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Edited by Achim A. Beylich, John C. Dixon and Zbigniew Zwoliński
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PART I

Solute and sedimentary fluxes and budgets in changing cold climate environments

1

Introduction to the theme

ACHIM A. BEYLICH

Climate change, human activity, and other environmental disturbances can affect Earth surface systems via alteration of vegetation cover, hydrologic regime, permafrost distribution, and glacier fluctuations. For example, Pleistocene temperature drop had profound climatic and geomorphic influences worldwide, including abrupt glacial advance in vast terrestrial areas that have both sculpted the topography and deposited extensive mantles of glacigenic materials. In consideration of such legacies, formerly glaciated landscapes today can be considered at a unique stage of readjustment (recovery) with respect to spatial organization of currently active geomorphic process domains (Brardinoni and Hassan, 2006) and the magnitude and patterns of sediment fluxes (Church and Slaymaker, 1989; Hewitt et al., 2002; Warburton, 2007). Accordingly, both contemporary environmental changes and disturbances over the Quaternary are significantly influencing patterns of weathering, detachment, transport, and deposition of material across landscape components. It is a challenge to develop a better understanding of how such changes and disturbances interact to modulate sedimentary source-to-sink fluxes and budgets in the light of peculiar landscape sensitivities (Beylich et al., 2006; Slaymaker et al., 2009; Milliman and Farnsworth, 2011).

Key components for understanding sediment dynamics and for constructing sediment budgets include the identification and definition of the linkages and the quantification (as volumes/total masses and rates) of (1) sediment sources, (2) storage sites, and (3) transport processes (e.g., Swanson et al., 1982; Reid and Dunne, 1996; Beylich, 2011).

Current knowledge on the sediment cascade within Holocene to contemporary climates forms the basis for predicting the consequences of future environmental change and disturbances. However, much of this information is still limited in terms of spatial and temporal coverage and needs to be extended and consolidated. Only after coordinated research efforts and integration of regional datasets it is advisable to apply and test, with an acceptable degree of reliability, models of landscape response to environmental change and disturbance (e.g., Beylich, 2007; Beylich et al., 2012). Within such efforts, the integration of multiple techniques of data collection and analysis (e.g., field-based measurements, remotely sensed mapping, GIS-based analyses, and modeling) across temporal scales (e.g., through real-time monitoring, dendrochronology, or cosmogenic nuclides) allows to obtain increasingly reliable and insightful results (e.g., Hinderer, 2012).

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The I.A.G./A.I.G. SEDIBUD (Sediment Budgets in Cold Environments) program

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Amplified climate change and ecological sensitivity of polar and cold climate environments has been highlighted as a key global environmental issue (ACIA, 2004). Projected climate change in largely undisturbed high-latitude and high-altitude cold regions is expected to alter melt season duration and intensity, along with the number of extreme rainfall events, total annual precipitation, and the balance between snowfall and rainfall. Similarly, changes to the thermal balance are expected to reduce the extent of permafrost and seasonal ground frost and increase active layer depths. These effects will undoubtedly change surface environments in cold regions and alter the contemporary fluxes of sediments, nutrients, and solutes, but the absence of quantitative data and coordinated geomorphic process monitoring, analysis, and modeling to understand the sensitivity of the Earth surface environment is acute in cold climate environments. Contemporary cold climate environments generally provide the opportunity to identify solute and sedimentary systems where anthropogenic impacts are still less important than the effects of climate change. Accordingly, it is still possible in such largely undisturbed environments to develop a library of baseline fluvial yields and sedimentary budgets before the natural environment is completely transformed (Slaymaker, 2008).

The *SEDIBUD (Sediment Budgets in Cold Environments)* Program of the International Association of Geomorphologists (I.A.G./A.I.G.) was formed in 2005 to address this key knowledge gap (Beylich, 2007; Beylich et al., 2007).

The central research question of this global group of scientists is to

Assess and model the contemporary sedimentary fluxes in cold climates, with emphasis on both particulate and dissolved components.

Initially formed as European Science Foundation (ESF) Network SEDIFLUX (2004–; Beylich et al., 2005; 2006), SEDIBUD has further expanded to a global group of researchers with field research sites located in polar and alpine regions in the Northern and Southern Hemispheres (Beylich et al., 2008; 2009; 2012; 2014). Research being carried out at each site varies by program, logistics, and available resources, but typically represents interdisciplinary collaborations of geomorphologists, hydrologists, ecologists, permafrost scientists, and glaciologists. SEDIBUD has developed a key set of primary surface process monitoring and research data requirements to incorporate results from these diverse projects and allow coordinated quantitative analysis across the program. *SEDIBUD key test sites* provide data on annual climate conditions, total discharge and particulate and dissolved fluxes, as well as information on other relevant surface processes. A number of selected key test sites is providing high-resolution data on climate conditions, runoff, and sedimentary fluxes, which in addition to the annual data contribute to the *SEDIBUD metadata database*. To support these coordinated efforts, the *SEDIFLUX Manual* (Beylich and Warburton, 2007) has been produced to establish common methods and data standards (Beylich, 2007; Beylich et al., 2007). In addition to that, a framework paper for characterizing fluvial sediment fluxes from source to sink in cold environments has been published by the group (Orwin et al., 2010). Comparable datasets from different SEDIBUD key test sites are

Table 2.1 *The 56 key test sites as defined by SEDIBUD*

Country		**SEDIBUD Key Test Site**
Antarctica	1	Garwood Glacier, Garwood Valley
	2	Joyce Glacier, Garwood Valley
	3	McMurdo Dry Valleys
Argentina	4	Laguna Potrok Aike
Austria	5	Gradenbach Valley
	6	Johnsbach Valley
	7	Obersulzbachkees
	8	Pasterze
	9	Schöttelbach Valley
Bulgaria	10	Begovitsa
	11	Musala area
	12	Upper Banderitsa
Canada	13	Cape Bounty
	14	Castle Creek Glacier
	15	Lillooet River
	16	Mt. St. Pierre Valley
	17	Robson River
Finland	18	Kidisjoki
	19	Tana River
Germany	20	Reintal
Greenland	21	Kangerlussuaq-Strømfjord
(Denmark)	22	Mittivakkat Glacier Catchment
	23	Zackenberg
Iceland	24	Austdalur
	25	Botn í Dýrafirði
	26	Fnjóskadalur-Bleiksmýrardalur
	27	Hofsjökull, northern forefield
	28	Hrafndalur
	29	Reykjarströnd
	30	Tindastöll
	31	Örravatnrústir
India	32	East Dabka Watershed (Kumaon Himalaya)
Italy	33	Reno Catchment (Northern Apennines)
New Zealand	34	Mt. Cook area
	35	Godley Valley
	36	Unnamed Valley
Norway	37	Bødalen
	38	Erdalen
	39	Homla Valley
	40	Upper Driva Valley
	41	Vinstradalen
	42	Dynamisbekken (Svalbard)
	43	Ebbaelva (Svalbard)
	44	Hørbyeelva (Svalbard)
	45	Kaffiøyra (Svalbard)
	46	Petuniabukta (Svalbard)
	47	Scottelva (Svalbard)
Russia	48	Igarka area
	49	Mezen
	50	Yenisei River
Sweden	51	Latnjavagge
	52	Låktavagge
	53	Kärkevagge
	54	Kårsavagge
Switzerland	55	Illgraben
United Kingdom	56	Moor House

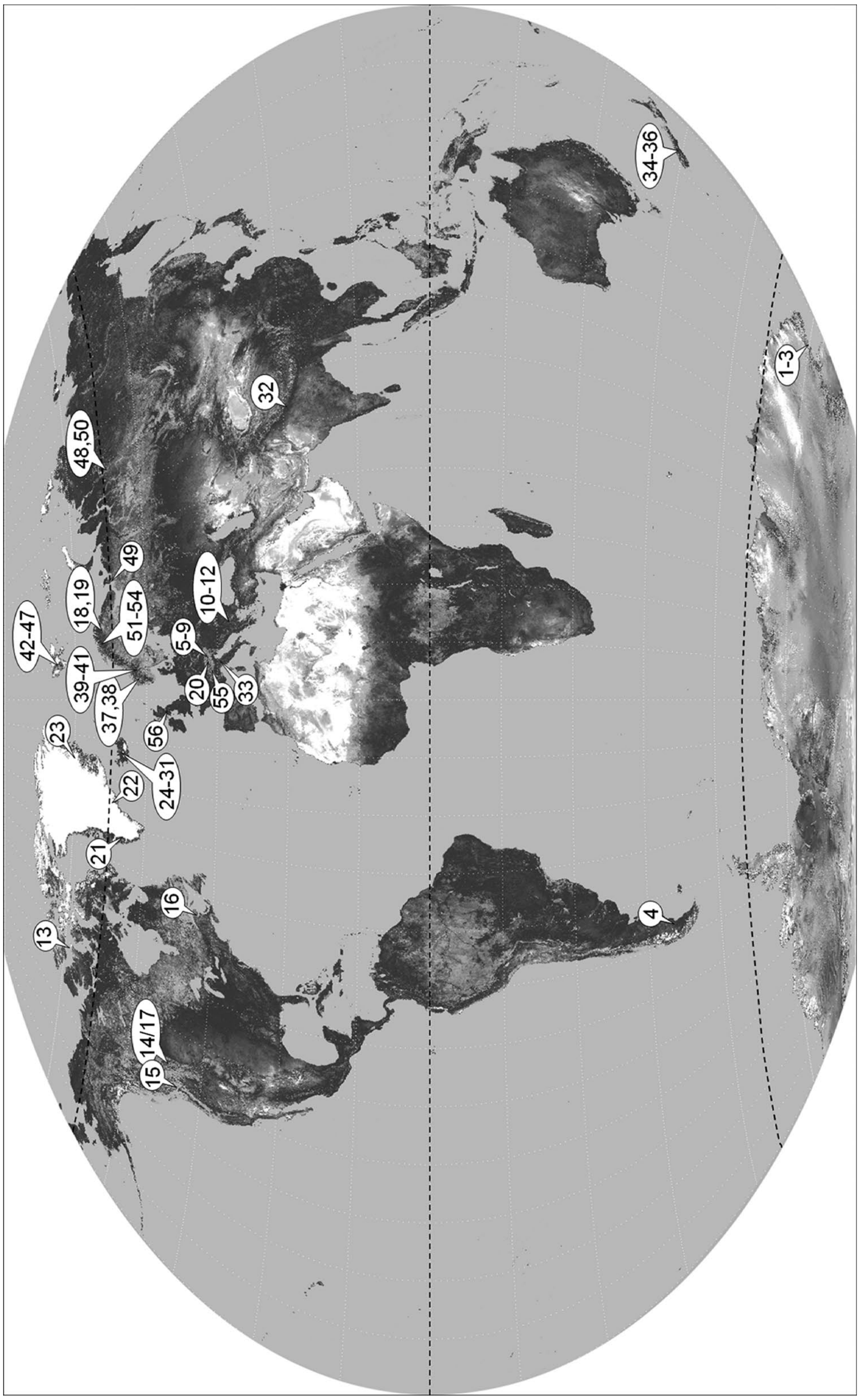

Figure 2.1 World map showing the locations of the 56 defined SEDIBUD key test sites.

(A)

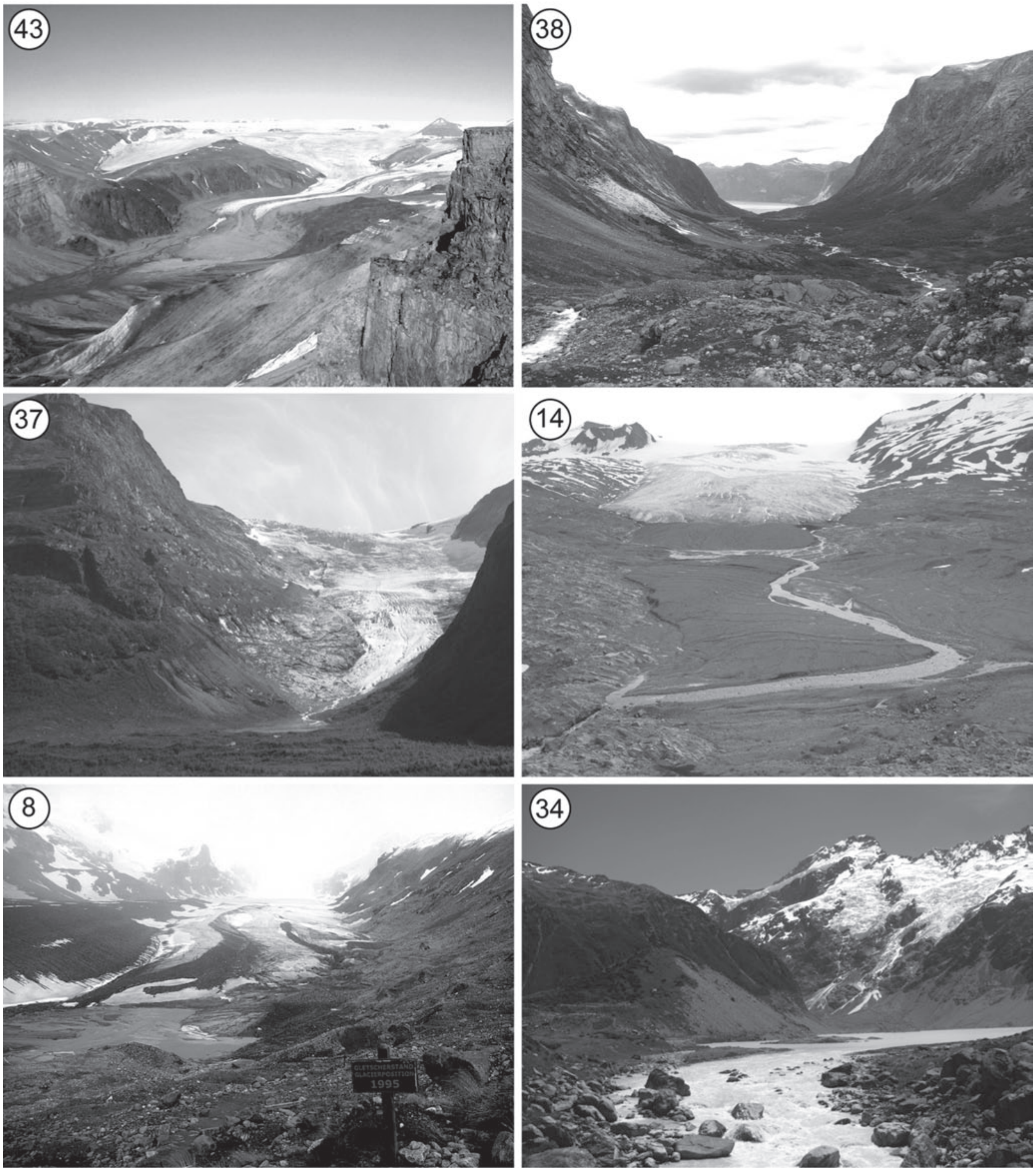

Figure 2.2 Views of selected SEDIBUD key test sites (catchment systems), reflecting the complex diversity and high spatial variability of catchment characteristics found across high-latitude and high-altitude cold climate environments worldwide. A: Glacierized or partly glacierized catchment geosystems, B: Nonglacierized catchment geosystems. The numbers refer to the SEDIBUD key test site numbers given in Figure 2.1 and Table 2.1. The photos were taken by Achim A. Beylich (18, 51, 49, 28, 24), Katja Laute (38, 37, 8, 34), David Morche (20), Grzegorz Rachlewicz (43), and Tim A. Stott (14).

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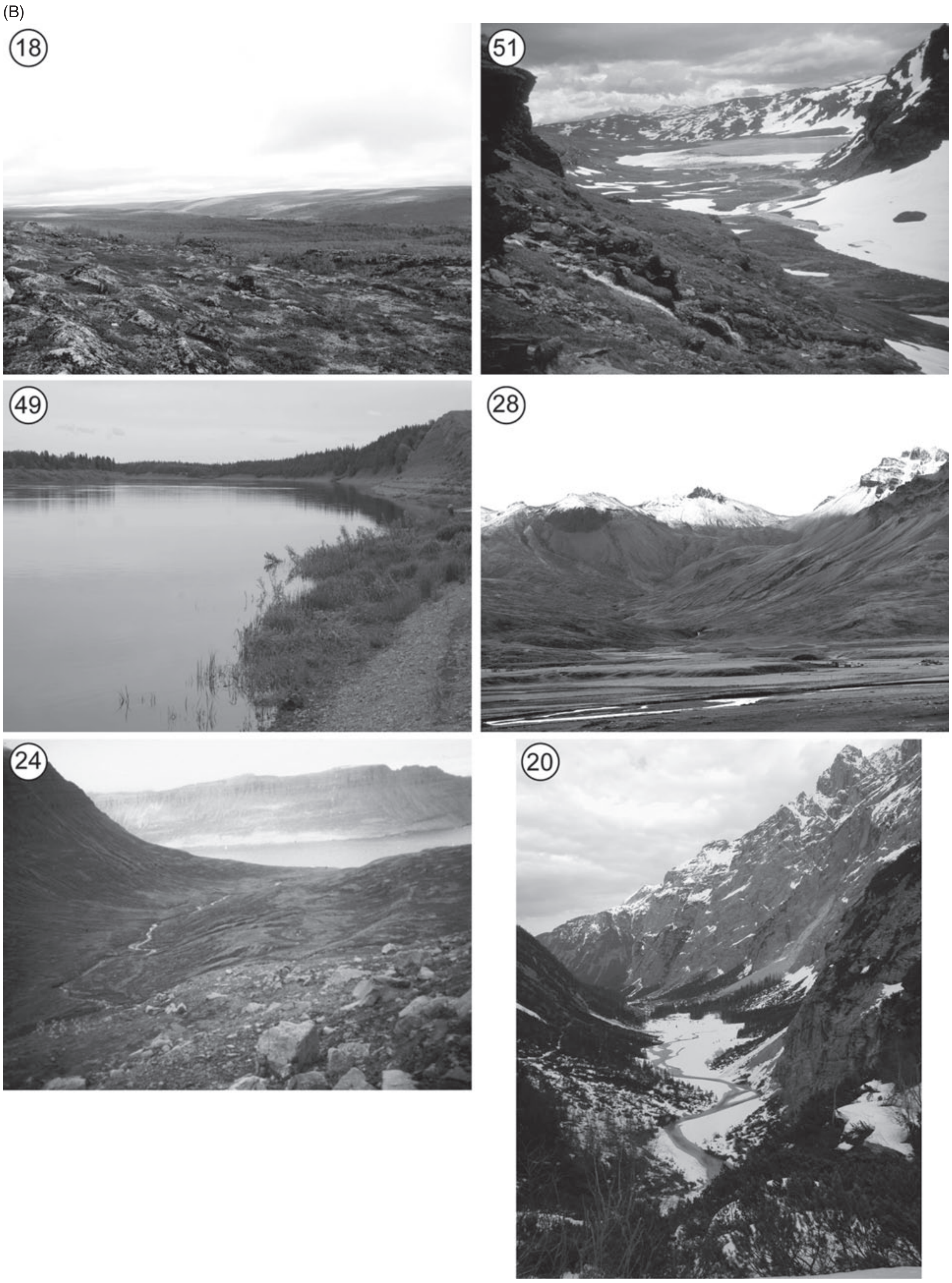

Figure 2.2 (*Continued*)

analyzed to address key research questions of the SEDIBUD program as defined in the *SEDIBUD working group objective* (available online at the SEDIBUD website at www.geomorph.org/wg/wgsb.html; www.geomorph.org/sedibud-working-group/).

SEDIBUD has currently identified 56 SEDIBUD key test sites worldwide, reflecting the complex diversity and high spatial variability of catchment characteristics found across high-latitude and high-altitude cold climate environments worldwide (Figs. 2.1 and 2.2 and Table 2.1). The *SEDIBUD Key Test Site Database* (Laute et al., 2016) and the *SEDIBUD Fact Sheets Volume* (Lamoureux et al., 2008) provide significant information on selected SEDIBUD key test sites.

Defined ongoing *SEDIBUD key tasks* include (Beylich et al., 2012; 2014):

- The ongoing and continued generation and compilation of comparable longer-term datasets on contemporary solute and sedimentary fluxes and solute and sediment yields from SEDIBUD key test sites worldwide.
- The further extension of the SEDIBUD metadata database with these datasets
- The testing of defined *SEDIBUD hypotheses* (available online at the SEDIBUD website) by using the datasets continuously compiled in the SEDIBUD metadata database

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