Waldemar Kociuba
Grzegorz Janicki

5.4. Fluvial processes

Fluvial systems

The development of bottom sections of river valleys and plains of the NW section of Wedel Jarlsberg Land is associated with the deglaciation of the area during the Holocene (e.g. Szczęsny *et al.* 1989; Pękala & Repelewska-Pękalowa 1988ab, 1990; Harasimiuk & Król 1993; Warowna 1994; Reder 1996; Zagórski 2002, 2005, 2007a; Zagórski *et al.* 2008a). The largest and the most developed fluvial systems are found within the vast and relatively poorly glacierised valleys of structural origin: Dunderdalen and Chamberlindalen, encircling the Caledonian Renardbreen Block from the SE and E (Dallmann *et al.* 1990; Birkenmajer 2004). The catchment areas of the two valleys are supplied from mixed sources including snow, rain, permafrost and glaciers, with a clear dominance of snowmelt waters or combined rainwater and snowmelt waters. Accumulation of the snow cover during the winter period, and its ablation in spring, as well as summer weather conditions, should thus be recognised as major factors affecting fluvial processes (Bartoszewski 1988).

The Dunderelva (Dunder River) valley, situated on the flank of a monocline and stretching SE-NW for nearly 20 km, collects water from a relatively compact catchment area with a shape resembling a rectangle. The average width of the valley is 7.3 km (the maximum is 8.3 km), while the total area amounts to 142 km^2 (Fig. 5.4.1, Photo 5.4.1). The maximum difference in altitude within the catchment is 775 m, while the average inclination is 40%. The morphology of the valley comprises two main sections differing in genetic aspects and age. The upper section (60% of the catchment area) is a glacially remodelled mountain valley, while the lower section (40% of the catchment area) occupies a vast and glacio-isostatically uplifted abrasion platform – a former bay (Harasimiuk & Król 1993; Zagórski 2002). The upper section is distinctive for numerous talus cones formed by glacial streams descending towards the basin-like valley bottom and modelled by a complex system of distributary channels. There are also two outwash plain systems of different age: older, with permanently dry beds or drying out periodically, and younger, often embedded into the older ones. The zone also features an alluvial plain modelled by a multi-channel river system with multiple currents and the bottom gradient of 0.035-0.045 ‰. The riverbed at this section does not exceed 100 m in width and is confined to the channel zone. Downstream, after the margins of outwash plain fans, along a distance of ca. 0.5 km, the river develops the characteristic braided form with the alluvial plain width exceeding 500 m. The average depth of river channels does not exceed 0.3 m. The alluvial plain consists mainly of coarse-grained gravels (>5 cm in diameter) covered with a layer of sandy clays and clays up to several centimetres thick. The areas between the river channels, covered by tundra vegetation, are situated ca. 0.6 m above the channel bottom and only receive flow during floods (Harasimiuk & Król 1993).

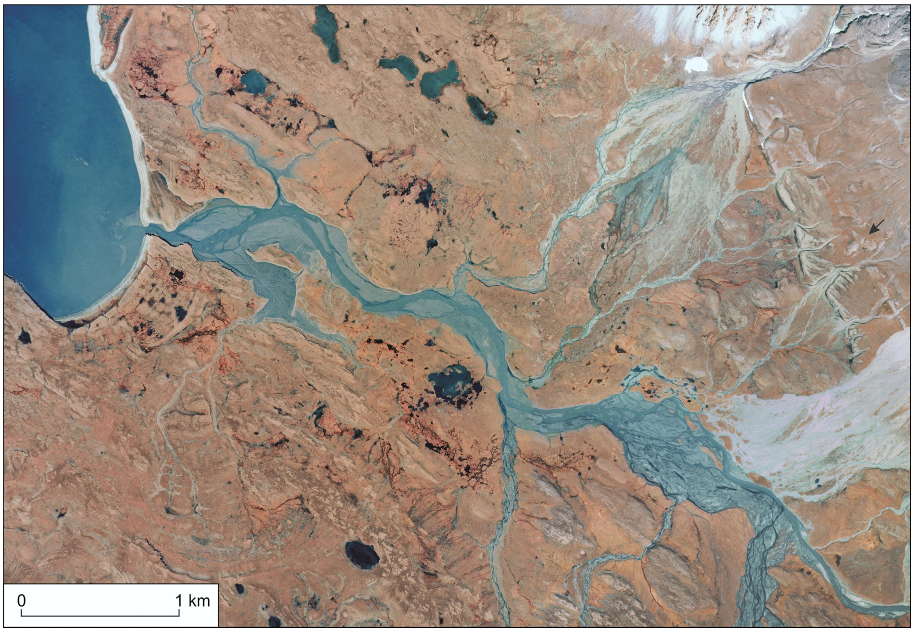

Fig. 5.4.1. Lower course of Dunderelva – fragment of orthophotomap (Zagórski 2005).

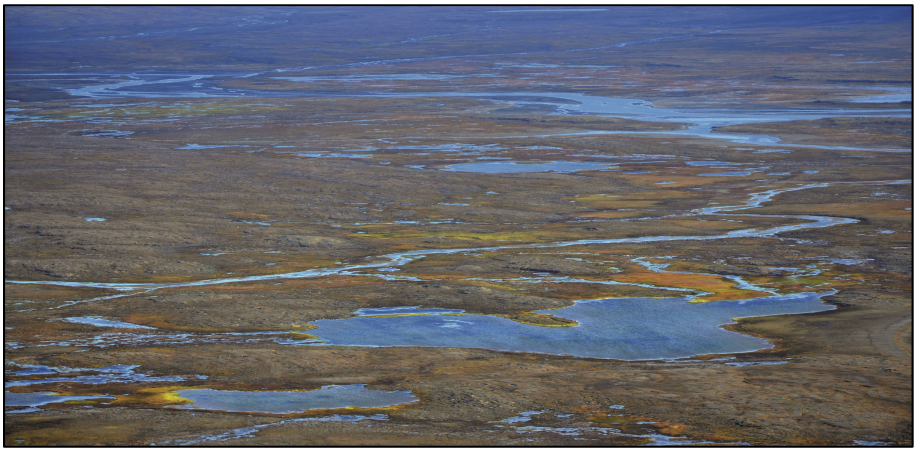

Photo 5.4.1. Fluvial relief of Dunderdalen (Photo P. Zagórski 2011).

A change in the channel development pattern occurs 2 km downstream, in the zone marked by a narrowing of the alluvial plain whose width ranges between 80 and 150 m, while the bottom gradient is ca. 0.02%. The channel development pattern alters from the multi-channel braided type into multiple anastomosing channels or anastomoses with numerous islands and inter-channel areas (Photo 5.4.1). The depth of the river channels increases to 1 m. The Dunderelva has a similar depth along its 4 km-long gorge section. The alluvial plain there is very narrow, between 30 and 50 m in width, and occupies about a half of the valley bottom area. The gently meandering single-channel river has a gravelly bottom with gravel bars, 5-8 m wide and 30 m long. Smaller (3 x 15 m) sandy inter-channel bars are much less common. The downstream part of that river section is bounded by initial banks (Harasimiuk & Król 1993).

Below the gorge, the river enters its lower course taking the form of an extensive coastal plain. Initially, the alluvial plain built of fine gravel covered with a layer of muds and loams, a dozen or so centimetres thick, is intersected by the multi-channel river of the anastomosing type. The alluvial plain, exceeding 500 m in width, consists of a floodplain terrace and a floodplain lying 0.5 m below. The floodplain consists primarily of gravels transported by the tributaries, overlain by a layer of loams, several centimetres thick and increasing in thickness to 40-50 cm on the floodplain terrace. The surface of the terrace is covered with tundra vegetation and scattered with multiple water-filled basins of thermokarstic origin. During medium and low river levels the river exhibits the multi-channel braided pattern with multiple inter-channel point bars. During flooding's events, however, the river has transitional channels of the mixed anastomosing braided type. Below, at the next narrowing of the valley (150 m in width), along a 200 m section, the river takes a single-channel straight-line course with several small inter-channel point bars. The bottom of the valley is distinctive for its floodplain terrace (3.5-4.0 m a.s.l.) formed out of sandy and clay deposits of marine origin. The mouth section of the Dunderelva is an estuary shaped by tidal eddies (Harasimiuk & Król 1993; Bartoszewski 1998).

The poorly glacierised Chamberlindalen is very similar in terms of genesis and formation to the Dunderdalen. Chamberlindalen, over 10 km long, has a longitudinal profile. The maximum width of the bottom is 2 km. The upper section is a subsequent postglacial valley, while the lower section represents an uplifted abrasion platform lying within an old bay of the sea (Pękala & Repelewska-Pękalowa 1988b, 1990). The Chamberlinelva catchment is 52 km^2 in area, with an average slope of 38 ‰ (Bartoszewski 1998). The bottom of the valley is marshy and poorly accessible in the upper and middle parts. The alluvial plain, which does not encompass the entire bottom of the valley, is modelled by the multi-channel river system (Photo 5.4.2). Where the valley is wider and receives a considerable amount of sediments (outwash plain fans), the river channel has a braided or anastomosing pattern. The river bottom features zones of varying size and inter-channel islands. The bottom of the valley has elongated bars which become uncovered during low-water periods. During high discharge events, the inter-channel zones are exposed. In the mouth section the river forms a delta, while sediments accumulated in the area form a vast tidal flat (Zagórski *et al.* 2006, 2012).

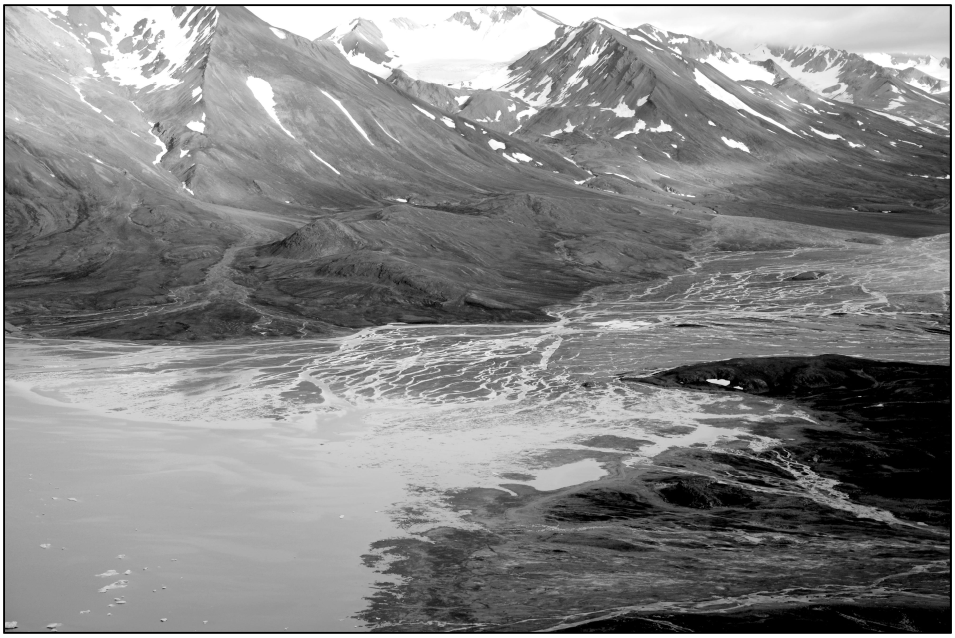

Photo 5.4.2. Fluvial relief of Chamberlindalen – lower part (Photo P. Zagórski 2011).

The NW part of Wedel Jarlsberg Land also contains a number of much smaller, partially glacierised valleys drained by the proglacial rivers: Logna, Dyrstadelva, Blomlielva, Tjørnelva and Scottelva (Table 5.4.1). The rivers have predominantly glacial alimentation regimes (Bartoszewski 1998), however the valleys are developed similarly to the large non-glacierised valleys, i.e. include two major genetically diverse sections. The upper section is confined to the glacially transformed mountain valley with a system of distributary channels weaving around outwash plain fans. The lower section is an alluvial valley incised in raised marine terraces. The river channel occupies a relatively narrow stretch within the bottom of the valley and is limited to the riverbed zone. The dominant river pattern is that of a multi-channel river system. Depending on the local conditions, the rivers represent the braided or anastomosing type. Single-channel rivers, either straight of meandering, can be found in the gorge sections (Pękala & Repelewska-Pękalowa 1988a, 1990; Bartoszewski 1998), however, they are a rarely occurring feature in the area. A good example of the fluvial modification of glacierised valley system is the Scottelva valley which has been systematically investigated since 1986.

The fluvial relief of this section of Spitsbergen is complemented by small periglacial valleys drained by perennial or ephemeral streams. These low-discharge watercourses have combined water supply system composed of waters from snowmelt, thawing permafrost and rainfall. Their valleys are characterised by a morphology ranging from small shallow valleys to canyons with well-developed gorges. The largest of these is the Tyvjobekken draining the coastal plain and flowing directly into the fjord (Photo 5.4.3). The Tyvjobekken is an example of a periglacial watercourse supplied predominantly by snow and permafrost. It is 1.2 km long, while the catchment has a total area of 1.3 km^2. The average gradient of the valley is 41 ‰. The valley can be divided into three sections, of which the upper one, quite poorly distinguishable, is drained by two periodic streams. After ca. 1 km, they join another stream which drains the former outer outwash plain of the Renardbreen. The middle section is drained on a permanent basis and receives the largest, nameless, tributary (350 m long, with a catchment area of 0.1 km^2) featuring multiple water-filled basins of cryogenic origin. The valley at that point is narrow and deep, with gorge-like features, and stretches for a distance of 0.7 km (Bartoszewski 1998). The riverbed, which fills the entire bottom of the valley, is shaped by a single-channel river system. The bottom of the shallow river channel is covered by accumulation of rocks and small bars formed out of fine gravels. In the lower part of the mouth section the Tyvjobekken occupies an old alluvial fan that was previously drained by Renardbreen rivers. The fan zone is covered by both dry and active channels with rapidly changing bars and islands. The Tyvjobekken carries little water and bedload, what leads to cutting off the river mouth from the fjord by gravel-dominated storm ridge and formation of a micro-lagoon. The alluvial sediments of the stream are reworked by coastal processes.

Photo 5.4.3. View of the lower part of Tyvjobekken (Wydrzyca Stream) (Photo P. Zagórski 2011).

Table 5.4.1. Selected geometric parameters of the catchment in the NW part of Wedel Jarlsberg Land (based on Bartoszewski 1998, expanded).

River	Valley length [km]	Catchment area [km^2]	Average valley gradient [‰]
Dunderelva	19.2	142.0	40.0
Chamberlinelva	10.0	52.0	38.0
Logna	6.6	20.4	15.3
Dyrstadelva	4.1	14.8	61.0
Blomlielva	2.7	7.0	63.2
Tjørnelva	3.2	6.2	75.0
Scottelva	2.6	10.1	35.0
Tyvjobekken	1.2	1.3	41.0

Studies of fluvial processes

Studies of fluvial processes which have been conducted in the NW part of Wedel Jarlsberg Land for the past 25 years can be divided into two different trends. The first trend comprises investigations carried out since 1986 and focused on the qualitative assessment of changes occurring in the mouth sections of rivers and streams intersecting the Calypsostranda area. The most important studies in this trend of research included investigations of the dynamics of changes in fluvial processes and forms at the forefields of the Renardbreen (Łanczont 1988ab) and the Scottbreen (Reder 1996), and their discharge zones including alluvial fans (Harasimiuk & Król 1992; Warowna 1994; Superson & Zagórski 2007). The outcome of the studies is a detailed description of changes in the currents of braided-type rivers and the spatial extent of backwaters of the Scottelva and the Tyvjobekken in 1960, 1990, 1991 and 2006 (Superson & Zagórski 2007). In addition, a reconstruction was performed for the arrangement of the main channels of rivers flowing within the alluvial fan zone of Calypsostranda, identifying a variety of coexisting channel patterns: straight, meandering and braided. Superson & Zagórski (2007) claimed that the river channel development pattern depends on the supply of clastic material into the channel and local differences in bottom gradient. Over a long timescale, changes in the dynamics of fluvial processes resulted in the shift of river channels in the mouth sections, and alter the spatial arrangement of the main currents of braided rivers crossing the outwash fans. In the short timescale, changes in the arrangement of distributary channels can be observed in the river mouths. Other changes occurring in the mouth zone include changes in the size of small basins dammed by storm ridges, and changes in the location of river crevasses and the temporal pattern of their occurrence (Harasimiuk & Król 1992, 1993; Superson & Zagórski 2007).

A system approach to the assessment of directions and intensity of transport of material from the slope subsystem to the channel subsystem has been presented by Kociuba *et al.* (in press). Detailed topographic measurements were performed using a laser total station in selected representative study sites within the slope subsystem and in cross-profiles within the channel subsystem. The measurements led to the determination of the role of slope material in debirs supply to the proglacial river system. The inventory of both permanent and ephemeral macro-, meso- and micro-forms existing within the valley and the river channel was also carried out based on detailed geomorphological mapping. In addition, the basic parameters of bottom geometry along selected study profiles were determined. Study focused also on themeasurements of the cubature of erosion landforms (incisions, rills, gullies) and mapping of depositional landforms (mainly micro-fans) (Kociuba *et al.*, in press).

The second trend of research focuses on the quantitative parameters related to the functioning of the fluvial system of glacial and subglacial rivers in the changing climatic and hydrologic conditions. Quantitative fluvial investigations conducted to date in the NW part of Wedel Jarlsberg Land concentrated on the determination of the sources of river water supplies and the measurements of rates of suspended sediment and solute transport (Bartoszewski 1994; 1998; Bartoszewski & Repelewska-Pękalowa 1988ab; Bartoszewski & Rodzik 1988; Bartoszewski & Magierski 1989a; Michalczyk & Magierski 1990; Krawczyk & Bartoszewski 2008; Bartoszewski *et al.* 2003, 2004, 2007, 2009; Chmiel *et al.* 2007; Zagórski *et al.* 2008a; Chmiel *et al.* 2011, 2012). In 2009, the programme was expanded by a quantitative assessment of the transport of bedload material in the proglacial Scottelva (Fig. 5.4.2) performed within the framework of the research project initiated by Maria Curie-Skłodowska University Vice-Rector for Research and International Cooperation: *'The functioning of the riverbed and slope systems in the subpolar zone under global climate change conditions'* (Kociuba *et al.* 2010).

Studies into bedload transport were continued during the subsequent two summer seasons (2010 and 2011) thanks to the research grant received from the Ministry of Science and Higher Education (N N306 525738): *'The dynamics of matter circulation in polar catchment under deglaciation processes (Scottelva, Spitsbergen)'* during the 22nd and 23rd UMCS Spitsbergen Expedition. The range of measurements was extended in 2010 by a measurement profile located below an alluvial fan and in 2011 by an additional measurement profile situated in the mouth of the Rensdyrbekken (Reindeer Stream), the main right-bank tributary of the Scottelva (Fig. 5.4.2). In 2012, during the 24th UMCS Spitsbergen Expedition, the investigations included also a measurement profile located in the Tyvjobekken catchment. The studies were continued under the research programme approved by Poland's National Science Centre: *'Mechanisms of fluvial transport and delivery of sediment to the Arctic river channels with different hydrologic regime (SW Spitsbergen)'* (2011/01/B/ST10/06996). During all study seasons, the measurements of the intensity and dynamics of bedload transport were performed using special traps for bedload material: *River Bedload Traps* (RBTs). The traps and the measurement strategy were designed specifically for the project and first applied during the 2009 summer season (Kociuba *et al.* 2010, 2012). Bedload transport measurements were conducted on a continuous 24 hour basis. Each of the measurement sites was provided with a set of four RBTs distributed at even distances within the cross-profile of the river channel (Photo 5.4.4).

The 1-2 m distance between consecutive measurement sites allowed the determination of differences in bedload transport characteristics along the entire width of the channel and in individual hydrodynamic zones. The captured material was weighed (separately for each of measurement sites) and documented (Photo 5.4.4).

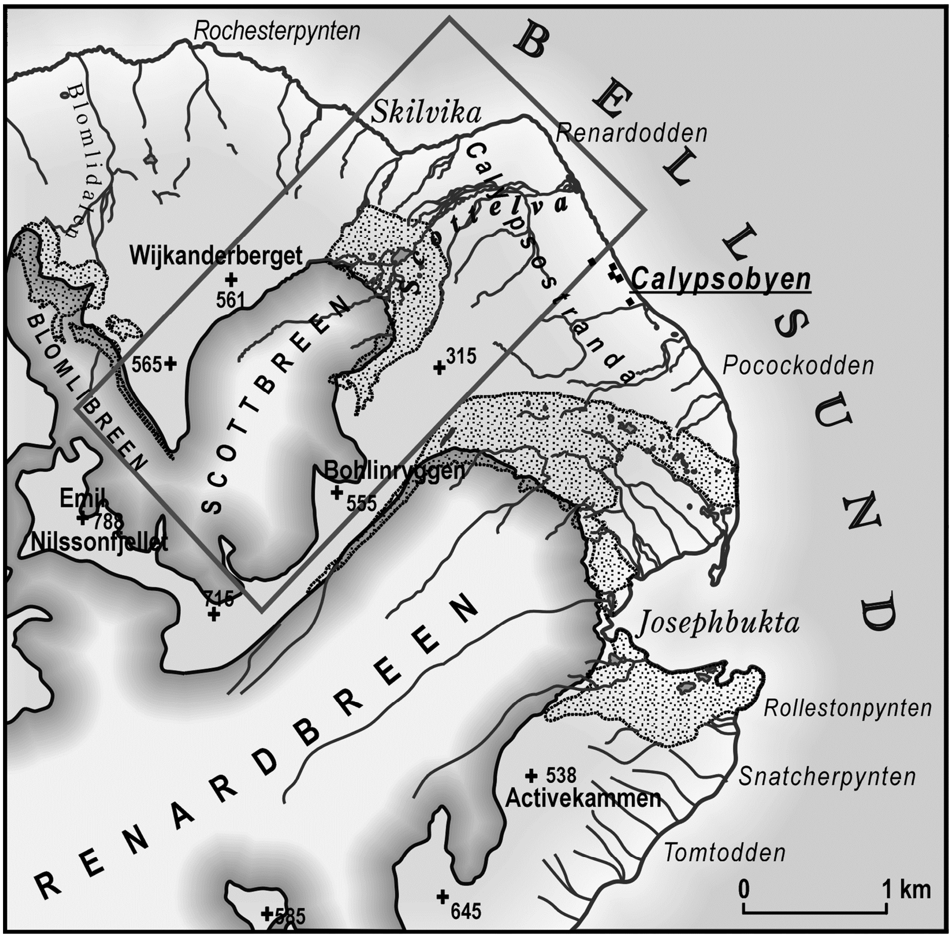

Fig. 5.4.2. Location of the Scottelva catchment.

Photo 5.4.4. A- the set of River Bedload Traps (RBT) in the cross profile of the Scottelva, B- mass of bedload material caught during twenty-four hours at one of measurement sites in the cross profile of the Scottelva (Photo W. Kociuba 2011).

Bedload transport during in the Scottelva during ablation seasons 2009-2010

During the 2009 summer season, bedload transport measurements were performed between 10th July and 6th September, i.e. from the time when the channel profile became completely exposed from under snow and ice cornices lining the banks until the first signs of river bottom freeze. A total of 227 samples were collected during 59 measurement days. The results indicate high variability of bedload transport dynamics under conditions of relatively stable flows: from 1.3 to 2.4 $m^3 \cdot s^{-1}$ (average: 2.0 $m^3 \cdot s^{-1}$), both in the 24-hr cycle and throughout the entire measurement period (Kociuba *et al.*, in press).

Bedload quantities identified in individual measurement sites ranged between 0 and 66 kg during the 24-hr cycle. The average bedload quantity transported during the 24-hr period at a measurement site was 2.2 kg, and varied between 1.3 kg and 4.7 kg over 24 hrs. Maximum daily quantities ranged between 41.5 and 66 kg, and were recorded during a high discharge event which occurred on 29th July, 2009 (Fig. 5.4.3).

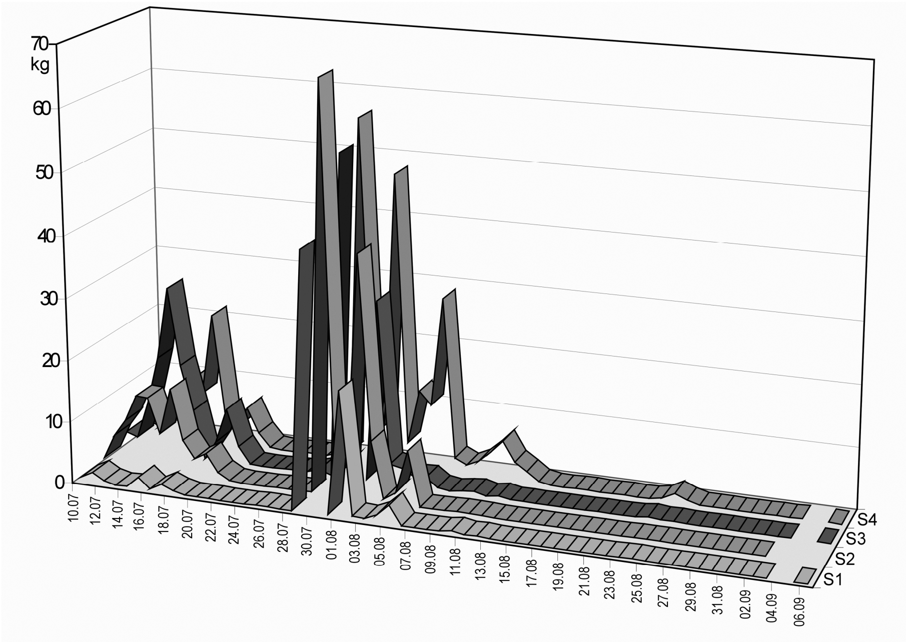

Fig. 5.4.3. 24-hr concentrations of bedload material [kg] at individual measurement sites along the cross-section of the Scottelva during the 2009 summer season (Kociuba *et al.* 2010).

The share of maximum 24-hr values in the total weight of material discharged in individual measurement sites varied from 20% to 50%. The total weight of material discharged during the study period in individual measurement sites was between 77 and 275 kg. The bedload discharge within the controlled cross-section can thus be estimated at ca. 100 kg per 24 hrs. (Fig. 5.4.4), while the total quantity transported throughout the measurement period was approx. 6 t.

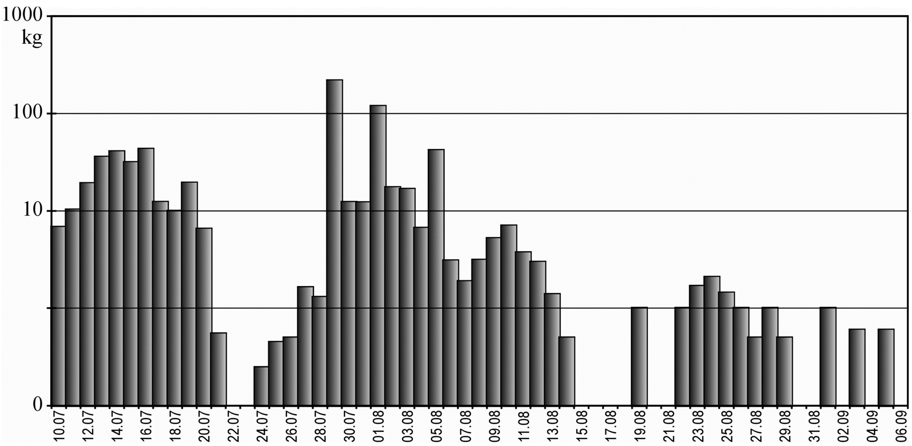

Fig. 5.4.4. Total 24-hr concentrations of dragged material [kg] in the Scottelva during the 2009 summer season (Kociuba *et al.* 2010).

The studies led also to the determination of links existing between the two identified sub-systems (slope and river channel) and to the estimation of the overall balance of bedload transport. In addition the erosion/deposition balance in the slope sub-system was determined, and the total balance of material drained from the river catchment area was calculated (Kociuba *et al.*, in press).

In the summer season of 2010, over a course of 45 measurement days (from 27th June until 10th August), a total of 300 samples were collected in two measurement sites (Photo 5.4.5AB). Due to the thick snow patch filling the gorge incised in raised marine terrace the measurements in were limited to 29 days and resulted in the collection of 116 samples. The material trapped in RBT was weighed (separately for each measurement site) and sieved using the collection of hand sieves (8 mm, 16 mm, 32 mm).

Detailed measurements conducted in the mouth of the Scottelva revealed high variation in bedload transport both over a 24-hr cycle and throughout the whole measurement period, under conditions of relatively low discharges not exceeding 50% of bankfull discharges (Kociuba *et al.* 2012). The total weight of material discharged from the Scottelva catchment was 4.7 t over 45 measurement days in 2010. The average quantity transported across the cross-section of the river channel was 102 kg during 24 hrs. (Kociuba *et al.* 2012).

The authors identified two periods with diverse patterns of 24-hr bedload transport variability. The first half of the measurement period (from 27th June until 15th July) was characterised by much higher bedload transport rates over a 24-hr period. High variability was also identified between individual measurement sites, contradicting the high dynamics of discharges in the Scottelva. The latter half of the period (from 16th July until 11th August) was distinctive for predominantly small 24-hr bedload quantities which, under conditions of stabilised discharges, results in the reinforcement of relations existing between these elements (Fig. 5.4.5).

The findings also indicated considerable variability in bedload transport in different measurement sites across the river channel: The average bedload quantity transported over a 24-hr period in a measurement site was 2.9 kg, and varied between 0.3 kg and 8.5 kg over the 24-hr cycle. Maximum 24-hr rates obtained for a profile varied between 4.8 kg and 45.6 kg, and were recorded during an ablation high discharge event which occurred on 12th July, 2010. The contribution of maximum values in the total weight of material discharged in individual measurement sites ranged between 12% and 46% (Kociuba *et al.* 2012).

An examination of the structure of bedload transport revealed a dominance of the medium-grained fraction (37%), and similar shares of fine-grained (31%) and coarse-grained (32%) fractions. The share of the coarse-grained fraction (32-64 mm) was only 7% throughout the entire measurement period (Fig. 5.4.6AB). An analysis of grain size distribution demonstrated moderate sorting and poor energy diversification of the river's current environment under similar hydrodynamic conditions. The average grain size identified during the measurement period was 10 mm, with standard deviation amounting to 0.5 mm. The grain distribution was close to normal with a slight dominance of the coarse-grained fraction. A slight left-sided asymmetry (-0.075) is indicative of higher than average flow rates and selective washing of the river bottom material with a tendency for re-deposition. The kurtosis coefficient (0.86) indicated pulsatile changes in the energy status of the sedimentation environment (Kociuba *et al.* 2012).

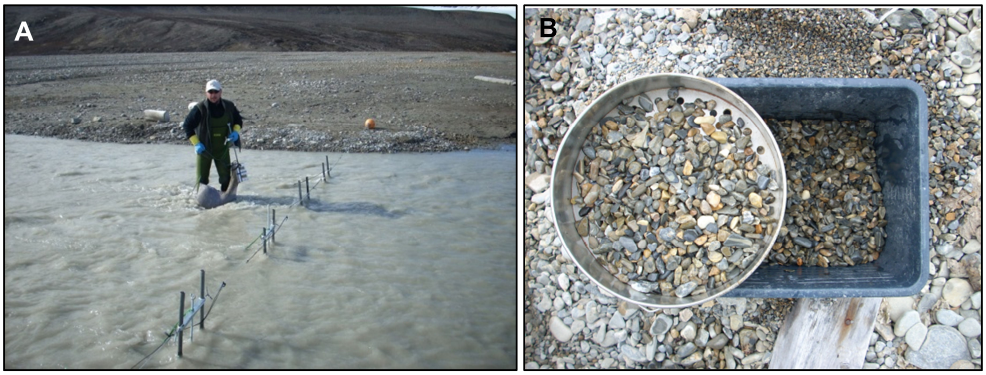

Photo 5.4.5. A- the procedure of bedload transport measurements, B- manual sieves (Photo W.Kociuba 2010).

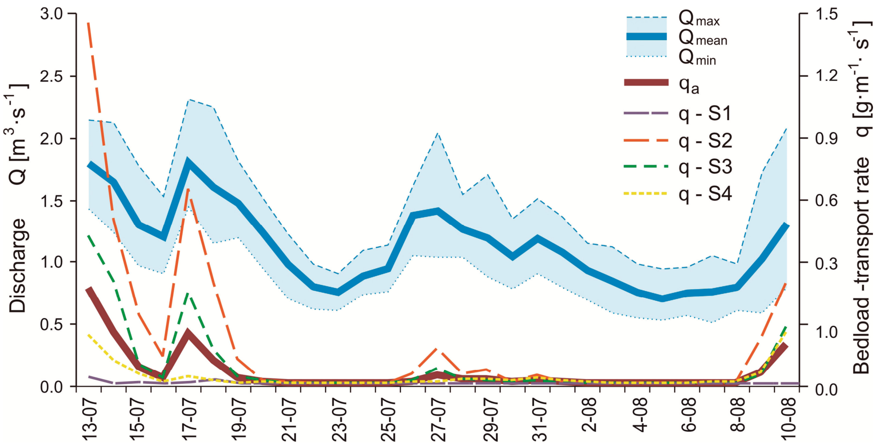

Fig. 5.4.5. Hydrograph of daily discharge in the Scottelva (Q), and bedload transport rate (q) at individual measurement sites (q S1-S4) and the channel-mean value (q_a) (Kociuba *et al.* 2012).

The causes of seasonal variability in the relationship between the intensity of bedload transport and flow rates include diversity and variation in the discharge of material into the river channel. The first period was clearly dominated by medium gravels with a considerable share of the coarse fraction and a large amount of poorly rounded material coming in from the eroded slopes of the gorge section of the river valley.

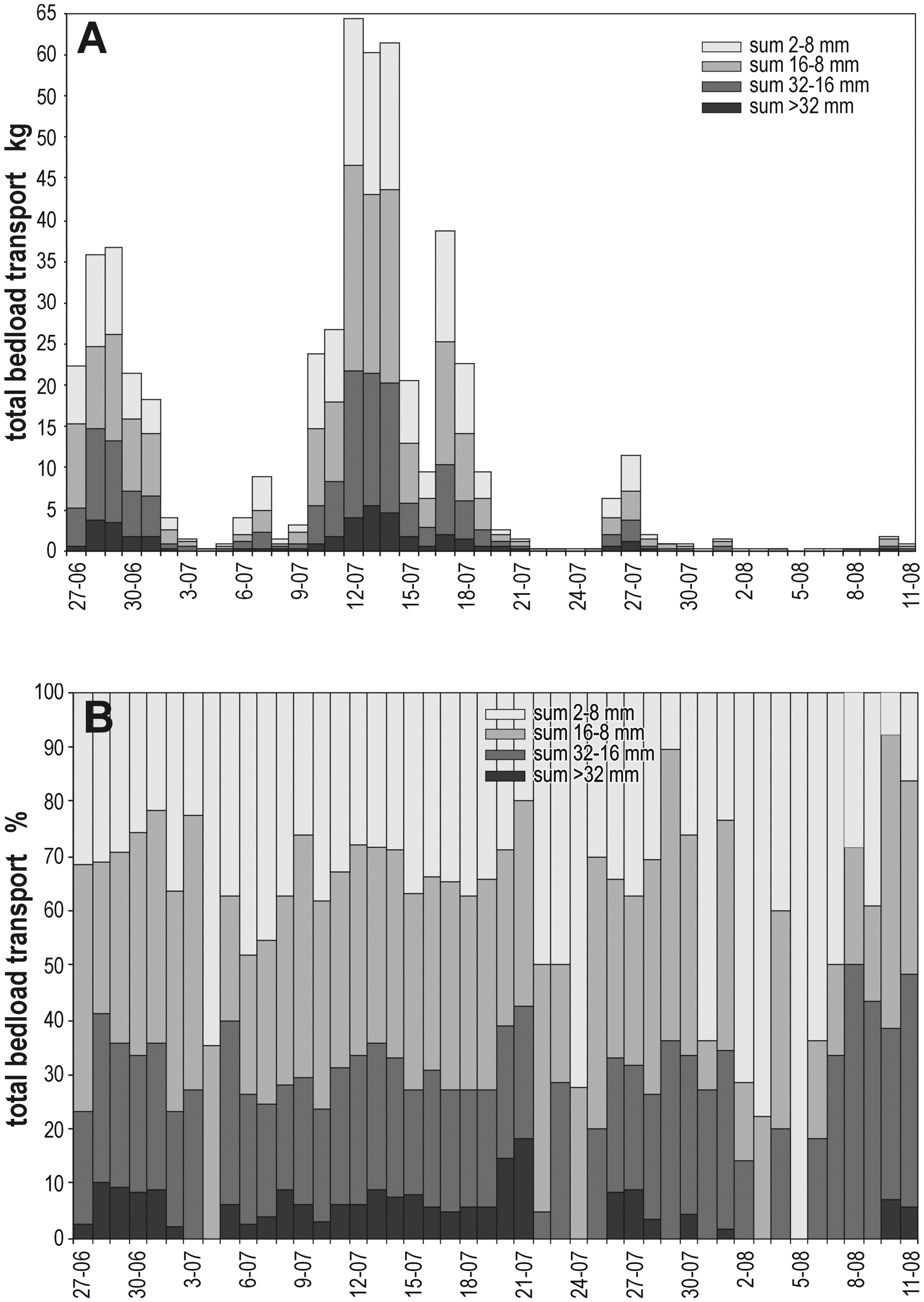

Fig. 5.4.6. 24-hr variability in bedload transport in the Scottelva in the 2010 summer season: A- weight in [kg], B- cumulative share in [%].

During the second period, the slopes of the valley had already stabilised and, consequently, the material supplied to the river originated primarily at the bottom of the valley and in the Scottbreen, which increased the share of the medium- and fine-grained fractions. Reduced flow rates in combination with the long distance covered by transported material were conducive to selective erosion and to the filling of free spaces between the gravel grains. In the short-term perspective, this resulted in the deposition of material, which contributed to an increase in river bottom height and to a levelling of river bottom surface. Selective erosion and deposition also increased the flow rate limit required for initiating bedload movement under conditions of river pavement by rocks. Consequently, there was considerable variation in bedload transport rates in different periods despite similar flow rates. This also explains why the share of fine-grained gravel was much greater in the second measurement period.

River channel morphology and development patterns

The ablation rate of the Scottbreen determines changes in the flow rate and quantity of transported material, which has an effect on the morphology of the river channel and the bottom of the valley (Reder 1996; Bartoszewski 1998; Zagórski *et al.* 2008a; Bartoszewski *et al.* 2007, 2009). The development of the valley is also affected by groups of factors which can be recognised as independent variables (causes) conditioning the pattern of river channel development and its evolution in various timescales (Pękala & Repelewska-Pękalowa 1990; Harasimiuk & Król 1992). Long-term variables are: the geological structure including the lithology of underlying rocks, glaciotectonics or development of the terminoglacial zone (Fig. 5.4.7).

Over the medium timescale (10^3-10^2) a major role seems to be played by global and regional climate variation, changes in the extent of the glacier front, glacier balance and accompanying changes in the alimentation regime including the discharge of material. Over the short timescale ($<10^2$) the rate of fluvial processes is affected predominantly by the weather pattern during the measurement period, and the occurrence of high flow events and flooding (Kostrzewski *et al.* 1989; Kociuba *et al.* 2010, 2012). Geological factors have induced the development of two gorge-type narrowings of the valley and a distinctive division of the valley bottom into three diverse sedimentation zones (Photo 5.4.6).

The gorge through a frontal moraine ridge defines the upper, fan-like outwash plain section of the river valley, up to 700 m wide, dominated by outwash deposits. The bottom gorge, cutting through an raised marine terrace, separates the middle section of the alluvial valley from the mouth part (an alluvial fan). Along this section, the Scottelva creates a vast multi-channel system fed by small tributaries (Fig. 5.4.7).

In the bottom gorge zone, stretching along a distance of several dozen metres, the discharge becomes concentrated to just one channel. Below the gorge, the zone of the alluvial fan with a network of distributary channels begins. A wide gravel-dominated storm ridge blocks the passage of the river directly into Recherchefjorden, creating a raised reservoir and concentrating the discharge in a single channel (Fig. 5.4.8). The Scottelva flows into the fjord through crevasse-splay cuts in the storm ridge, whose locations vary depending on the season (Superson & Zagórski 2007). Below the crevasse-splay cuts in the storm ridge the river builds a subaquatic prodelta.

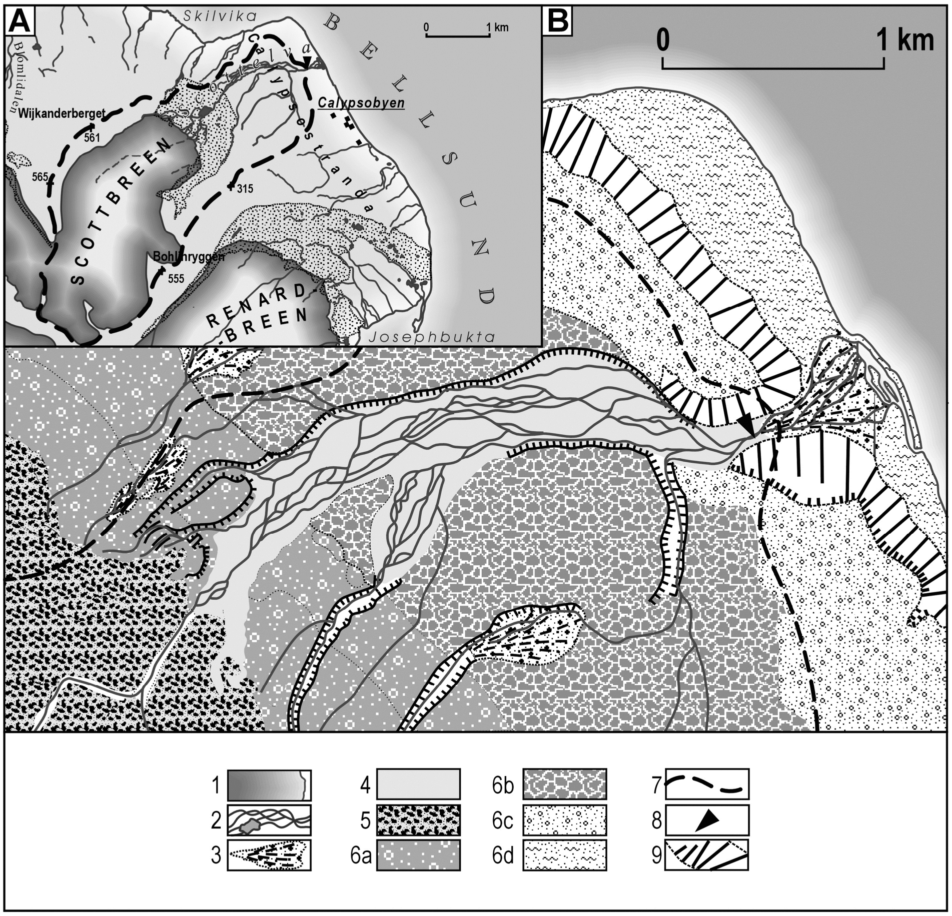

Fig. 5.4.7. A- situation of the Scottelva catchment. B- geological-morphological conditions (after: Szczęsny *et al.* 1987, modified): 1- glaciers, 2- rivers and water bodies, 3- alluvial fans, 4- extramorainal outwash plain, 5- glacial and nival landforms, 6- marine terraces with structural features: 6a- 50-100 m a.s.l., 6b- depressions, 6c- 18-45 m a.s.l., 6d- 0-6 m a.s.l., 7- catchment border, 8- location of river gauge and research cross-profiles, 9- scarps (Kociuba *et al.* in press).

The complex proglacial fluvial sedimentary system of the Scottelva also determines diverse patterns of river channel development, often representing the threshold type. The upper proximal section of the valley is dominated by a system of narrow and shallow distributary channels fed by sub- and supraglacial waters. The channels shape the present-day marginal zone of the glacier and flow into a marginal lake. In the middle (distal) section the channel development pattern changes from the single-channel

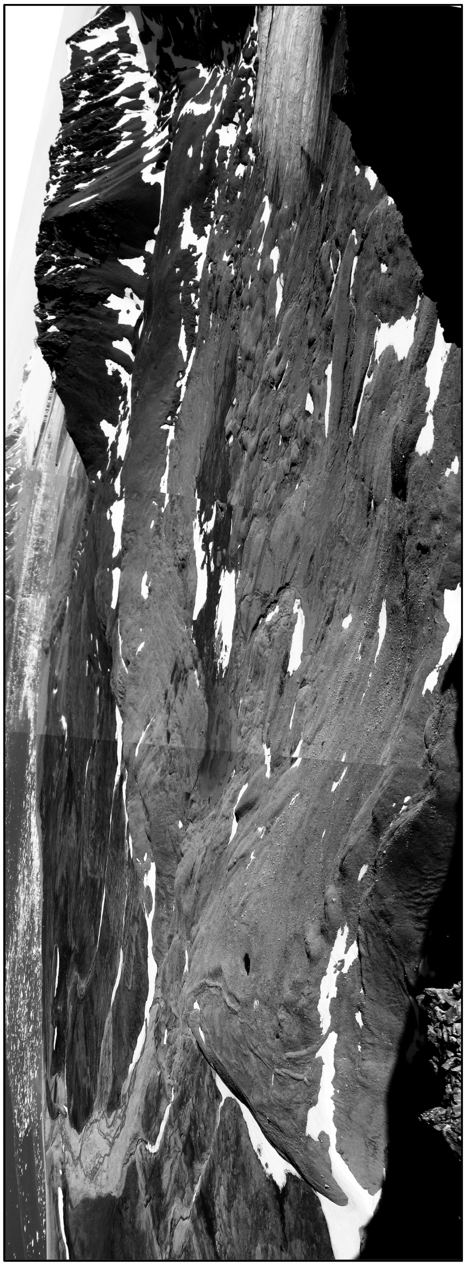

Photo 5.4.6. View of the Scottelva valley with a clearly visible division into three zones - proximal, distal and mouth sections (Photo W. Kociuba 2010).

meandering type to the multi-channel wandering type and (locally) to the classic braided type. In the mouth section the river pattern changes again from the single-channel meandering type through the multi-channel wandering form (modelling the southern portion of the alluvial fan) to the straight-line channel pattern.

The wetted perimeter of the Scottelva is dominated by the gravel fraction. The share of the loam fraction is considerable (up to 10%) only in the mouth section. The morphology of the gravel-bottomed river channel is distinctive for marked elongated bars that become exposed during low flow periods. Other channel bottom forms are also found locally depending on the bottom gradient and the texture of sediments. The zone of concentrated current represents a thalweg and riffle pattern. Locally, where the river bottom gradient drops, the river channel has deeper pool-type portions (Fig. 5.4.8). Hydraulic jump zones, on the other hand, are marked for sediment bars and shadows.

The contemporary alluvial valley is almost entirely occupied by a floodplain and constitutes the river bed in the multi-channel system. The channel system seems stable over the short timescale. Changes only occur during the snowmelt periods. As the snow cover recedes, the river channels exhibit high stability and their system typically undergoes transformation during high discharges caused by ablation or ablation combined with precipitation (Kociuba *et al.* 2010, 2012).

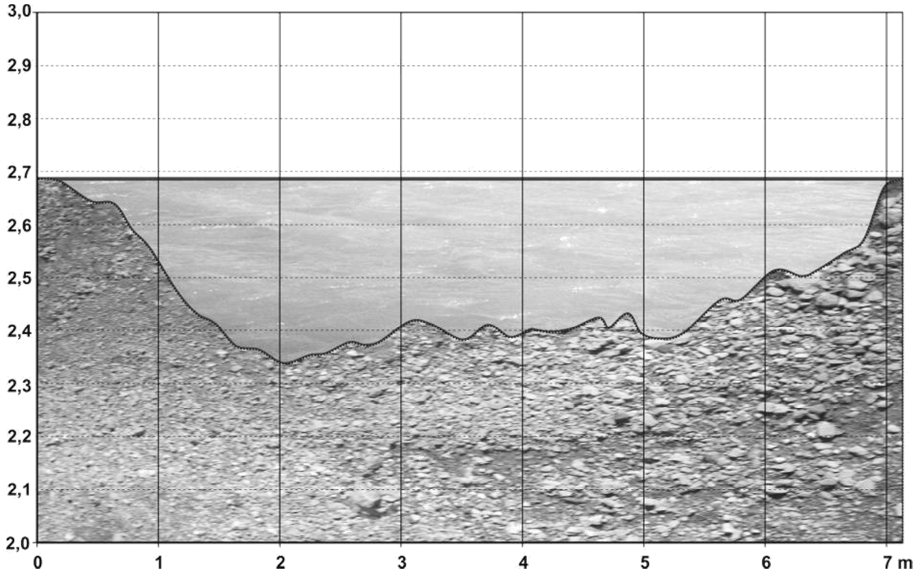

Fig. 5.4.8. Morphology of the Scottelva channel (gorge section through the raised marine terraces, 2009). Profile location in Fig. 5.4.7.

Summary and conclusions

Studies conducted during ablation seasons 2009/2010 in the catchment of the Scottelva, in a profile enclosing the catchment area, demonstrated a low rate of transport of bedload material (100 kg·24 hrs^{-1}, on average). The largest quantity of bedload is transported by the river during high flow events of ablation origin when, during high flow culminations, the quantity estimated in different measurement sites ranged between 12 and 46% of the total weight of released bedload material (Kociuba *et al.* 2010, 2011, 2012).

The intensity of bedload transport from the Scottelva catchment area is much lower than that mentioned in literature as typical for proglacial rivers (Rachlewicz 2007, Orwin *et al.* 2010). The findings of the study should be attributed to the retreat of the Scottbreen, which has been quite rapid over the past decade, resulting in an enlargement of non-glacierised area of the catchment and a gradual increase of retention capacity of the valley, also due to increased thickness of the active zone (Repelewska-Pękalowa & Pękala 2007; Zagórski *et al.* 2008a; Bartoszewski *et al.* 2009). This causes the attenuation of high discharge waves and regularisation of irregular flows that are characteristic for the Scottelva. The effect builds up in the second part of the ablation season (Kociuba *et al.* 2010, 2012). Consequently, even increased supply of water resulting from the ablation of the Scottbreen fails to bring a directly proportional effect in the form of increased intensity of fluvial transport – including the transport of bedload material. It should be emphasised, though, that 2010 was the coldest and the driest season during the past decade, which may be an additional factor limiting the intensity of glacial ablation, i.e. the main source of alimentation for the Scottelva (Kociuba *et al.* 2010, 2012).

Results of studies conducted in the Scottelva catchment area during 2009 and 2010 ablation seasons point to high diversity and variation in fluvial processes stemming from hydroclimatic factors, particularly the condition of the glacier and the rate of ablation, the extent of glaciation of the catchment area, the thickness of the active layer of the permafrost and weather conditions determining flow rates. The findings obtained in the study indicate variable dynamics of bedload transport: the quantity of material transported through measurement sites ranged from close to zero to several dozen kilogrammes over a 24-hr period (Kociuba *et al.* 2010, 2012). The first part of the measurement period was notable for both increased bottom erosion and processes of lateral and vertical accumulation of sediments: formation of sediment bars and ridges, and an increase in river bottom height. During the second half of the measurement period, the river bottom and river channel forms were found to be stabilising in line with the process of attenuation of irregular flows, and the channel pattern became fixed (Kociuba *et al.* 2010, 2012).

Studies investigating the intensity of fluvial processes in the catchment of the Scottelva in 2009-2011 also showed the mixed type of stream load with a relatively minor share of bedload material. Previous research conducted in pro- and periglacial rivers have typically demonstrated high diversity of fluvial transport constituents (Kostrzewski *et al.* 1989; Hodgkins *et al.* 1997, 2003; Hodson *et al.* 1998, 2002; Hodson & Ferguson 1999; Beylich 2007; Beylich *et al.* 2007; Strzelecki 2007; Warburton 2007, Warburton *et al.* 2007; Zwoliński 2007; Beylich & Kneisel 2009), while the share of bedload material varied from <1% to 37% (Church & Gilbert 1975; Hammer & Smith, 1983; Carson & Griffiths 1987; Orwin *et al.* 2010). The Scottelva currently seems to be dominated by the transport of suspension. The share of suspension in total fluvial transport recorded in the mouth section of the river may exceed 90% (Chmiel *et al.* 2012).

Streszczenie

Procesy fluwialne

Rzeźba fluwialna NW części Ziemi Wedela Jarlsberga, badana przez zespół lubelski od 1986 roku, jest reprezentowana przez, zróżnicowane pod względem genetycznym, różnowiekowe doliny aluwialne, często o założeniach strukturalnych (ryc. 5.4.1). W morfologii dużych dolin (A >50 km^2): Dunderdalen i Chamberlindalen, wyróżniają się dwa charakterystyczne odcinki. Górne odcinki obejmują górskie doliny przemodelowane glacjalnie (fot. 5.4.1). Odcinki dolne zostały wypreparowany na rozległych, podniesionych glacjoizostatycznie platformach abrazyjnych (fot. 5.4.2). Te duże doliny są obecnie słabo zlodowacone, a w ich rozległych dnach występują dość wąskie równie zalewowe, przeważnie ograniczone do strefy korytowej. Główne rzeki odwadniające te doliny mają złożone zasilanie śnieżno-deszczowo-zmarzlinowo-glacjalne, z przewagą wezbrań roztopowych lub deszczowo-roztopowych. Ważną rolę w dynamice procesów fluwialnych odgrywa więc akumulacja pokrywy śnieżnej w okresie zimowym oraz jej wiosenna ablacja, podyktowana przebiegiem pogody w okresie letnim. Największe rzeki, Dunderelva i Chamberlinelva, mają zróżnicowane wzory rozwinięcia: przeważają odcinki wielokorytowe, które w zależności od czynników lokalnych mają charakter roztok lub anastomoz. Wyjątkowo w strefach przełomów występują rzeki jednokorytowe: proste lub meandrowe.

Znacznie mniejsze doliny (A =1-20 km^2), zlodowacone w różnym stopniu lecz odwadniane przez rzeki o ustroju lodowcowym, jak: Logna, Dyrstadelva, Blomlielva, Tjørnelva i Scottelva (tab. 5.4.1), mają morfologię podobną do dużych dolin niezlodowaconych (ryc. 5.4.2). Łożyska tych małych rzek są również ograniczone prawie wyłącznie do dość wąskiej strefy korytowej. W ich górnych odcinkach, obejmujących doliny górskie, występują zwykle rozległe systemy koryt rozprowadzających w obrębie stożków sandrowych. W dolnych odcinkach, obejmujących doliny aluwialne, wykształcone w obrębie wyniesionych teras morskich, występują wzory koryt przejściowych, od jednokorytowych prostych (ryc. 5.4.5, fot. 5.4.3) i meandrowych, po wielokorytowe roztokowe lub anastomozujace (ryc. 5.4.8, fot. 5.4.4). W profilu zwilżonym koryt rzek proglacjalnych i peryglacjalnych przeważały osady żwirowe (śr. ok. 90%), które budują podłużne odsypy korytowe i międzykorytowe. W morfologii dna koryta wyróżniają się również strefy przegłębień (talwegi) oraz bystrza – w miejscach lokalnego wzrostu spadku dna doliny (ryc. 5.4.9). Rzeki te mają obciążenie mieszane, wydaje się również, że w ich odcinkach ujściowych udział rumowiska dennego nie przekracza kilku procent.

W korycie Scottelvy w sezonach letnich 2009 i 2010 roku zmierzono małe natężenie transportu rumowiska dennego (ryc. 5.4.3, 5.4.4), średnio ok. 100 kg·na dobę. Większość materiału (do 40%) była wynoszona podczas kilkudniowych wezbrań ablacyjno-opadowych (ryc. 5.4.6). W strukturze transportowanego materiału dennego udziały frakcji średnioziarnistej i drobnoziarnistej przekroczyły 30%, przy niewielkim (7%) udziale frakcji gruboziarnistej (ryc. 5.4.7). Materiał ten był umiarkowane wysortowany, a rozkład jego uziarnienia był zbliżony do normalnego.

Objaśnienia

Ryciny

Ryc. 5.4.1. Dolny bieg Dunderelvy – fragment ortofotomapy (Zagórski 2005).

Ryc. 5.4.2. Położenie zlewni Scottelvy.

Ryc. 5.4.3. Dobowe wartości koncentracji materiału wleczonego [kg] w poszczególnych stanowiskach pomiarowych przekroju poprzecznego Scottelvy w sezonie letnim 2009 r. (Kociuba i in. 2010)

Ryc. 5.4.4. Dobowe sumaryczne wartości koncentracji materiału wleczonego [kg] w wodach Scottelvy w sezonie letnim 2009 r. (Kociuba i in. 2010)

Ryc. 5.4.5. Hydrogram dziennego przepływu w Scottelvie (Q) i natężenie transportu materiału wleczonego (q) dla poszczególnych stanowisk pomiarowych (q S1-S4) oraz jego średnie natężenie dla całego przekroju poprzecznego koryta (qa) (Kociuba i in. 2012).

Ryc. 5.4.6. Dobowa zmienność wielkości transportu dennego Scottelvy w sezonie letnim 2010 r. (A) wartość w [kg], (B) udział skumulowany w [%].

Ryc. 5.4.7. A- Położenie zlewni Scottelvy, B- warunki geologiczno-morfologiczne (Szczęsny i in. 1989, zmodyfikowane): 1- lodowce, 2- rzeki i zbiorniki wodne, 3- stożki aluwialne, 4- sandr ekstramorenowy, 5- elementy rzeźby glacjalnej i niwalnej, 6- terasy morskie o cechach strukturalnych: 6a- 50-100 m n.p.m, 6b- obniżenia, 6c- 18-45 m n.p.m., 6d- 0-6 m m.p.m., 7- granica zlewni, 8- położenie punktu pomiarowego i profilu badawczego, 9- krawędzie (Kociuba i in. w druku).

Ryc. 5.4.8. Morfologia koryta Scottelvy (przełom przez podniesione terasy, 2009 r.). Lokalizacja profilu patrz: ryc. 5.4.7.

Fotografie

Fot. 5.4.1. Rzeźba fluwialna Dunderdalen (fot. P. Zagórski 2011).

Fot. 5.4.2. Rzeźba fluwialna Chamberlindalen – dolna część (fot. P. Zagórski 2011).

Fot. 5.4.3. Widok na dolną cześć doliny Tyvjobekken (potok Wydrzycy) (fot. P. Zagórski 2011).

Fot. 5.4.4. A- zestaw łapaczy RBT pracujących w profilu poprzecznym Scottelvy. B- materiał wleczony pozyskany w okresie 24 h w jednym ze stanowisk pomiarowych przekroju poprzecznego Scottelvy (fot. W. Kociuba 2011).

Fot. 5.4.5. A- technika pomiaru transportu materiału wleczonego, B- recznie przesiany materiał (fot. W. Kociuba 2010).

Fot. 5.4.6. Widok dna doliny Scottelvy, z wyraźnym podziałem na trzy strefy - proksymalną, dystalną i ujściową (fot. W. Kociuba 2010).

Tabele

Tabela 5.4.1. Wybrane parametry geometryczne zlewni NW części Wedel Jarlsberg Land (Bartoszewski 1998, uzupełnione).