

Past and current valley-to-fjord sediment transport - processes and products (SEDITRANS): A transect from Jostedalsbreen to Nordfjorden, western Norway

Summary

Valleys and fjords are spectacular features of the Norwegian landscape. This nature system may be considered as conduit for sediment transport from the mountain areas to the ocean. Studying present sediment transport in the different parts of the valley-fjord system and sediment accumulations within it, makes it possible to reconstruct the evolving sediment filling in three dimensions from the present glacier, through the valley, and into the fjord. Previous investigations within fjords have resulted in increased understanding of fjord sediment fill. Contrary, relatively little is known about the sediment fill of the sub-aerial valley extensions of the fjords, and even less about the combined fjord-valley systems.

The proposed research targeting the Nordfjorden valley – fjord system in western Norway aims at filling this gap in knowledge by:

- Identifying recent sedimentary processes and determine their relative importance and spatial variability along a mountain-valley-fjord profile,
- determining the distribution of sediments from the last deglaciation to the present and identifying the controlling factors,
- constructing qualitative and quantitative models for the glacier-valley-fjord sedimentary system during deglacial and interglacial phases,
- providing basic knowledge on erosion-, transport- and sedimentary processes of glaciated coastal regions as input for models on glaciated margin development, and for the understanding of glacial depo-centres along the Norwegian margin,
- providing quantitative data and knowledge on fjord - valley deposits in order to contribute to optimal planning, and
- modeling, analyzing and visualizing fjord – valley geology based on various and large datasets using modern 3D/GIS tools.

These aims will be implemented by addressing seven tasks each representing specific geological elements of the valley-fjord system or the integration of these elements. A novel approach of the proposed project is the integrated study of modern and past sedimentary processes and products of an entire fjord-valley system in a transect from land to sea. The joint effort of geoscientists working with natural processes and stratigraphy, respectively, will optimize interpretations and the quality of scientific results. Furthermore, the coupling between basic research and applied aspects meets the needs in the society for increased knowledge on the fjord-valley land system, and for the education of geo-scientific expertise.

Scientific background

Valleys and fjords are spectacular features of the Norwegian landscape, and there are numerous scientific and applied aspects related to geological processes and sediments. This nature system may be considered as conduit for sediment transport from the mountain areas to the ocean. Studying present sediment transport in the different parts of the valley-fjord system and sediment accumulations within it, makes it possible to reconstruct the evolving sediment filling in three dimensions from the present glacier, through the valley, and into the fjord. Previous investigations within fjords have resulted in increased understanding of fjord sediment fill (Holtedahl 1975; Syvitski & Shaw 1995; Sejrup et al. 1996; Aarseth 1997). Contrary, relatively little is known about the sediment fill of the sub-aerial valley extensions of the fjords, and even less about the combined fjord-valley systems. The fjord-valley systems in Norway reflect a strong influence of glacier ice and are end-member within a wide range of ‘incised valley’ types, a topic that has received increasing scientific interest within the last decade (Dalrymple et al. 1994).

Past investigations of the system have primarily been restricted to surface mapping, morphological studies, and sedimentological and/or chronological studies of parts of the system (e.g. Mangerud et al. 1979; Longva et al. 1983; Svendsen et al. 1987; Blikra and Nemeč 1998; Lønne

1997). Recent investigations in the Målselv valley, northern Norway, comprise a considerable step forward within the research of valley fills in Norway (Eilertsen 2002). This work focuses on a more comprehensive understanding of the sedimentation in glacial carved valleys and its development from deglaciation to its modern stage. In Canada a qualitative approach has resulted in the establishment of a depositional model of part of a valley fill from deglaciation to the present (Vanderburgh & Roberts 1996).

Quantitative investigations of fjord and valley fills are relatively few. Sediment volumes may be obtained from seismic studies and cores, and combined with dates this can provide the basis for calculating denudation rates, sedimentation rates and sediment fluxes of valley and fjord basins. This approach has been used for the estimation of the mean Holocene denudation rate of a valley on Svalbard (Svendsen et al. 1989), and for the calculation of sedimentation rates and sediment fluxes in Norwegian fjords during the Late Weichselian and the Holocene (Aarseth 1997; Plassen & Vorren 2001). Calculations of glacier erosion rates based on down stream glacial, lacustrine and deltaic deposit volumes have been performed by Larsen & Mangerud (1981). Estimates of the total erosion and its products have been made for Sognefjorden, western Norway (Nesje & Whillans 1994). Replication of sedimentary systems through numerical modelling has given insight into the character and origin of sedimentary fill sequences (Syvitski & Shaw 1995).

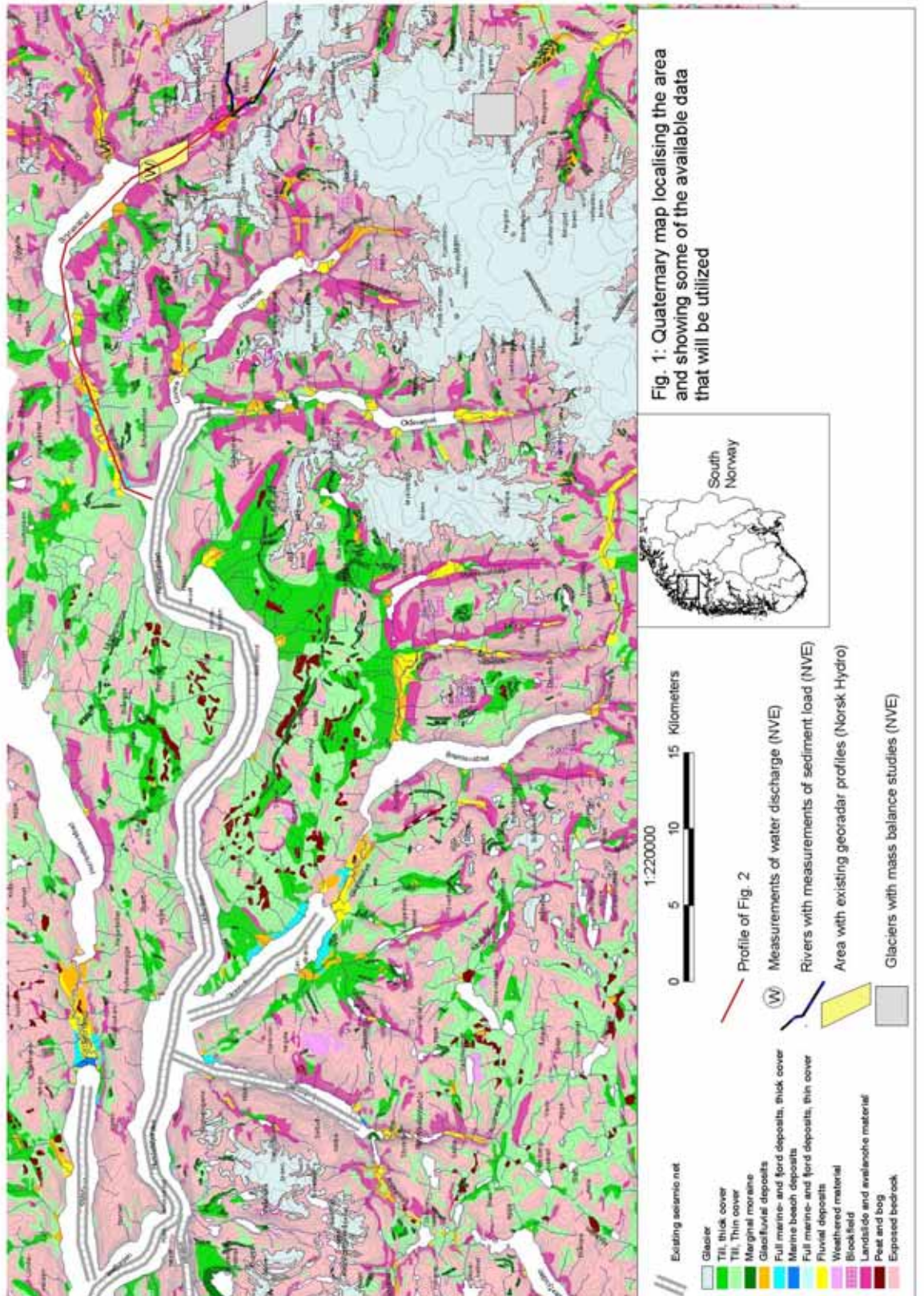
Interdisciplinary approaches, e.g. the use of complex 3D sedimentological models for hydrogeological modelling, have improved due to an increased availability of advanced computer tools (Thorleifson & Berg 2002). Modern 3D/GIS tools meet today's challenge of combining and visualize large, varied datasets, help the calculation of e.g. volumes and help to interactively produce comprehensive sedimentological models for scientific as well as applied purposes. An example is the construction of a 3D sedimentary model of Quaternary deposits in the St Lawrence Valley, Canada, for hydrogeological modelling (Ross et al. 2002).

Study area (Fig. 1)

Both in terms of physiography, what is already known from previous investigation, and ongoing projects, the Nordfjord area in western Norway is well suited for the proposed research. In this region scientists involved in this proposal have activities in climate change studies (NORPAST), glacier modeling (NSF) and potential geohazard mapping (NGU). The project suggested herein will be coordinated with these activities both in terms of logistics, field-work, joint use of data etc. The Nordfjorden valley-fjord system is a typical representative for glacial carved valley systems both in Norway and other countries.

The coastal area of Nordfjorden was deglaciated approximately 12,300 ^{14}C yr BP (e.g. Mangerud et al. 1979; Larsen & Mangerud 1981; Rye et al. 1987). During the Younger Dryas, a considerable glacial re-advance to the middle part of the fjord occurred forming large marginal deposits both below and above sea level (e.g. Mangerud et al. 1979; Fareth 1987; Rye et al. 1987). In each of the valleys of Stryn, Loen, and Olden are three ice-marginal deposits within the Younger Dryas moraines. The youngest of these were deposited at the Preboreal/Boreal transition, and is located only some 1 km beyond the «Little Ice Age» moraines. (Nesje et al., 1991). In the 1990s the western outlets of Jostedalbreen advanced considerably. Probably annual glacier expansions of such magnitude since the last deglaciation only occurred during the "Little Ice Age" (ca. A.D. 1650-1920). During deglaciation of the ice sheet the marine limit in the inner fjord areas was some 80 m above present. Thus low-lying lakes had marine sedimentation continuing well into the Holocene before being replaced by lacustrine sedimentation. Also due to adjustments to gradually lowering of relative sea level, a series of fluvial terraces and successively lower marine deltas are found in the valley.

The Nordfjorden valley extends as several branches joining down-valley of the ice cap Jostedalbreen, continuing further down as two parallel branches before the fjord merge just outside Nordfjordeid. Along the course of the valley, melt-water passes through lakes before continuing to the modern marine delta. Also along its course, tributary streams and avalanches are contributing material to the system.



For the present purposes we focus on the valley segment from the Jostedalbreen glacier outlets, Vetledalsbreen and Erdalsbreen, downvalley trough Erdalen, and the parallel valley Hjelledalen, both these valleys with rivers entering the lake Strynevatnet. Further downvalley, the target area include lake Strynevatnet, and the valley segment downstream of Strynevatnet with the river Stryneelva entering the fjord at Stryn (Figs. 1 and 2). The part of the present fjord to be studied extends from the innermost parts at Stryn and a little west of Nordfjordeid, i.e. including the Younger Dryas marginal moraines in the Lote-Anda and Nordfjordeid area.

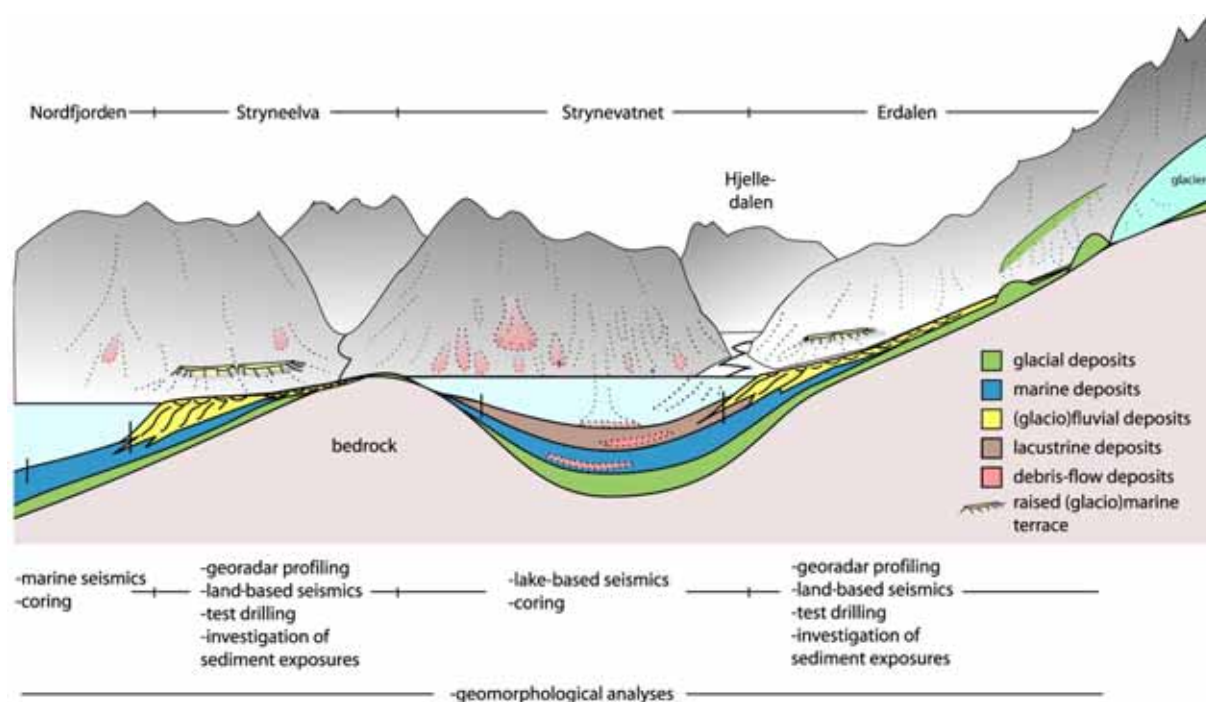


Figure 2. Profile from Erdalsbreen to Nordfjorden (not to scale) showing the main sedimentary elements and data/methods to be applied.

Research aims

The valley-fjord nature system can be considered as conduit for sediment transfer from mountain areas onto the shelf and further into the deep sea. In the full glacial situation this type of system is normally emptied of its sediments and further deepened by glacier activity, although occasional exceptions are found (e.g. Larsen et al. 1988), whereas the deglacial and interglacial/interstadial situations are characterized by sediment trapping. Thus over interglacial – glacial cycles the valleys and fjords may be considered as temporary depositories that are being occasionally emptied (Aarseth 1997). Within the valley-fjord system itself only the deglacial to recent evolution can be studied. This time span followed after a period of emptying the system of sediments during the last glacial maximum. The period from deglaciation to the present was initially characterized by large sediment input as the ice wasted back, and a lowered sediment input to the system in the interglacial situation.

Systematic attempts to combine all geological elements or subsystems in a valley-fjord system into a comprehensive model covering its geological evolution, are lacking. The proposed research project aims at filling this gap in knowledge by studying the entire sediment production and deposition phases of a valley-fjord system. To accomplish this we will address all constituents (fluvial, marine, glacial and gravitational) in the system, determine their role in time and space, and combine them into models for valley-fjord sedimentation (cf. Figs 2 and 3). Most geological features in the system are represented with modern analogues in the study area. This is highly favorable for making reconstructions of past sedimentary environments with a high degree of precision and for increasing the understanding of valley-fjord development. The project will be using a qualitative as well as a quantitative approach. The composition, internal architecture and depositional history of sediment fills will be investigated in a transect reaching from the present valley glaciers into deeper parts of the fjord, and the various components (fluvial, marine, gravitational etc.) will be linked to

observed/monitored sediment fluxes and depositional processes. This will give estimates of erosion, sediment fluxes and sediment accumulation rates in the different constituents of the depositional system. These constituents or subsystems of the valley-fjord sediment fill will be integrated into realistic valley-fjord fill models showing gradual evolution from the last deglaciation to the present. Thus the aims are:

- To identify recent sedimentary processes (fluvial, marine, glacial and gravitational) and determine their relative importance and spatial variability along a mountain-valley-fjord profile in the Nordfjorden area, western Norway.
- To determine the distribution of sediments from the last deglaciation to the present in the Nordfjorden region and identify controlling factors on sedimentation, such as sea level change, climate change and circulation change.
- To construct qualitative and quantitative models for the glacier-valley-fjord sedimentary system during deglacial and interglacial phases.
- To provide basic knowledge on erosion-, transport- and sedimentary processes of glaciated coastal regions as input for models on glaciated margin development, and for the understanding of glacial depo-centres along the Norwegian margin.
- To provide quantitative data and knowledge on fjord valley deposits in order to contribute to optimal planning of human activity.
- To model, analyse and visualize fjord – valley geology based on various and large datasets using modern 3D/GIS tools

A novel approach of the proposed project is the integrated study of modern and past sedimentary processes and products of an entire fjord-valley system in a transect from land to sea. The joint effort of geoscientists working with natural processes and stratigraphy, respectively, will optimize interpretations and the quality of scientific results. Furthermore, the coupling between basic research and applied aspects meets the needs in the society for increased knowledge on the fjord-valley land system, and for the education of geo-scientific expertise.

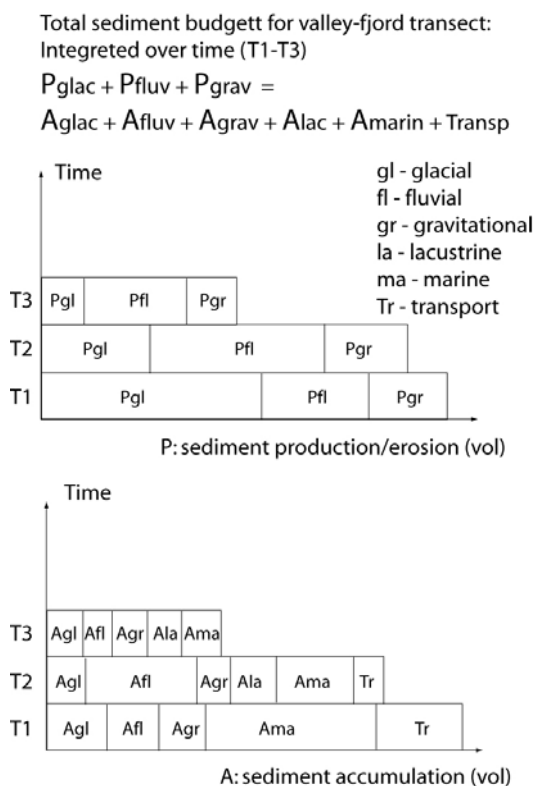


Figure 3. One way of presenting a time-dependent sediment budget.

Tasks and deliverables

The overall aim is to contribute to the understanding of the fjord-valley system in time and space. Parts of the system will be investigated through a qualitative as well as a quantitative approach. The main subsystems are illustrated in Fig. 2. Each subsystem is addressed in the following with a description of research potential, methods and investigations needed to fulfil the main goals of the study. The quantitative approach requires access to chronological information, which is possible on different scale throughout the stratigraphy. The main time intervals are:

- Deglaciation/late glacial
- Holocene
- Little Ice age- to present

The chronology for the two first mentioned is mainly obtained from stratigraphic information whereas additional high resolution information is available for the younger part of the latter due to a decadal monitoring of selected sedimentological processes. Marker beds found as investigations proceed will possibly allow a higher resolution on certain intervals of time. AMS radiocarbon and ^{210}Pb will be the principal dating methods. Geomorphological information from the different subsystems will be gathered through GIS (task 1) whereas additional geological information will be combined in a 3D model. With chronological information the results from each task will be combined into actual time-dependant valley- and fjord fill models. Results from each task will be published separately as well as being deliverable to the integrated model (task 7). The flow chart below illustrates the work plan within each task over the 4-year project period. The main tasks are:

SEDITRANS TASKS	2004				2005				2006				2007			
	W	S	S	A	W	S	S	A	W	S	S	A	W	S	S	A
1 SURFICIAL MAPPING AND GIS (PI: K. STALSBERG)																
Construction of database																
Compilation of map (land and sea)																
Data management																
GIS analysis																
2 GLACIER SUBSYSTEM (PI: E. Larsen)																
Field and lab work/analysis				—				—					—			
Input to GIS database				—				—					—			
Sub-system modelling																
3 FLUVIAL SUBSYSTEM (PI: L. Hansen)																
Field and lab work/analysis				—				—					—			
Input to GIS database				—				—					—			
Sub-system modelling																
4 GRAVITATIONAL SUBSYSTEM (PI: L. H. Blikra)																
Field and lab work/analysis				—				—					—			
Input to GIS database				—				—					—			
Sub-system modelling																
5 LACUSTRINE SUBSYSTEM (PI: A. Nesje)																
Field and lab work/analysis				—				—					—			
Input to GIS database				—				—					—			
Sub-system modelling																
6 MARINE SUBSYSTEM (PI: H. P. Sejrup)																
Field and lab work/analysis				—				—					—			
Input to GIS database				—				—					—			
Sub-system modelling																
7 INTEGRATED MODEL (PI: E. Larsen and SEDITRANS group)																
Input from all subsystems				—				—					—			
Implementation of 3D/GIS modelling tools				—				—					—			
Intergrated valley and fiord modelling																

Task 1. Surficial mapping and GIS (Task leader: Knut Stalsberg). The goal is to produce a

GIS gathering all valley – fjord fill geological components covered by the SEDITRANS area. Assessment of the aerial distribution of certain geomorphological features will help assessing their relative quantity and thereby their relative importance in the valley. Geomorphological analysis also help to outline the relative chronology of major events. The GIS is thus an important link between the subsystems addressed below. Existing data (including Quaternary maps at different scales), data collected in other tasks, and additional field mapping combined with interpretation of aerial photographs and satellite images will be combined into the GIS. This task has the overall GIS responsibility but all other tasks will deliver their data on GIS format to task 1 for further modelling in task 7.

Task 2. Glacier subsystem (Task leader: Eiliv Larsen). The purpose of this task is to calculate sediment production and deposition rates related to recent glacier-front oscillations, and to estimate the total production of glacial sediments since deglaciation of the valley – fjord system between Jostedalbreen and Nordfjordeid (Fig. 1). Recent measurements of mass balance variations at Vetledalsbreen and glacialfluvial transport from the rivers downstream of Vetledalsbreen and Erdalsbreen, are published (Roland and Haakensen 1985). Through additional field studies we will attempt to establish a relationship between sediment production and glacier oscillations in recent times. To outline the deposition of glacial sediments through the Little Ice Age, glacial landscape types/associations across the Little Ice Age moraines (Nesje et al. 1991) and within the moraines will be mapped. Sediment volumes will be estimated through a detailed mapping focusing on ice marginal and subglacial deposits constituting these landscape associations. The results will be compared with volumes of glacialfluvial sediments derived through task 3. Information on age, distribution and architecture of the distal part of the glacial depositional system, the present fjord, will be derived through task 6.

Task 3 Fluvial subsystem: (Task leader: Louise Hansen). The aim of this task is to describe the components of the (glacio-)fluvial and deltaic system and to calculate average net sediment accumulation rates since local deglaciation. Focus is on the Erdalen Valley connecting Vetledalsbreen and Erdalsbreen with Strynevatnet. Investigations will also be carried out in Stryn valley connecting Strynevatnet with Nordfjorden. In this way glacial sourced and lake sourced systems can be compared. In the fluvial system the magnitude of intermediate sediment storage is an important aspect. The volumes and stratigraphic architecture of fluvial and deltaic sediments in the valley will be estimated from geophysical data (georadar, refraction seismics, lake and marine seismics). Georadar profiles from the central part of the Erdalen valley, have already been retrieved by Norsk Hydro AS (Fig. 1). Sediment composition is retrieved from sediment exposures, and test drillings. Chronology is obtained from existing uplift curves, the known deglaciation history and dates from cores and exposures. Results will be compared to recent mass transport measurements from the Erdalsbreen and Vetledalsbreen glacier rivers (Roland and Haakensen 1985), and to discharge measurements carried out by NVE (The Norwegian Water Resources and Energy Directorate).

Task 4. Gravitational subsystem (Task leader: Lars Harald Blikra). Deposits from snow avalanches, debris flows and rock avalanches will be studied in sections across fans and in cores in their distal lacustrine and marine counterparts (tasks 5 and 6). Sediment geometries and volumes will be acquired by seismics and georadar. Event frequencies will be obtained through dating of the sediment sequences in cores and sediment exposures. Slides and turbidites will be mapped and dated in order to better understand the mechanisms behind such events (floods, earthquakes, tsunamis, source material etc.), and the importance of such deposits as part of fjord and valley sediment fills.

Task 5. Lacustrine subsystem (Task leader: Atle Nesje). Seismics and georadar studies will provide the basis for estimating the volumetric input from rivers and mass movements, and for selection of coring sites. Short (30-50 cm) and long (5-6 m) cores will be obtained from lake Strynevatnet. We anticipate the coring sites to be in the flat, deep basin (water depth ca. 230 m) close to the river delta fronts at Erdalen and Hjelledalen, in the central part of the lake basin, and in the distal part of the lake basin. In addition, cores will be retrieved from the small, distal lake segment of lake Strynevatnet. The cores will be subject to analyses of minerogenic and organic content, magnetic susceptibility, laminae/(varve?) counting.

Task 6. Marine system (Task leader: Hans Petter Sejrup). A major aim for the marine component is to map the seafloor and the different sediment packages (e.g. deltas, turbidites, mass

flow events and pelagic sediments) in the Nordfjord system in order to estimate the volumes of sediments deposited by the use acoustic equipment. The acquisition of seismics will also be used as a background in identification and genetic interpretation of sediments that has been deposited since the last deglaciation in the fjord basins. In addition cores will be sampled at selected sites for providing a chronologic framework and for estimating sedimentation rates in the fjord system. Through further investigations (sedimentology, stable isotopes and biostratigraphy) of cores and sediment surface samples the present/Holocene sediment transport and deposition in the fjord will be related to the hydrographic circulation pattern (Mikalsen et al. 2001; Sejrup et al. 2001).

Task 7. Integrated model (Task leader: Eiliv Larsen). The purpose is to combine all data from the above tasks into two basic valley-fjord time-dependent models covering the period from the last deglaciation to the present:

- 1) A qualitative sequential valley-fjord fill model showing types of sediments and their distribution in space and time.
- 2) A quantitative model with a calculated sediment budget for one or several intervals of time including rates of erosion and deposition for the different subsystems, and to outline the relative importance of the main controlling factors on sedimentation. Fig. 3 illustrate one way of presenting a time dependant sediment budget. The periods T1-T3 preferentially correspond to the three main time intervals mentioned above (deglaciation, Holocene, after Little Ice Age).

Total budget

X1000 NOK*	2004	2005	2006	2007
Equipment	295			
Field work/cruises	450	530	400	170
Analyses/consumables	255	245	245	180
Meetings/publication	80	150	150	150
Positions	576	1318	1318	842
<i>Grand Total</i>	<i>1656</i>	<i>2243</i>	<i>2113</i>	<i>1342</i>

* A detailed budget is given as enclosure 4.

Applied aspects

The understanding of valley- and fjord-fill sequences has broad applications within the society since a large part of the infrastructure in western Norway is located on valley floors, on deltas, or fluvial plains. The wide array of applications discussed briefly below demonstrates the need for increased knowledge about valley deposits and their variability. It also underlines the practical as well as scientific importance of educating young scientists with good basic understanding of valley and fjord fill geology.

Groundwater reservoirs. The upper, coarser-grained part of valley fills are often used as ground-water reservoirs. The composition and lateral as well as vertical extent of the aquifers determine their hydraulic properties and the residence time of groundwater (Huggenberger & Aigner 1999). This is relevant for groundwater quality and for the potential spread of contaminant plumes.

Salt groundwater from submarine deposits may be a good alternative for use in fish farming in cases where the seawater might be polluted. Development of fjord valley fill models may contribute to the understanding of interaction between salt and fresh groundwater controlling water quality and salinity.

Waste disposal sites. Several waste disposal sites are located in valleys. Knowledge about hydraulic properties, geometry and distribution of unconsolidated valley deposits around such disposal sites are relevant for preventing pollution into groundwater reservoirs.

Geothermal heat. Various types of deposits have different geothermal properties and understanding their volumetric distribution is thus of importance. Groundwater may have temperatures that are high and steady enough for energy extraction or may in some cases be used for cooling. Groundwater reservoirs may also be applied for the storage of energy.

Material extraction. Valley deposits are used for material extraction and contain important resources of sand and gravel. The three dimensional distribution of the deposits is relevant for volume

and quality estimates.

Stability of fine-grained deposits. The thickness and distribution of fine-grained deposits, especially of those containing quick-clay, have influence on the nature and the potential size of landslides. The stratigraphic architecture of raised marine deposits control groundwater flow and certain stratigraphic conditions allow pore pressures to build up resulting in enhanced slide activity.

Geohazards in alpine landscapes. Snow avalanches, rock avalanches and debris flows threaten communities and infrastructure along narrow fjords and valleys. Safe planning in these areas depend on better understanding of the factors controlling gravitational processes, including climate.

Recruitment/positions

One Dr. scient. (equivalent to PhD) and one Post doctoral stipendiat are applied through the project. In addition there will be several cand. scient. (Master) students in the project. We anticipate an increased demand for scholars with training in valley – fjord geology, this concerns both the basic science and applied aspects. The training program started through SEDITRANS will contribute to meet this demand.

The Dr. scient. and the Post doctoral stipendiat will be assigned to the two following research projects, both cutting across several of the SEDITRANS tasks:

- 3D/GIS modeling, mainly for the integrated valley – fjord geological models. Although his/her research will be predominantly model oriented, the student will be given at least one field oriented project in order to secure a basic understanding of the type of data involved.
- Modern (Medieval time through the Little ice age to the present) erosional and sedimentary system. This concerns all subsystems both in the marine and terrestrial realms. The purpose is to reconstruct the fluctuations of the glacier outlets Erdalsbreen and Vetledalsbreen by collecting new field data and utilizing sediment transport and glacier mass balance measurements in order to investigate the influence of these changes to downvalley – fjord sedimentation changes.

Which of the above will be assigned to a Dr. scient. and to a Post. doctoral student will be dependant on the actual availability of good candidates. Candidates will be tried recruited through our international contacts, and the positions will also be internationally advertised. The cand.scient. students recruited into the project will be given research projects from all of the SEDITRANS tasks with the task leader as main supervisor and working in close contact with other partners, students and stipendiats.

The budgeted technical assistance (Enclosure 4) is for various purposes such as GIS/Database, laboratory analyses, and field assistance (drilling, lake seismics etc.).

Shared data and results with ongoing projects in Nordfjorden

The ongoing NFR funded project NORPAST 2 and the NSF (USA) "Scandinavian Ice Sheet Project" both have the Nordfjorden area as one of their targets. The former perform climate change studies from the time of the last deglaciation to the present. The latter perform a numerical time-dependant glaciological model of the Nordfjorden glacial system starting with the ice build-up before the last glacial maximum and ending at the deglaciation of the fjord – valley area. Through NORPAST 2 a seismic cruise covering all marine areas in Nordfjorden was performed in 2003. A joint NORPAST 2 – SEDITRANS coring cruise is planned for 2004. As new field data is acquired, the NSF project will use these as input for improving the glaciological model. The modeling results will in turn be a test of the deglaciation history worked out through SEDITRANS and providing insights into the glaciodynamic and climatic processes operating during deglaciation. Many of the PI's in SEDITRANS, including both leaders and other participants, are central partners in both these two projects assuring close cooperation and exchange of data. In addition NGU is running a geohazard project in the Nordfjord area, and there will be close cooperation also with this project.

Project group and organization

Core group at the Department of Geology, University of Bergen:

Professor II Eiliv Larsen, Department of Geology/Geological Survey of Norway (Leader), professor Hans Petter Sejrup (Co-leader), and professor Atle Nesje.

Core group at the Geological Survey of Norway:

Dr. Louise Hansen (fluvial/glaciofluvial sedimentology and architecture), Dr. Lars H. Blikra, (gravitational processes) and Dr. Knut Stalsberg, (Quaternary mapping and GIS).

Other key participants:

Dr. Kurt H. Kjær, University of Lund and professor Johannes Krüger, University of Copenhagen (modern ice marginal processes), Eirik Mauring, Geological Survey of Norway (georadar investigations), Dr. Kari Sletten, Geological Survey of Norway (gravitational processes), Dr. Geir Vatne, Norwegian University for science and technology (GIS and glacial processes), Vidar Raubakken, The Norwegian Water Resources and Energy Directorate (glacier and fluvial monitoring), Dr. Dorte K. Kristensen, University of Bergen (marine processes), professor Wojtek Nemeč, University of Bergen (sedimentology), Dr. Inge Aarseth, University of Bergen (seismics, fjord sedimentology), and Dr. Svein-Olaf Dahl, University of Bergen (glacier variations, lake sediments).

Eiliv Larsen and Hans Petter Sejrup are responsible towards NFR and mother institutions. Eiliv Larsen, Lars H. Blikra, Louise Hansen, Atle Nesje, Hans Petter Sejrup and Knut Stalsberg are PI,s with scientific leadership of each defined subsystem/task. Monthly project meetings within the groups in Bergen and Trondheim will be held. Eiliv Larsen and Hans Petter Sejrup will attend most of the meetings, and when necessary also other participants from cooperating institutions will participate. Joint field work/cruises across tasks, institutions and also with NORPAST and NSF/SIP projects will be organized. Data from all tasks will be stored in a GIS data-base and retrieved from it for analyses/modeling purposes.

Research collaboration and links with other projects*International*

NSF (USA): Scandinavian Ice-Sheet Project; NFR (Sweden): Bruarjøkull (BUP) Project; NERC (UK): DICTICE; EU: STRATAGEM, COSTA and HOLSMEER (Two-way participation with these projects).

James Scource, Univ. of Wales; James Syvitski, INSTAAR; Michael Roberts, Simon Fraser University, Burnaby; David M. Mickelson, University of Wisconsin; Jaap van der Meer, University of London.

National

NFR NORPAST, NFR NORPEC, NFR NOCLIM, NGU -geohazard mapping (Two-way participation with these projects).

Kari Grøsfjeld, Jan F. Tønnesen, Oddvar Longva, Heidi Olsen, Alvar Braathen, John Dehls, Iain Henderson and Kirsti Midttømme, Geological Survey of Norway; Geoffrey D. Corner and Raymond Eilertsen, University of Tromsø; Øyvind Nordli and Kjetil Isaksen, The Norwegian Meteorological Office; Halgeir Elverhøy and Sverre Huseby, The Norwegian Water Resources and Energy Directorate (NVE).

References

- Aarseth, I. 1997: Western Norwegian fjord sediments; age, volume, stratigraphy, and role as temporary depository during glacial cycles. *Marine Geology* 143, 39-53.
- Blikra, L.H. and Nemeč, W. 1998: Postglacial colluvium in western Norway; depositional processes, facies and palaeoclimatic record. *Sedimentology* 45, 909-959.
- Dalrymple, R.W., Boyd, R. and Zaitlin, B.A. 1994: Incised-valley systems: origin and sedimentary sequences. SEPM Special Publication No. 51. Tulsa, Oklahoma. 391 pp.
- Eilertsen, R. 2002: Sedimentological and geophysical investigation of valley-fill sediments in Målselv, northern Norway. Ph.D. thesis, University of Tromsø. 173 pp.
- Fareth, O. W. 1987: Glacial geology of the Middle and Inner Nordfjord, western Norway. *Norges geologiske undersøkelse Bulletin* 408, 55 pp.
- Holtedahl, H. 1975: The Geology of the Hardangerfjord, West Norway. *Norges geologiske undersøkelse Bulletin* 323, 1-87.
- Huggenberger, P. and Aigner, T. 1999: Introduction to the special issue on aquifer sedimentology: problems, perspectives and modern approaches. *Sedimentary Geology* 129, 179-186.
- Larsen, E., Klakegg, O. & Longva, O. 1988: Brattvåg og Ona. Kvartærgeologiske kystsonkart 1220 III og 1220 IV - M 1:50 000. Forklaring til karta. *Norges geologiske undersøkelse. Skrifter* 85, 1- 41.
- Larsen, E. & Mangerud, J. 1981: Erosion rate of a Younger Dryas cirque glacier at Kråkenes, western Norway. *Annals of Glaciology* 2, 153-158.

- Longva, O., Larsen, E. & Mangerud, J. 1983: Stad. Beskrivelse til kvartærgeologisk kart 1019 II - M 1:50.000 (Med fargetrykt kart). *Norges geologiske undersøkelse* 393, 66 pp.
- Lønne, I. 1997: Facies characteristics of a proglacial turbidite sand-lobe at Svalbard. *Sedimentary Geology* 109, 13-35.
- Mangerud, J., Larsen, E., Longva, O. and Sønstegeard, E. 1979: Glacial history of western Norway 15,000-10,000 B.P. *Boreas* 8, 179-187.
- Mikalsen, G., Sejrup, H. P. and Aarseth, I. 2001: Late Holocene changes in ocean circulation and climate : Foraminiferal and isotopic evidence from Sulafjorden, western Norway. *The Holocene* 11, 437-446.
- Nesje, A., Kvamme, M., Rye, N. and Løvlie, R. 1991: Holocene glacial and climate history of the Jostedalbreen region, western Norway; evidence from lake sediments and terrestrial deposits. *Quaternary Science Reviews* 10, 87-114.
- Nesje, A. and Whillans, I.M. 1994: Erosion of Sognefjord, Norway. *Geomorphology* 9, 33-45.
- Plassen, L. and Vorren, T. 2001: Late Weichselian and Holocene sediment flux and sedimentation rates in Andsfjord and Vågsfjord, North Norway. *Journal of Quaternary Science*, 161-180.
- Roland, E. and Haakensen, N. 1985: Glasiologiske undersøkelser i Norge 1982. NVE, Rapport 1-85, 102 pp.)
- Ross, M., Parent, M., Lefebvre, R. and Martel, R. 2002: 3D geologic framework for regional hydrogeology and land-use management; a case study from southwestern Quebec, Canada. In. Three-Dimensional Geological Mapping for Groundwater Applications (Workshop). Geological Survey of Canada, Open File 1449, extended abstract.
- Rye, N., Nesje, A., Lien, R. and Anda, E. 1987: The Late Weichselian ice sheet in the Sunnmøre area and deglaciation chronology for Nordfjord, western Norway. *Norsk geografisk Tidsskrift* 41, 23-43.
- Sejrup, H.P., King, E., Haflidason, H. and Elverhøi, A. 1996: Quaternary erosion and depositional processes: western Norwegian fjords, Norwegian Channel and North Sea Fan. *Geological Society of London* 117, 187-202.
- Sejrup, H. P., Haflidason, H., Flatebø, T., Kristensen, D. K., Grøsfjeld, K. and Larsen, E. 2001: Late-glacial to Holocene environmental changes and climate variability: evidence from Voldafjorden, western Norway. *Journal of Quaternary science* 16, 181-198
- Svendsen, J.I. and Mangerud, J. 1987: Late Weichselian and Holocene sealevel history for a crosssection of western Norway. *Journal of Quaternary Science*, 2, 113-132.
- Svendsen, J.I., Mangerud, J. and Miller, G.H. 1989: Denudation rates in the Arctic estimated from lake sediments on Spitsbergen, svalbard. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 76, 153-168.
- Syvitski, J.P.M. and Shaw, J. 1995: Sedimentology and Geomorphology af fjords. In. Perillo, G.M.E., Perillo (ed.): Geomorphology and sedimentology of Estuaries. Developments in Sedimentology No. 53. Elsevier Science, 113-178.
- Thorleifson, L.H. and Berg, R.C. 2002: Introduction – The Need for High-Quality Three-Dimensional Geologic Information for Groundwater and Other Environmental Applications. In. Three-Dimensional Geological Mapping for Groundwater Applications (Workshop). Geological Survey of Canada, Open File 1449, extended abstract.
- Vanderburgh, S. and Roberts, M.C. 1996: Depositional systems and seismic stratigraphy of a Quaternary basin: north Okanagan valley, British Columbia. *Canadian Journal of Earth Science* 33, 917-927.