed an increasing downstream trend, although the channel width trend was irregular. As for bed material, sediment sources markedly control clast roundness with little effect of petrological properties.

**KEY WORDS:** Proglacial stream, Channel width, Clast roundness, Sediment sources, Sediment connectivity, Antarctica.

**RIASSUNTO:** ONDRÁČKOVÁ L., SURIAN N., NÝVLT D & STUCHLÍK R., *Variabilità longitudinale delle caratteristiche morfologiche e sedimentologiche in un corso d'acqua a canali intrecciati: il Fiume Keller, Isola James Ross, Antartide.* (IT ISSN 0391-9838, 2020).

Variazioni della disponibilità di sedimento e delle portate liquide nei corsi d'acqua sono legate ai cambiamenti climatici in atto e alla riduzione delle masse glaciali. L'aumento delle temperature e i processi ad esso associati controllano fortemente la dinamica dei corsi d'acqua a canali intrecciati negli ambienti proglaciali. Il presente lavoro si focalizza sulla variabilità longitudinale delle caratteristiche morfologiche (i.e., larghezza dell'alveo e indice d'intrecciamento) e sedimentologiche (i.e., petrografia e arrotondamento dei clasti) e sui possibili fattori di controllo (i.e., sorgenti e connettività dei sedimenti). Nel lavoro viene analizzato il Fiume Keller (8.6 km di lunghezza) per quanto concerne: a) la morfologia dell'alveo e della piana alluvionale e b) sorgenti e connettività dei sedimenti a scala di bacino. Otto sorgenti di sedimento, distinte in tre tipologie, sono state identificate: una da depositi glaciali, quattro con prevalenza di colate detritiche, tre con prevalenza di trasporto fluviale. Oltre ad un'elevata connettività dei sedimenti, l'apporto di sedimento dai tributari influisce in modo significativo sulla variabilità longitudinale della morfologia e dei processi del corso d'acqua. La larghezza dell'alveo e l'indice d'intrecciamento mostrano un incremento progressivo verso valle, sebbene l'andamento longitudinale della larghezza abbia una certa irregolarità. Per quanto riguarda le caratteristiche sedimentologiche, le sorgenti di sedimento controllano in modo rilevante l'arrotondamento dei clasti, mentre hanno un effetto limitato sulla petrografia dei clasti.

**TERMINI CHIAVE:** Corso d'acqua proglaciale, Larghezza alveo, Arrotondamento clasti, Sorgenti di sedimento, Connettività dei sedimenti, Antartide.

## INTRODUCTION

It is well known that river morphology and processes are closely connected to catchment characteristics (e.g., lithology, tectonics and vegetation cover) and processes (e.g., slope instability and sediment connectivity) (Fryirs & *alii*,

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2007; Cavalli & *alii*, 2013). Increasing our understanding of such relationships requires investigating appropriate fluvial systems, chiefly those where human impact is low or absent. Proglacial rivers are often ideal for such investigations (Carrivick & *alii*, 2013). The transport of bed material in proglacial rivers has been analysed in several studies (Ashworth & Ferguson, 1986; Ferguson & *alii*, 1992; Wathen & *alii*, 1995; Knighton, 1998; Beylich & *alii*, 2017; Carrivick & Heckmann, 2017; Kammerlander & *alii*, 2017; Ondráčková & *alii*, 2018; Ondráčková & *alii*, 2020), but few studies have compared channel and catchment processes (e.g., Ashmore & Day, 1988; Rachlewicz, 2007; Bartsch & *alii*, 2009; Carrivick & *alii*, 2013; Kidová & *alii*, 2016).

Sediment transport in various localities and previously glacierised areas has been described by many researchers (Hambrey, 1994; Maizels, 1997; Hodson & *alii*, 1998; Bhutyiani, 2000; Bogen & Bønsnes, 2003; Marren, 2005; Rachlewicz, 2007; Slaymaker, 2011; Marren & Toomath, 2014; Carrivick & Heckmann, 2017; Park & Hunt, 2017; Weckwerth & *alii*, 2019; Mancini & Lane, 2020), but few such studies pertain to Antarctica (Carrivick & *alii*, 2012; Davies & *alii*, 2013; Kavan & *alii*, 2017; Kavan & Nývlt, 2018; Ondráčková & *alii*, 2018; Sroková, 2019). Antarctica is a special and vulnerable region that deserves our attention. It is almost entirely without vegetation cover and save for some terrestrial algae, cyanobacteria, lichens and mosses, which stabilise catchment surfaces little and affect only areas with sufficient nutrients (Navas & *alii*, 2008, Barták & *alii*, 2015; Marečková & Barták, 2016; Nývlt & *alii*, 2016; Chattová, 2018; Ruiz-Fernández & *alii*, 2019; Hrbáček & *alii*, 2020) and therefore in some other Antarctic areas can have a quite important effect. The proglacial areas are affected by the harsh climatic conditions (van Lipzig & *alii*, 2004; Láska & *alii*, 2010; Láska & *alii*, 2011; Glasser & *alii*, 2012) with a combination of the influence of glaciers, snow cover and permafrost degradation (Smellie & *alii*, 2008; Baewert & Morche, 2014; Nývlt & *alii*, 2014; Oliva & Ruiz-Fernández, 2015; Hrbáček & *alii*, 2016).The morphological and sedimentary conditions of glacier outwash plains depend on several other factors: the geomorphic and tectonic history of the river catchment, ongoing climate change and base level variations (Lane & *alii*, 1997; Baewert & Morche, 2014; Knight & Harrison, 2014; Kociuba, 2017, Strzelecki & *alii*, 2018; Weckwerth, 2018).

Several works from many regions worldwide have pointed out the longitudinal trend of reduced bed material size, i.e., "downstream fining" (e.g., Ferguson & *alii*, 1996; Rice & Church, 1998; Surian, 2002; Gasparini & *alii*, 2004; Piégay & *alii*, 2006; Rice & Church, 2010; Weckwerth & *alii*, 2018; Sklar & *alii*, 2020). Three mechanisms contribute to downstream fining: abrasion, hydraulic sorting or transport and in-situ weathering (Knighton, 1998). Tributaries and other lateral sources, such as banks, can introduce sediment to the main stream causing discontinuities in the downstream fining process (Ferguson & *alii*, 1996). Tributary size, as well as the size of sediments carried by the tributary, are two factors that determine whether a tributary will change bed material characteristics (Knighton, 1998).

Sediment sources and connectivity are key aspects controlling downstream changes in bed material. Sediment connectivity refers to the relationship between components in a geomorphic system and plays a crucial role in sediment transport (Baartman & *alii*, 2013; Geilhausen & *alii*, 2013; Heckmann & *alii*, 2018). As particles are transported downslope and delivered to channels, the size of sediments produced on hillslopes evolves (Sklar & *alii*, 2020). Sediments produced in the uplands, where hillslopes and channels are closely connected, can influence downstream fining trends in a channel (Ferguson & *alii*, 1996; Sklar & *alii*, 2020).

In this paper, we present the findings of a study investigating the role of sediment sources in channel morphology and bed material characteristics in the Keller Catchment (James Ross Island [JRI], East Antarctic Peninsula). The Keller Catchment was selected for its position in a changing polar environment and its proximity to the Czech Antarctic station. There is no existing fluvial geomorphological study from this sector of Antarctica. The aims of this study are (a) to analyse the downstream changes of channel morphology and bed material in the Keller River and (b) to explore the controlling factors of such downstream changes in a braided river under natural conditions.

## STUDY AREA

The Keller Catchment is located on the JRI (64°10'S; 57°45'W), the JRI's total surface area is 2450 km² and is located in the north-western Weddell Sea behind the Antarctic Peninsula (fig. 1), which acts as an orographic barrier. Its northernmost part, the Trinity Peninsula, is separated from the JRI by the 6-24 km-wide and 450-1600 m-deep Prince Gustav Channel (Camerlenghi & *alii*, 2001).

The study area is approximately 15 km away from the Johann Gregor Mendel Czech Antarctic Station. The mean elevation of the Keller River catchment is roughly 370 m a.s.l., and its 31 km$^2$ catchment area is bounded by the periphery of the Davies Dome Glacier, Medina Peak (199 m), Sekyra Peak (553 m), Lookalike Peaks (706 m) and the lateral moraine of the Whisky Glacier (Nelson & *alii*, 1975; Czech Geological Survey, 2009). The most important glaciers here are Davies Dome, Whisky Glacier and Unnamed Glacier in the upper part of the catchment (Engel & *alii*, 2012).

The mean annual air temperature in the vicinity of Johann Gregor Mendel station at 10 m a.s.l. was -6.9 °C from 2006-2014 (Hrbáček & *alii*, 2016), with January being the warmest month (+8.0 °C) and July and August (-30.0 °C) being the coldest months (Láska & *alii*, 2010; 2011). The region sees over 200 positive degree days and 100 freeze-thaw days (days in which there are both negative and positive temperatures with at least one value greater than ±0.5 °C; cf. Michel & *alii*, 2014) per year, which vary highly year by year. Precipitation in this area mostly consists of snow (about 450 mm/year), mainly from March to November (van Lipzig & *alii*, 2004; Hrbáček & *alii*, 2016). Because of the area's topography, most snow cover is blown away during windstorms.

Landforms within braidplain are created by the extensive Cretaceous mudstone and sandstone rocks covered in layers of massive basalts and hyaloclastite breccia boulders (Kňažková & *alii*, 2020; Mlčoch & *alii*, 2020). The catchment can be separated into three parts based on geology.

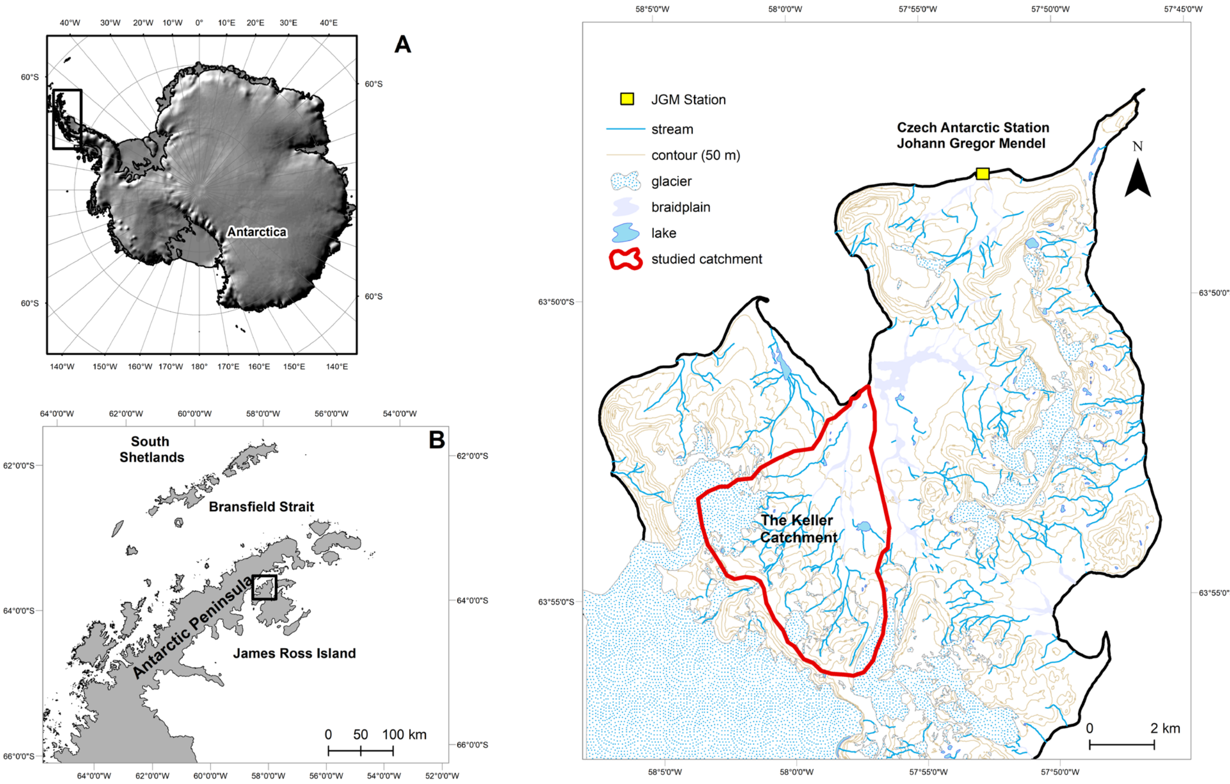


FIG. 1 - Location of the Keller Catchment (A - Antarctic Peninsula; B - James Ross Island; C - Ulu Peninsula and the Keller Catchment).

The upper part, which is made up of Neogene hyaloclastite breccias and basalts. The middle part, which is composed of Cretaceous sandstones and siltstones (Santa Marta Formation). The lower part and surrounding areas, which are covered by Holocene periglacially reworked subglacial till (Mlčoch & *alii*, 2020). Geological map of the Keller Catchment is presented in fig. 2. The entire catchment is underlain by permafrost with seasonal thawing of the active layer usually 0.5-0.6 m thick (Hrbáček & *alii*, 2017).

This part of the JRI is one of the largest deglaciated areas in Antarctica with small remaining glaciers (Engel & *alii*, 2012). Regarding the deglaciation of this area, altitudes between 20-50 m have been ice-free since 12.9 ± 1.2 ka (Nývlt & *alii*, 2014). According to Nývlt & *alii* (2014) and Glasser & *alii* (2014), most of the Keller Catchment has been ice-free since 6.7 ± 0.3 ka.

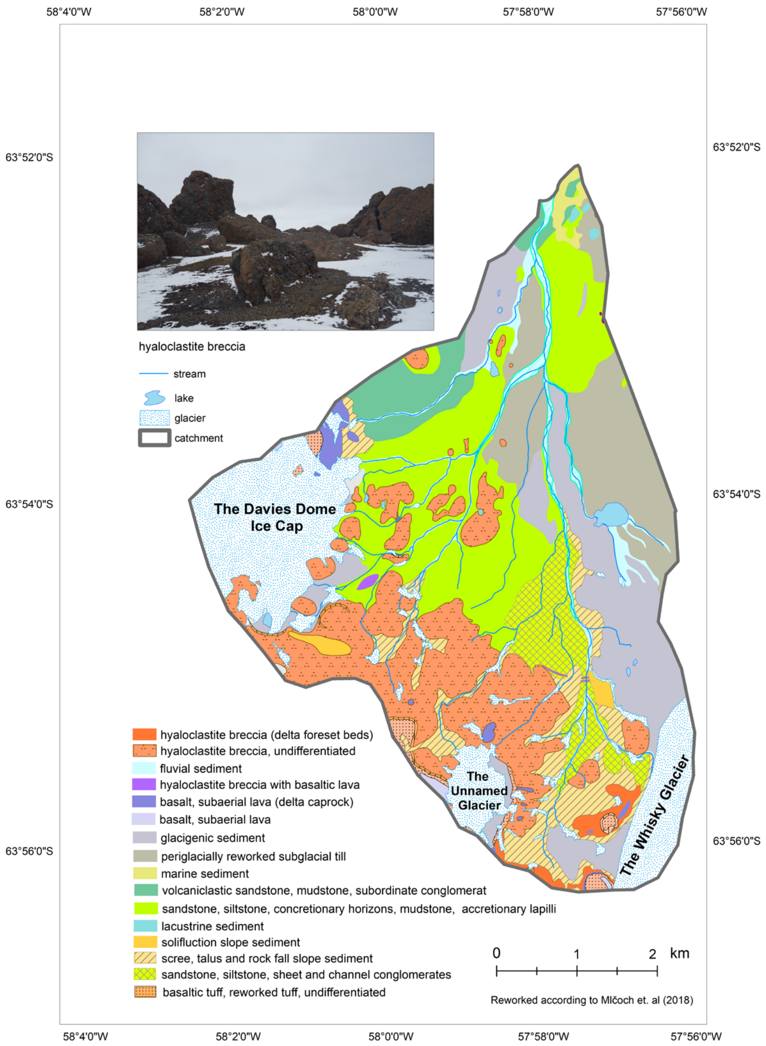
The length of the Keller River is 8.6 km. Its starting position was delimited from a Digital Elevation Model (DEM) and verified in the field, but it should be noted that during the ablation period of the glaciers and snowfield, this position can differ with each season. The stream ends at an inlet of Brandy Bay. The Keller River is a confluence of small streams in the uppermost parts of the catchment under Lookalike Peaks that stem from the melting Unnamed Glacier. The most important tributary is the Monolith River running out of Monolith Lake, which is filled by two unnamed streams and melting snowfields. The Keller River ends in Brandy Bay following its confluence with the Monolith River. Both rivers are characterised by braided patterns, the presence of channel bars and many confluences with side-channels. Other tributaries also act as important sediment sources (see fig. 4).

## MATERIAL AND METHODS

### *Preliminary analysis and field work design*

Pre-selection of the studied catchment together with the sediment sampling sites was done before the Czech Antarctic Expedition in austral summer 2018 (January-March 2018). For preliminary analyses, an aerial Orthophoto Image (2006), REMA (The Reference Elevation Model of Antarctica) model (Howat & *alii*, 2019) and geological and topographical map from the Czech Geological Survey (2009) and Mlčoch & *alii*, 2020) were used (fig. 1 and fig. 2). This dataset was pre-analysed in Geographic Information System (GIS) environments, namely ArcGIS and QGIS. The slope raster, aspect raster and flow accumulation raster were derived from the DEM and then combined with the glacier locations and stream network to pre-select sediment source localities (fig. 3 and fig. 4). A plan for field work and sediment sampling was designed before the expedition.

During the austral summer research campaign, a detailed geomorphological mapping of the Keller Catchment was completed. However, the final selection of sediment sources occurred during field work. The sediment source type were debris-flow-dominated fans, fluvial-flow-dominated fans and moraine source (De Haas & *alii*, 2015; Tomczyk



Reworked according to Mlčoch et. al (2018)

Fig. 2 - Geological map of the Keller Catchment (based on Mlčoch & *alii*, 2018).

& Ewertowski, 2017). In total eight representative sediment sampling sites in each of the eight defined sediment sources were selected (fig. 4). For sediment sampling in the active part of the channel, 31 sampling sites were chosen (fig. 4).

### *Channel morphology*

After geomorphological mapping, the active zone of the Keller River was analysed in ArcGIS and QGIS. The active zone surrounds the 7 km of the length of the river, because the first 1.6 km flows within a very narrow valley (fig. 5). We then focused on segmentation to obtain a detailed assessment of channel morphology. Along the whole length of the Keller River, seven reaches were defined according to their differences in longitudinal slope profile, valley morphology, confinement and connection to sediment sources and important tributaries (see fig. 5). After that, channel width was measured perpendicularly to the centreline of the active zone at every 25 m. Along with channel width, the braiding index was counted in the number of active flowing channels (Rinaldi & *alii*, 2011).

### *Bed material characteristics*

Sediment sampling and measuring was carried out at selected areas of each sediment source locality (eight sites) and along the Keller River (31 sites). Sediments were sampled using a sieving method (Bunte & Abt, 2001) (fraction 8-16 mm) and processed in a laboratory to define their petrography, shape and roundness. Each sample from the sediment sources (8 localities) and from the active channel (31 localities) contained 100 clasts and was collected from channel bars. The field sample data were accompanied by their respective GPS positions, site descriptions and photo documentation of sites and their surroundings (see fig. 4).

Laboratory and petrological analyses of clasts entailed (i) identifying petrology using a geological map of the northern part of the JRI (Mlčoch & *alii*, 2020), (ii) measuring the a, b and c axes (Wadell, 1932) and (iii) assessing roundness using the roundness scale by Powers (1953). For clast characteristics, the Triplot macro by Graham & Midgley (2000) was used.

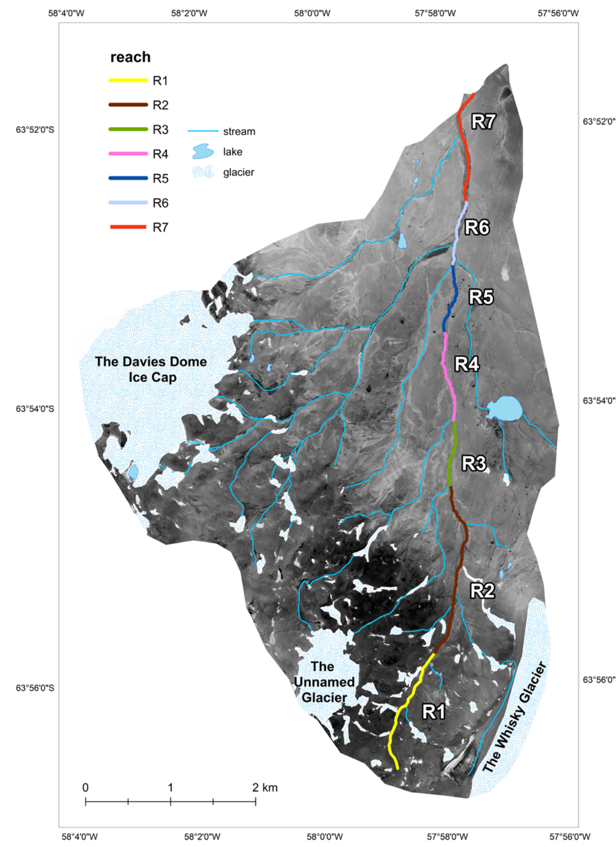


FIG. 3 - The Keller River segmentation and identification of the seven reaches.

### *Sediment sources and connectivity*

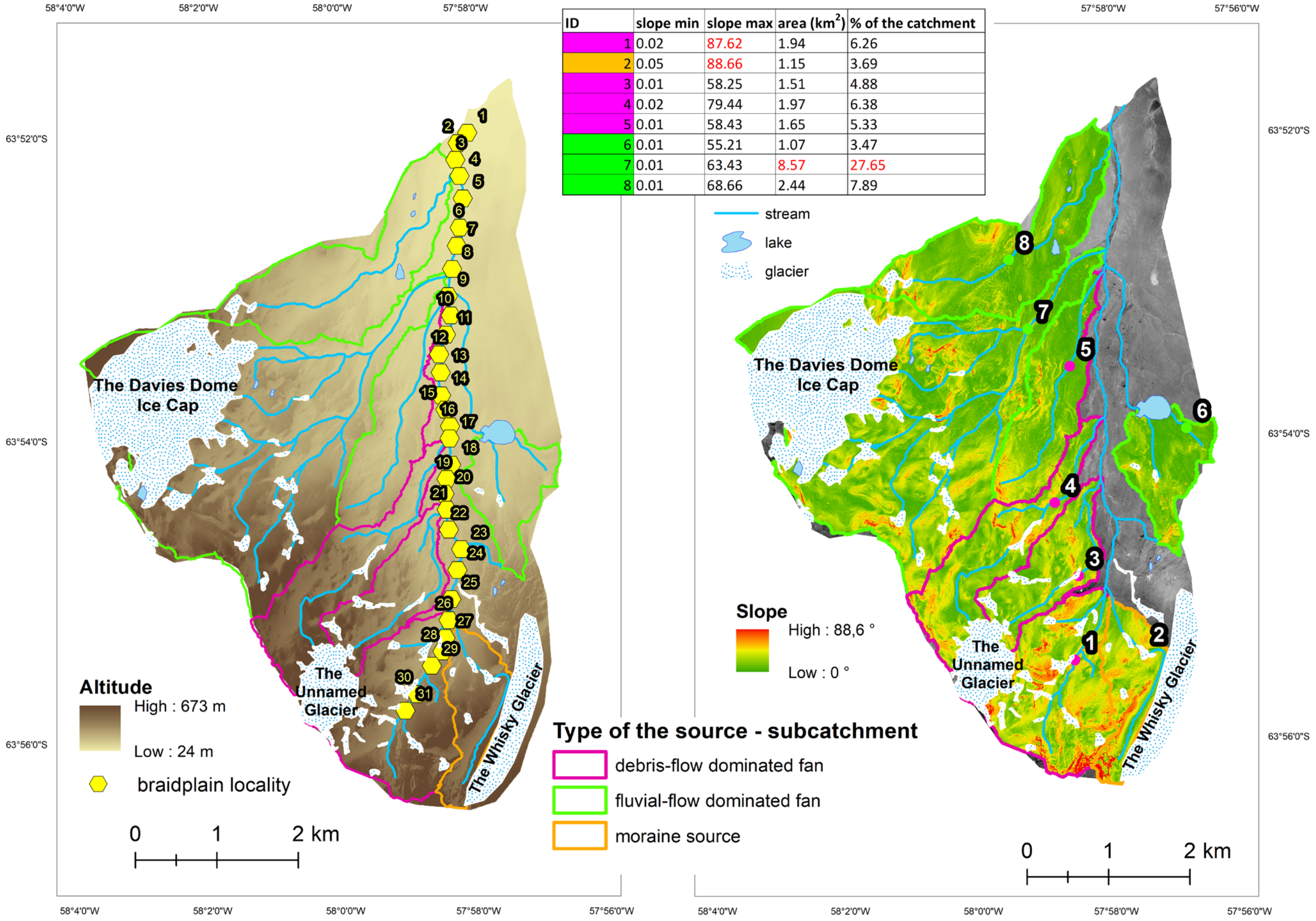
To assess sediment supply, it was necessary to analyse sediment connectivity. To do this, a raster (fig. 8) was used in Cavalli & *alii*'s (2013) model. SedInConnect 2.3 software (Crema & Cavalli, 2018) is a freeware tool that implements Cavalli & *alii*'s (2013) approach with further improvements. An index of connectivity evaluates the potential connection between hillslopes and features acting as targets or storage areas for transported sediment (Cavalli & *alii*, 2013). The method used in this software for the computation of the contributing area, a roughness index as the weighting factor for transport sediments. It has been implemented to adapt the model to sediment transfer processes within the catchment, which are characterized by contrasting morphology and affected by hillslope sediment transfer of different type and intensity of the source. The connectivity index focuses on the influence of topography on sediment connectivity, whereas other aspects such as vegetation cover and type, the effect of different active layer depths on various lithologies (Hrbáček & *alii*, 2017) are not taken into account (Cavalli & *alii*, 2013). This model clearly shows the index of connectivity in the whole Keller Catchment, especially in sediment source subcatchments. We used the DEM for delimiting the subcatchments. Selected subcatchments with each sediment source were defined previously (fig. 4). The index of connectivity in the whole catchment, selected subcatchments and the whole Keller River is shown in fig. 8. This analysis helps to verify the importance of slope processes as potential sediment sources and highlights their influence on channel morphology and processes.

## RESULTS

### *River segmentation and channel morphology*

Segmentation was carried out taking into account similar stream properties, active zones and valleys in the surroundings (fig. 3). The Keller River was divided into seven reaches (R1 at the spring, R7 at the bay). Reach 1 is located in the source area starting at 369 m a.s.l., which consists of a single-thread channel in a confined V-shaped valley. The first reach, which is 1550 m long with a longitudinal slope of 10.5%, yielded the debris-flow-dominated sediment at the beginning of the river. Reach 2 begins at the active zone of the Keller River. At this reach, there is a U-shaped valley and confluence with the right-side morainic sediment source. This reach is the longest (2150 m) and its longitudinal slope is 4.1%. At the beginning of Reach 3, a left-side debris-flow-dominated sediment source lies, which is very close to the river channel. This reach is 775 m long with a longitudinal slope of 2.4%. Reach 4 contains another left-side debris-flow-dominated sediment source, which is also located at the beginning of the reach, and is characterized by a wide active zone with several channels. Its length is 1075 m and its longitudinal slope is 2.2%. At the end of Reach 5, which is flat and consists of a wide active zone, there is a confluence with a left-side debris-flow-dominated sediment source. This reach is 825 m long with a longitudinal slope of 1.8%. Reach 6 is the shortest (750 m) with a longitudinal slope of 1.7%. At the beginning of Reach 6 is the Monolith fluvial-flow sediment source tributary on the right; on the left lies another large fluvial-flow tributary from the Davies Dome Glacier. Here is a wide active zone, several channels and well-developed channel bars. The last left-side fluvial-flow-dominated sediment source lies at the final reach, Reach 7. Its right slope is roughly 3-4 meters high and is 1350 m long with a longitudinal slope of 1.6%. It has a wide active zone, several channels and bars and braided morphology. Reaches 1 and 2 are confined, Reaches 3 and 4 are partly confined and Reaches 5, 6 and 7 are unconfined.

Fig. 5a shows channel width and corresponding longitudinal variability. The active zone starts after 1550 m from the spring. At every 25 m following the start of the active zone, the channel width was measured with an orthophoto image and also verified using the DEM. The most important tributaries (sediment sources) are indicated using black arrows. For clarity, a scale of confinement and a line identifying reaches are also presented. The trend shows an increase in channel width moving downstream (the maximum width of 108 m is reached



| ID | slope min | slope max | area (km$^2$) | % of the catchment |
|---|---|---|---|---|
| 1 | 0.02 | 87.62 | 1.94 | 6.26 |
| 2 | 0.05 | 88.66 | 1.15 | 3.69 |
| 3 | 0.01 | 58.25 | 1.51 | 4.88 |
| 4 | 0.02 | 79.44 | 1.97 | 6.38 |
| 5 | 0.01 | 58.43 | 1.65 | 5.33 |
| 6 | 0.01 | 55.21 | 1.07 | 3.47 |
| 7 | 0.01 | 63.43 | 8.57 | 27.65 |
| 8 | 0.01 | 68.66 | 2.44 | 7.89 |

FIG. 4 - Map of the sediment sampling localities within the braidplain of the Keller River (on the left side); the sediment sources within the Keller Catchment with the slope characteristics (on the right side).

7.8 km away from the spring), but also demonstrates significant variability. Fig. 5b outlines the braiding index and longitudinal variability. The symbology for tributaries, confinement and reaches is the same as in the case of channel width. The trend shows increased braiding intensity moving downstream. The maximum braiding index was 8 located at 7.8 km away from the start of the active zone, which corresponds to the maximum channel width in the relative flat area at the beginning of the last reach.

### *Downstream changes in bed material characteristics: lithological composition and roundness*

The geological map of the Keller Catchment (fig. 2) shows some differences in the lithological composition of the area. We should note that while the whole area was glacially reworked, the main petrological types among the clasts are Cretaceous sandstones, and Neogene basalts and palagonites (from the hyaloclastite breccias). The downstream change of each dominant petrological type is presented in fig. 6. Among 31 sampling sites in the active channel, the most dominant types were sandstone (usually more than 50%) and basalt (approximately 30%), with the remainder being palagonites. Overall, sandstones and basalts showed a slight decreasing trend along the flow of the river, while palagonite rates increased.

Another important clast characteristic is roundness. Clast changes, along with the longitudinal profile of the Keller River, are presented in fig. 7. The most important degrees of roundness are sub-angular (SA, denoted in green) and sub-rounded (SR, denoted in red), while the more extreme categories of angular (VA+A, denoted in black) and rounded (R+WR, denoted in grey) are complementary here to other categories. Generally, increasing downstream clast's roundness can be observed alongside their decreasing angularity. Moreover, there are two small histograms in this graph that describe two important sediment sources: moraine and fluvial-flow fan. The effects of these tributaries are clearly visible in the graph, especially the increased amount of angular material derived from moraine sediment sources. A significant portion of angular clasts (VA+A, 22%) and sub-angular clasts (SA, 65%) can be observed.

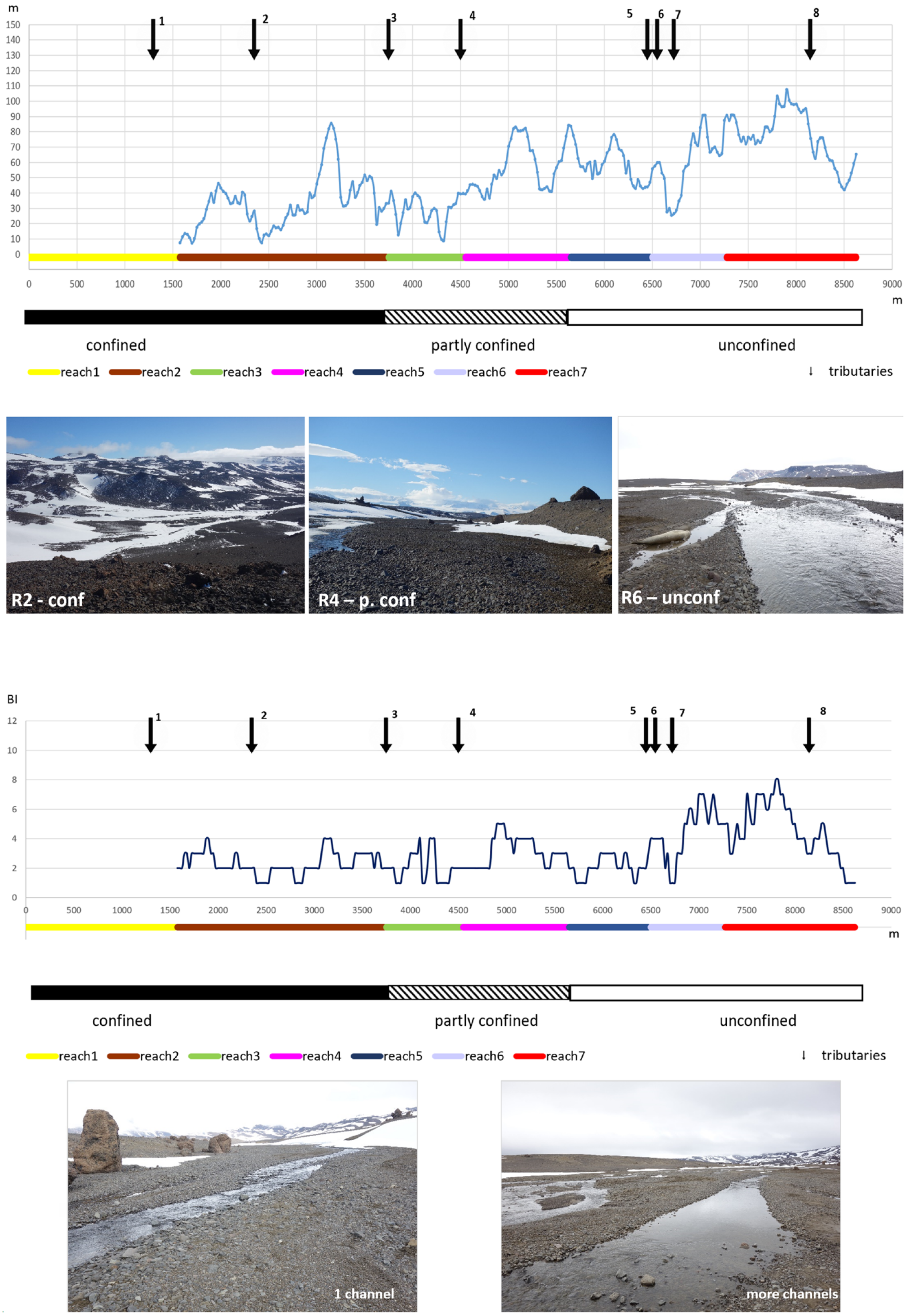


FIG. 5 - Downstream change of channel width (a - above) and braiding index (b - below) in the Keller River.

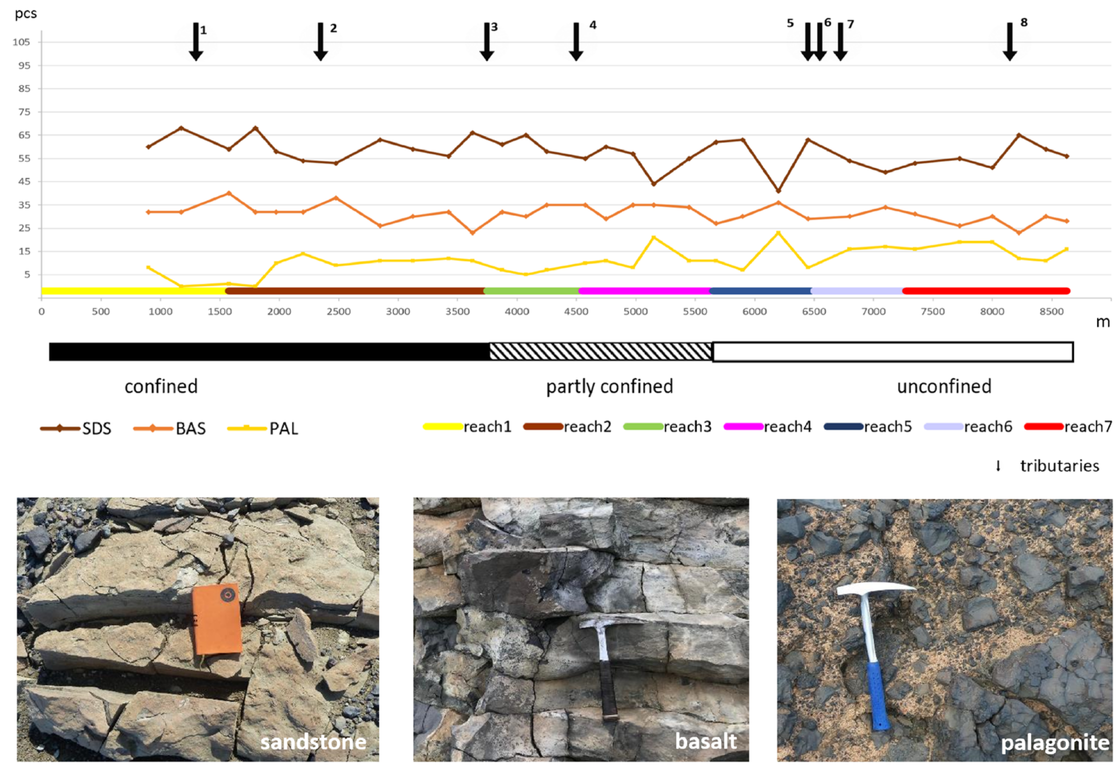


FIG. 6 - Downstream change of the main petrological types of sediments in the Keller River braidplain.

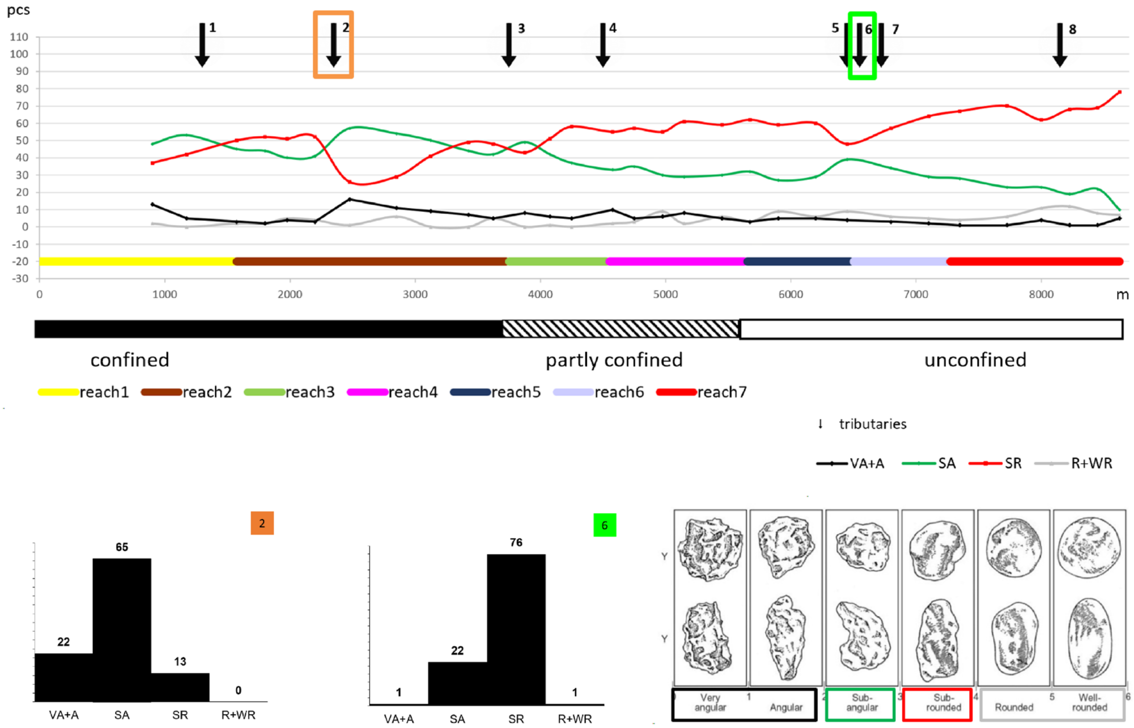


FIG. 7 - Downstream change of sediment roundness in the Keller River braidplain.

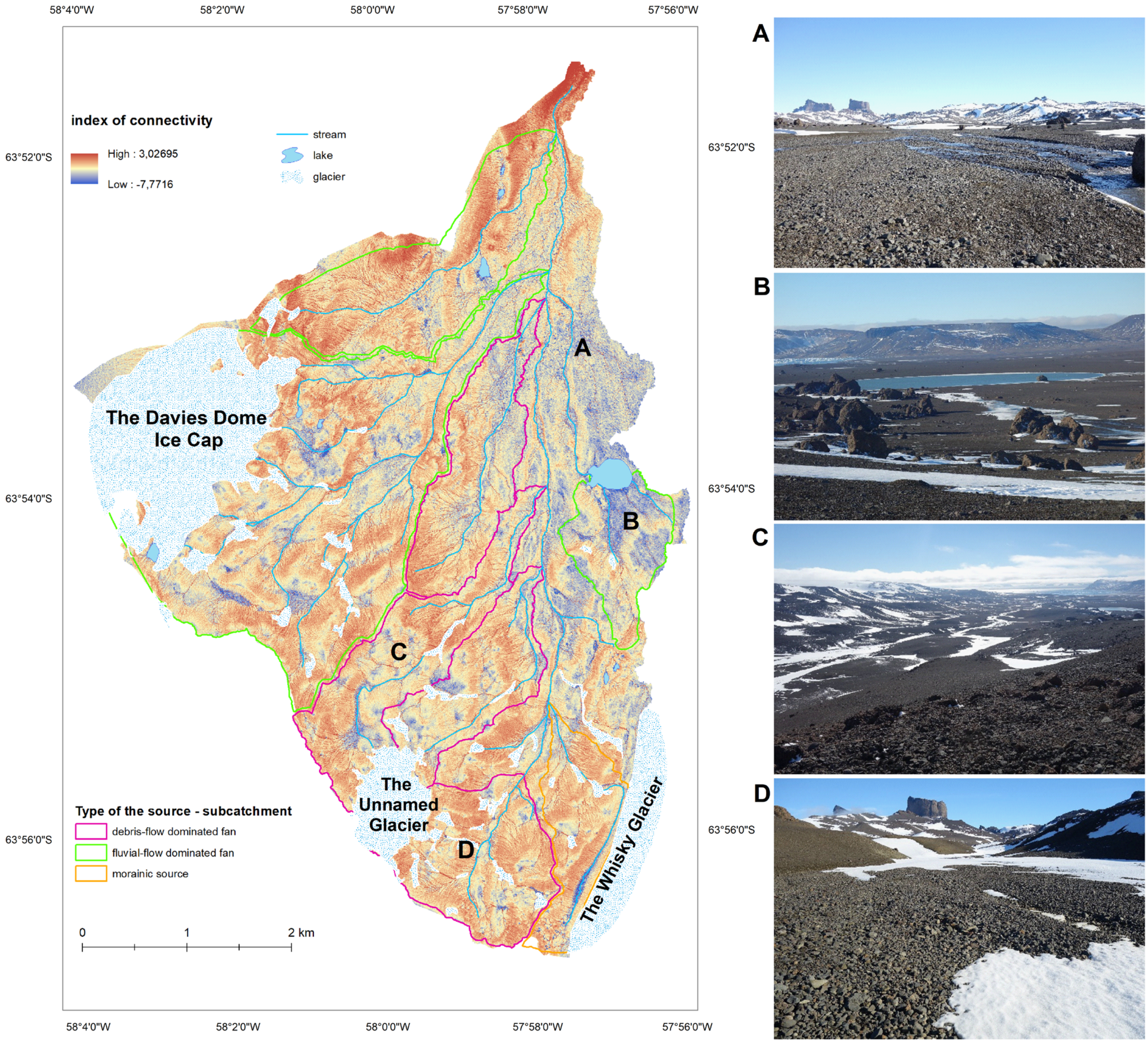


FIG. 8 - The sediment connectivity map; the photographs (A to D) show areas with different degree of connectivity.

### *Sediment sources and connectivity*

To explain the effects of sediment source subcatchments (fig. 4), it is necessary to know the type, position and activity of each source.. Source 1 is at the upper part of the Keller River and is a debris-flow-dominated fan with an area of 1.9 km$^2$ and a highest slope greater than 87%. The moraine sediment source (Source 2) is right-side with a highest slope greater than 88% and an area of 1.2 km$^2$. Other left-side debris-flow-dominated fans are sources 3, 4 and 5, which are similar in area and activity. Sediment source 6 encompasses the Monolith fluvial-flow sediment source, which flows from the Monolith Lake and is a flat area with braided morphology. With an area of 8.5 km$^2$, debris-flow-dominated fan source 7 is the largest, which can be owed to the Davies Dome Glacier in the upper parts of this tributary. The eighth and last sediment source is fluvial-flow-dominated and close to the Brandy Bay with an area of 2.4 km$^2$. Clast analysis and geomorphological mapping was carried out at each sediment source.

For a better understanding of how such sediment sources affect channel morphology and processes and bed material characteristics, the index of connectivity was determined for the whole Keller Catchment (fig. 8). Using Cavalli & *alii*'s (2013) index, this analysis is accompanied by some documentary photographs. Blue areas indicate places with a low index of connectivity (e.g., areas around the Monolith Lake and in the middle part of the active zone), while red colour highlights the areas with a high index of connectivity (e.g., first sedimentary source, moraine of the Whisky Glacier, upper parts of the tributaries and the left-side slope of the last tributary).

This analysis allowed for the identification of different degrees of connectivity – that is, sources that are more connected (Source 1) and those that are almost disconnected (Source 6). The studied catchment area, which is devoid of human activity, is a good reference for fluvial systems characterised by high sediment connectivity and high sediment supply.

## DISCUSSION

### *Downstream changes in the sediment characteristics*

Small petrological differences were observed in sediments, but it is unclear if these were influenced by tributaries. Notwithstanding this, the catchment was influenced by glacier retreat, which reworked sediments and caused sandstone to be the dominant type, whereas basalt was decreased and palagonite was increased along the river from the spring to the mouth. The only notable change in sediment characteristic trend was observed in reach 5 at locality 10, where the confluence with left-side tributary from Monolith Lake is located. The Monolith Lake area is known for the presence of large hyaloclastite breccia boulders (Kňažková & *alii*, 2020), from which palagonites originated due to weathering.

### *Factors controlling downstream changes in channel morphology and clast roundness*

From a channel morphology point of view, tributaries (sediment sources) impact the widening of channels, in contrast with the findings of Ondráčková & *alii* (2020). Significant disruptions can be explained by natural factors, such as sediment input into the main channel and changes in valley morphology (e.g., confinement, confluences and flat areas). Braiding indices are closely linked with channel width, and unconfined conditions make more space for braiding to develop. It is worth noting that under the conditions in this region (no vegetation cover and high sediment supply), braiding intensity increases remarkably, especially in the last reach after significant confluence with other important tributary sources 5, 6 and 7.

The association between discontinuities in roundness and tributaries has shown that some tributaries disrupt downstream roundness processes. The moraine sediment source (2) adds a significant portion of very angular, angular and sub-angular clasts into the main Keller River. It is a frontal to lateral moraine with traces of push processes. There is a 25% decrease in sub-rounded clasts, which is the most significant longitudinal trend change along the river. Afterward, the number of angular clasts transported by the stream decreases and is accompanied by a significant increase in clast roundness. This trend is amplified in the last two reaches (R6 and R7). The effects of axial river transport on clast roundness also increases in these two areas; this type of trend has been expressed in several proglacial streams (Gustavson, 1974; Huddart, 1994; Bennett & *alii*, 1997; Hambrey & Ehrmann, 2004; Hambrey & Glasser, 2012; Hanáček & *alii*, 2013). The dominance of axial transport is enabled by a stable channel belt. In a modern braided river, Gustavson (1974) described an increase in clast roundness in the downstream direction. Hambrey and Ehrmann (2004) and Hambrey and Glasser (2012) also noted the dominance of rounded grains in modern proglacial streams. In other words, the existing literature has noted that in general, transported material in mountainous proglacial braided rivers exhibit trends in gradual roundness increases or in dominance of rounded classes.

## CONCLUSIONS

The results of this work enable a better understanding of channel morphology, bed sediment characteristics and factors controlling their variability along the Keller River on James Ross Island, Antarctic Peninsula. The focus shifts from the scale of the sediments transported in the Keller River to channel morphology, sediment sources and sediment connectivity.

The connectivity within the Keller Catchment plays a prevailing role in sediment transport from slopes to channels. The upper parts of the catchment are highly connected, and due to the instability of the material cover on the slopes, the debris-flow processes (or other gravitational processes) transport material into the channel. Fluvial-flow transport by tributaries was also found to be important in Keller Catchment. Both debris-flow processes and fluvial-flow transport are supported by melting of snow, active layer and glaciers.

Overall, the Keller Catchment is characterised by high sediment connectivity and high sediment supply, which clearly affect channel morphology and bed material characteristics. As for channel morphology, both channel width and braiding intensity show an increasing downstream trend, although its channel width is quite irregular. As for bed material, sediment sources have notable control of clast roundness with little effects on petrological characteristics.

This work presents the first fluvial geomorphological dataset from this region. The catchment area, which is devoid of human activity, is a good reference for studying braided river systems under natural conditions. Our study gives insights for understanding of channel morphology, bed material characteristics and factors controlling their variability at a local scale – or typical for proglacial rivers in polar regions. On the other hand, such insights about fluvial processes coupled to sediment connectivity can be used in another catchments in different climatic conditions.

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