Evaluation of sand and gravel in Finnmark as a guide to locating deposits suited to building purposes.

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Bakkejord, Knut J. 1985: Evaluation of sand and gravel in Finnmark as a guide to locating deposits suited to building purposes. *Nor. geol. unders. Bull. 403*, 209-218.

Bedrock mapping and investigations of rock-types in Finnmark as well as elsewhere in Norway have made it possible to classify the components by their strength or mechanical properties. Three categories of strength, high, medium-high or low, are recognised. In terms of influence of bedrock and Quaternary processes it is further possible to divide the county of Finnmark into areas where sand and gravel deposits are classified as good, medium-good or poor. The evaluation of sand and gravel deposits is based on the total volume and grain-size variation of the deposit and the composition and mechanical properties of rocks in the gravel fraction.

The largest and most useful sand and gravel deposits are found in the valley and fjord areas of Finnmark. Although nearly a half of the county's population lives here, they have a great surplus of sand and gravel. In the outer fjords and eastern coastal areas the deposits are medium-good or good, but because many people live in these areas the deposits are of insufficient size to meet all needs and sand and gravel have to be imported. In the inner part of the county there are also medium-good or good deposits, but because of a small population the limited need is met. In the outer coastal areas of the western part of the county there are poor sand and gravel deposits, so that even though the population is small, sand and gravel have to be imported from the fjord areas to the south.

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Introduction

Investigations of sand and gravel resources in the county of Finnmark were initiated by the Geological Survey of Norway (NGU) in the middle of the 1970s as a continuation of the general survey of superficial deposits (Figs. 1A and B). The surveys are mostly divided into preliminary, follow-up and detailed investigations and are described in Appendix 2.

By 1985, detailed surveys of the sand and gravel resources in many local councils such as Alta, Kvalsund, Karasjok, Kautokeino, Porsanger, Vadsø, Vardø and Sør-Varanger will have been completed. In most other local councils preliminary surveys of individual sand and gravel deposits have been carried out (Bakkejord 1982). By the autumn of 1985 a Gravel Register, which comprises a complete synopsis of sand and gravel deposits but not detailed surveys, should be completed in five councils and initiated in three others (Fig. 1B). By 1990, following a working plan initiated by NGU in 1983, there will be a Gravel Register for all of Finnmark.

This present paper is an evaluation of those sand and gravel deposits registered so far, in terms of the influence of the bedrock and Quaternary processes on their quality (Bakkejord 1985a). It is anticipated that the paper will form the basis for a part of the 1990 Finnmark Gravel Register.

Bedrock Geology

A simplified geological map, based on the 1:1 million bedrock map of Norway (Sigmond et al. 1984), is shown in Fig. 2.

The basement complex which covers most of the areas in Alta, Kautokeino, Karasjok, Tana, Nesseby and Sør-Varanger consists of rocks of Precambrian age. These rocks are mostly gneiss, granite and quartzite, but there are also units of greenstone, amphibolite and schist.

In areas of *sedimentary rocks, partly metamorphosed,* the rocks are of Late Precambrian age. The metamorphic grade is low in parts of Tana, Nesseby and Vadsø where the predominant rocks are metagraywacke, shale, mudstone and slate together with sandstone and quartzite. In the rest of the area the metamorphic grade is higher. In Porsanger and Lebesby the sequences consist mainly of sandstone, quartzite, shale, dolomite and tillite. In Berlevåg, Båtsfjord and Vardø the main lithologies are sandstone and quartzite but there are also units of shale, mudstone, slate and phyllite.

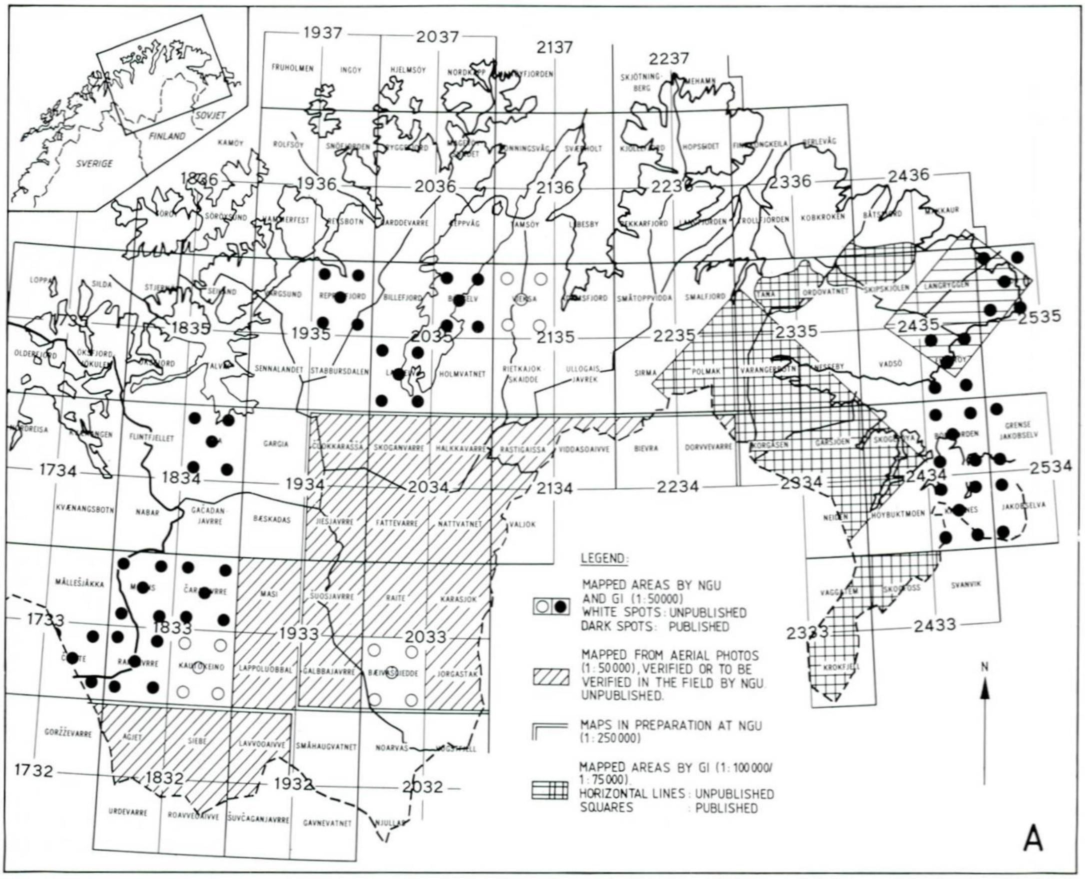

Fig. 1A. Quaternary mapping in Finnmark undertaken by the Geological Survey of Norway (NGU) and the Department of Geography, University of Oslo (GI) up to 1985.

The Caledonian *Nappes* which cover most parts of western Finnmark consist of rocks of different ages and metamorphic grade (see Roberts, this volume). The rocks are mainly of Late Precambrian age and the metamorphic grade is generally high. The dominant rock-types are meta-arkose and gneiss, but schist, marble and quartzite are also present. The metamorphic grade decreases eastward.

In Sørøysund, Kvalsund and Måsøy, the nappes contain thick tectonic slices of gneiss derived from the basement complex. In Porsanger, Nordkapp, Lebesby and Gamvik the main rock-types are mica schist, phyllite, slate, quartzite and quartzitic sandstone.

Plutonic rocks of Caledonian age cover large areas on the islands in Loppa, Alta, Hasvik and Sørøysund and consist mostly of different types of gabbro, amphibolite, diorite and ultramafic rocks.

Quality of the rocks

Based on earlier investigations of rock-types from Finnmark (Sørensen 1969, 1970, Neeb 1979, Nålsund 1982) it has been possible to group the rocks according to their strength or mechanical properties (Fig. 2). The rocks have either high (A), medium-high (B) or low strength (C).

The strength is determined by the Swedish Impact Test on fragments in the size range 8 - 11.2 mm. The test method is described in Statens Vegvesen, Håndbok -014 (1983) and -018 (1980). A classification diagram based on strength (brittleness) and grain shape (flakiness) has been constructed for Norwegian road building materials. In this, the materials are classified from 2 - 5, where the classes 2 and partly 3 signify high strength, the rest of 3 and partly 4 and 5 denote medium-high strength and the rest of 4 and 5 signify low strength.

Another test method for testing the strength

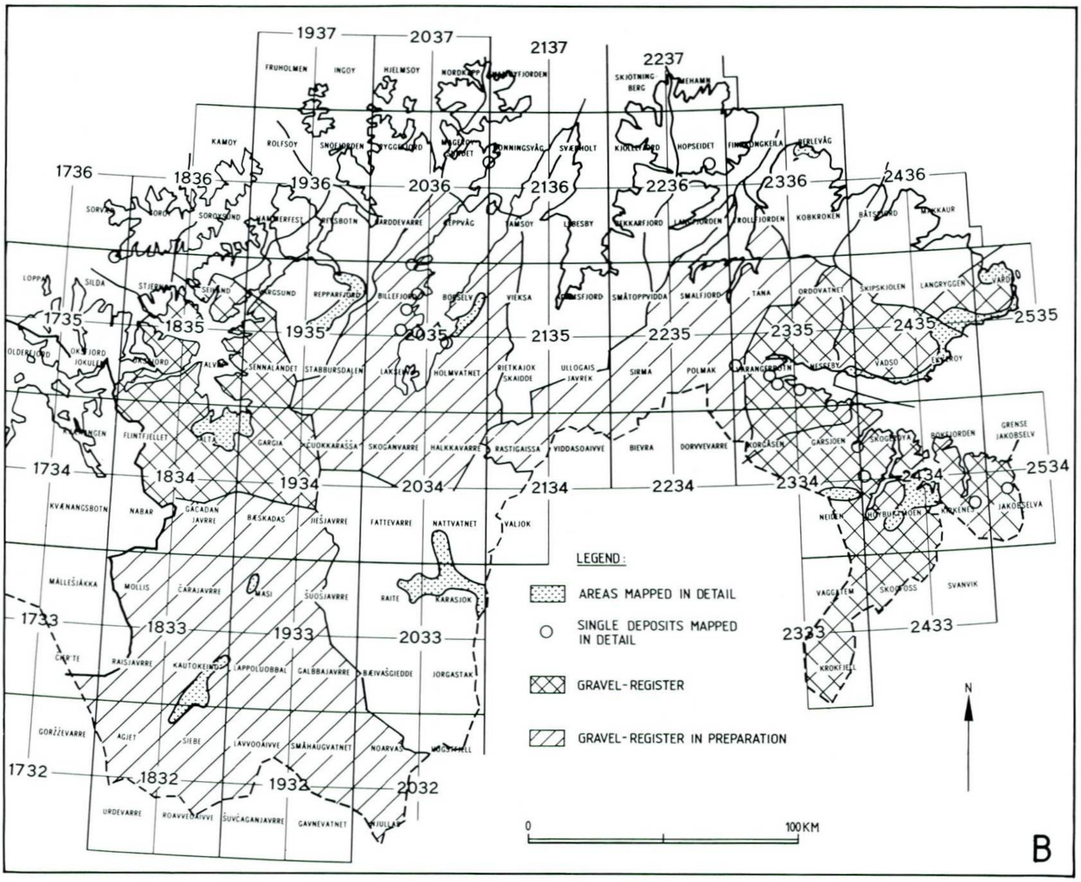

Fig. 1B. Surveys of sand and gravel resources undertaken by the Geological Survey of Norway (NGU) up to 1985.

is the Abrasion Test, which is also described in Statens Vegvesen, Håndbok -014 (1983) and -018 (1980). The method which determines the abrasive strength of the rock components has not been used in this paper. The specifications for the abrasive strength of Norwegian rock-types are given by a classification (very good, good or poor) based on the volume loss of a sample (Hugdahl & Nålsund 1984). The two methods are in general use for testing gravel for road building purposes, either alone or in combination. The abrasive strength alone or together with the brittleness certainly provides a better or equally good criterion for the strength or the mechanical properties of rock components than the combination of brittleness and flakiness (Hugdahl & Nålsund 1984).

The test results are shown in Table 1. Although only a few types of rocks from the basement complex were tested, most rock-types are represented. The sedimentary rocks, e.g. quartzite, quartzitic sandstone and shale of Late Precambrian age from Vardø and Vadsø show medium-high strength. Rocks from Porsanger, Lebesby, Tana and Nesseby have lower strengths. Rocks from the the Caledonian nappes in the north and west were not tested; however, based on tests on similar rocks from Troms (Neeb 1981) and Trøndelag/Møre (Anundsen 1977, 1979), the strength or mechanical properties should be expected to be rather low. Although one would expect to find a greater percentage of low-strength rocks than are found elsewhere in the county, most of the rocks are of medium-high or high strength. It is especially schist and mudstone which have low strengths, while quartzite and quartzitic sandstone have high or medium-high strength. Different types of gabbro were tested from the areas of plutonic rocks of Caledonian age. Only a few of these rocks have low strength.

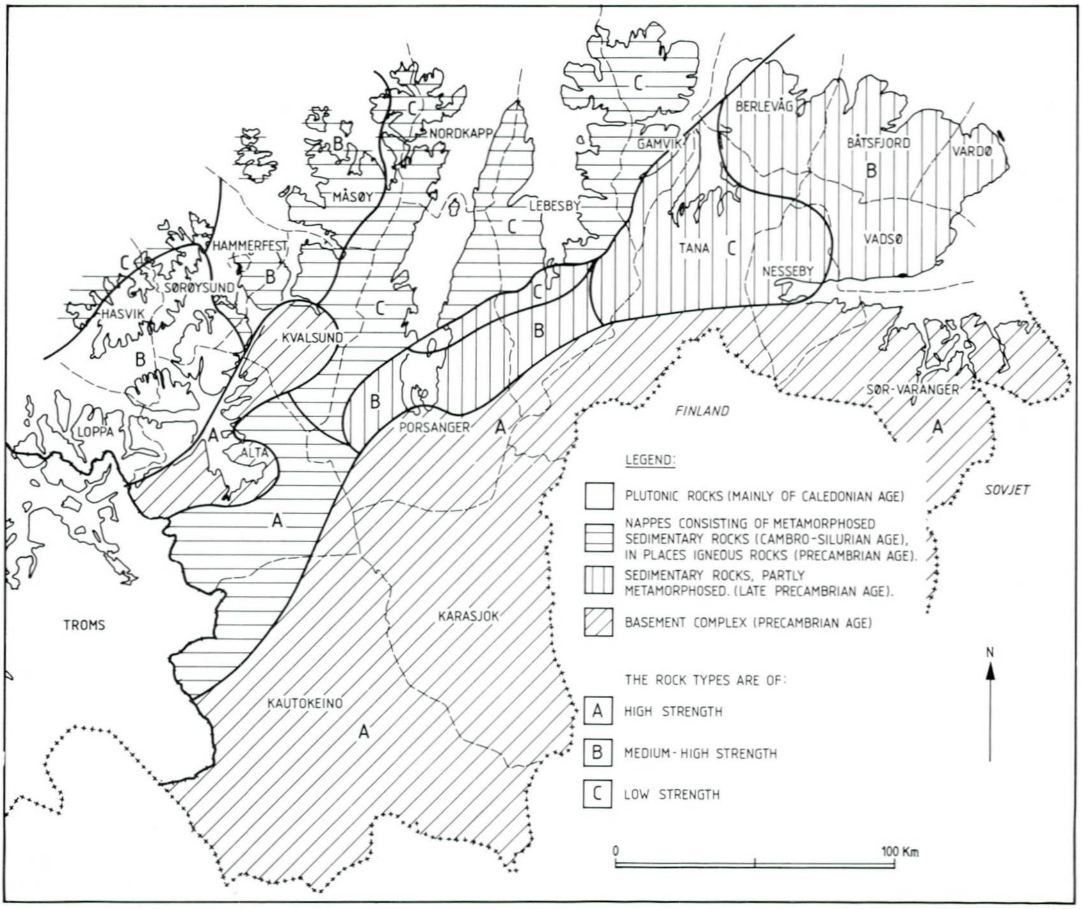

Fig. 2. Simplified classification of the bedrock in Finnmark (after Sigmond et al. 1984) and the strength of the rock-types. The strength is determined using the Swedish Impact Test (Table 1) and is classified as high (A), medium-high (B) or low (C).

Bedrock Type	% of sampled rocks with strength			Total strenght	Number of samples (tests)
	high	medium high	low		
Basement complex	80	10	10	high (A)	25 (75)
Sedimentary rocks, partly metamorphosed	30	60	10	medium high (B)	20 (60)
Caledonian nappe rocks	-	-	-	low (C)	See text
Plutonic rocks	50	45	5	medium high (B)	13 (40)

Table 1. Results from the Swedish Impact Test of rock components in fraction 8 - 11.2 mm from bedrock types in Finnmark. The total strength is the overall impression of the results listed to the left in the table.

Quaternary geology and formation of superficial deposits

The evolution of, and processes involved in the Quaternary era in Finnmark have been described by many geologists, the most well known regional descriptions being those of Marthinussen (1960, 1974) and Sollid et al. (1973). In addition NGUs mapping programme for superficial deposits (Fig. 1A) has provided several descriptions of smaller areas.

Three possible ice-marginal lines showing an interpretation of the extent of the glacier during its retreat from the shore area have been reconstructed after Sollid et al. (1973)(Fig. 3). The reconstruction of these lines is based on the character and formation of different types of deposits at the ice margin.

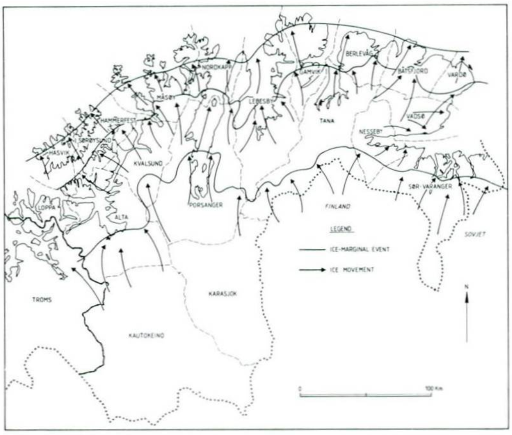

Fig. 3. The Quaternary development in Finnmark shown by three possible ice-marginal events and associated ice-movement directions.

Ice-movement directions are shown in Fig. 3 and indicate among other things from which area or areas the rock material in the gravel fraction was derived. In the Porsanger area rocks derived from the basement complex have been transported several kilometres into the metamorphosed sedimentary rock provinces (Follestad 1981). There are also indications of rock transport from one bedrock province into another in the Alta (Bakkejord 1985b) and Nesseby areas (Bakkejord 1986).

Quaternary processes have been responsible for the production of extensive superficial deposits. Of these, the most useful in providing sand and gravel for building purposes are:

- glaciofluvial deposits
- marine shore deposits
- fluvial deposits
- tills.

Figure 4 shows characteristic grain-size distributions for these types of deposits and also gives the grain-size limits for sand and gravel

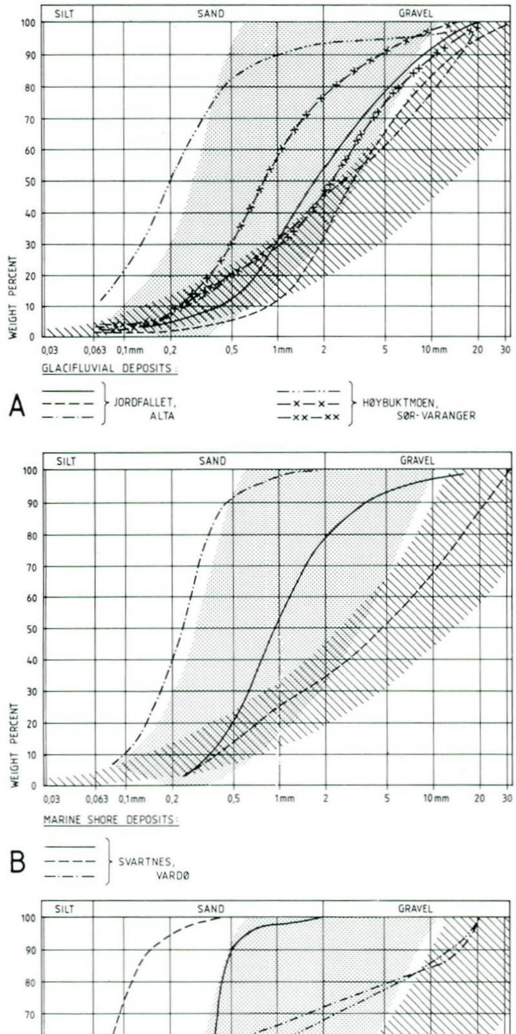

Fig. 4. Grain-size distribution curves for four types of superficial sediments containing sand and gravel suited to building purposes. Grain-size limits for sand and gravel suited to concrete and road building are also plotted.

used for concrete and road material purposes. Descriptions of the form and genesis of the deposits are given in Appendix 1.

Glaciofluvial deposits are the most common deposits containing sand and gravel and occur in many places in Finnmark, especially in the valley and fjord areas of Alta, Kvalsund, Porsanger, Lebesby, Tana and Sør-Varanger. In the area of Alta in western Finnmark there are many large ice-marginal deposits. One of the biggest of these is Jordfallet; this is an *ice-marginal delta* and lies about 10 km south of the town of Alta on the eastern side of the Alta river. Grain-size distribution curves of samples from the deposit show relatively coarse-grained but well-sorted sand and gravel materials (Fig. 4A). The materials are well suited to most building purposes except for concrete where it is necessary to add more fines (fine-grained sand/coarse-grained silt) (Bakkejord 1980).

About 15 km west of Kirkenes in central Sør-Varanger lies Høybuktmoen, which is an extensive ice-marginal delta. Grain-size distribution curves of samples from the northern side of the deposit (the distal side) show well sorted sand and gravel (Fig. 4A). The materials are suitable for most building purposes (Bakkejord & Bergstrøm 1979).

One of the biggest *eskers* in the county occurs in the Kautokeino area in an almost endless band from Hæmmujavri, 20 km north of Kautokeino centre and along the Kautokeino river northwards to Masi, which is a distance of more than 30 km (Bakkejord 1985c). In the Pasvik valley in Sør-Varanger an esker system extends for more than 20 km (Carlson et al. 1983). Esker materials are commonly used for building purposes, but because of their form and highly variable grain size they are not utilized as gravel pits where the more suitable glaciofluvial ice-marginal deposits occur in the neighbourhood.

Marine shore deposits are generally of great extent, but of small thickness. Along those parts of the coast of Finnmark where there are virtually no other superficial sediments, such deposits are of great local interest as possible gravel pits, although glaciofluvial deposits are favoured if they occur in the neighbourhood. Figure 4B shows grain-size distribution curves from a section in a *beach ridge* near Vardø (Neeb 1979). The sediments were originally glaciofluvial, but now form a layer of stones under which there is sorted sand and gravel in a 4 m thick section. The whole sequence constitutes very good material for most building purposes.

Fluvial deposits have been mapped in the valleys of Alta, Porsanger and Tana and most consist of fine-grained sand and coarse-grained silt under a topset layer of coarser sand, gravel and stones. The topset layer is usually 1-3 m thick and is commonly used for construction material, which unfortunately leads to unsightly gravel pits over large areas of the valleys. The underlying fine-grained material is commonly used as plaster sand and ballast material, or is added to sand and gravel which are otherwise too coarse-grained for general use. Figure 4C shows examples of grain-size distribution curves for sediments from Eibymoen on the Alta river, about 10 km south of Alta (Bakkejord 1980).

Till is commonly used as ballast material in Finnmark. *Ablation till* and *marginal moraine* sediment are of satisfactory quality for road building and are sometimes used as such. Figure 4C shows grain-size distribution curves of such material from the eastern part of Sør-Varanger (Bakkejord & Lebesbye 1986).

Evaluation of the sand and gravel deposits

Sand and gravel are mainly used in concrete production and for road building, and their evaluation is based on the following criteria:

- grain size of the resulting product.
- composition, mechanical properties and strength of the component rocks and minerals.
- grain shape.
- fouling.

Sand and gravel materials for road building depend on all these criteria while those used for concrete production are dependent more on grain size and grain shape than on the strength of the component rocks and minerals. These criteria are explained in Appendix 2.

Using a classification scheme based on the overall impression of grain size and total volume, sand and gravel deposits in Finnmark are classified as either good, medium-good or poor (Fig.5). In addition, the Swedish Impact Test was used to measure the strength of rock materials in the gravel fraction (8 - 11.2mm), and the results have have been grouped as either high, medium-high or low in Fig. 5.

The test results are shown in Table 2. The bedrock types listed in the table are the source rocks for most of the rock components in the gravel. Gravel in which most components are

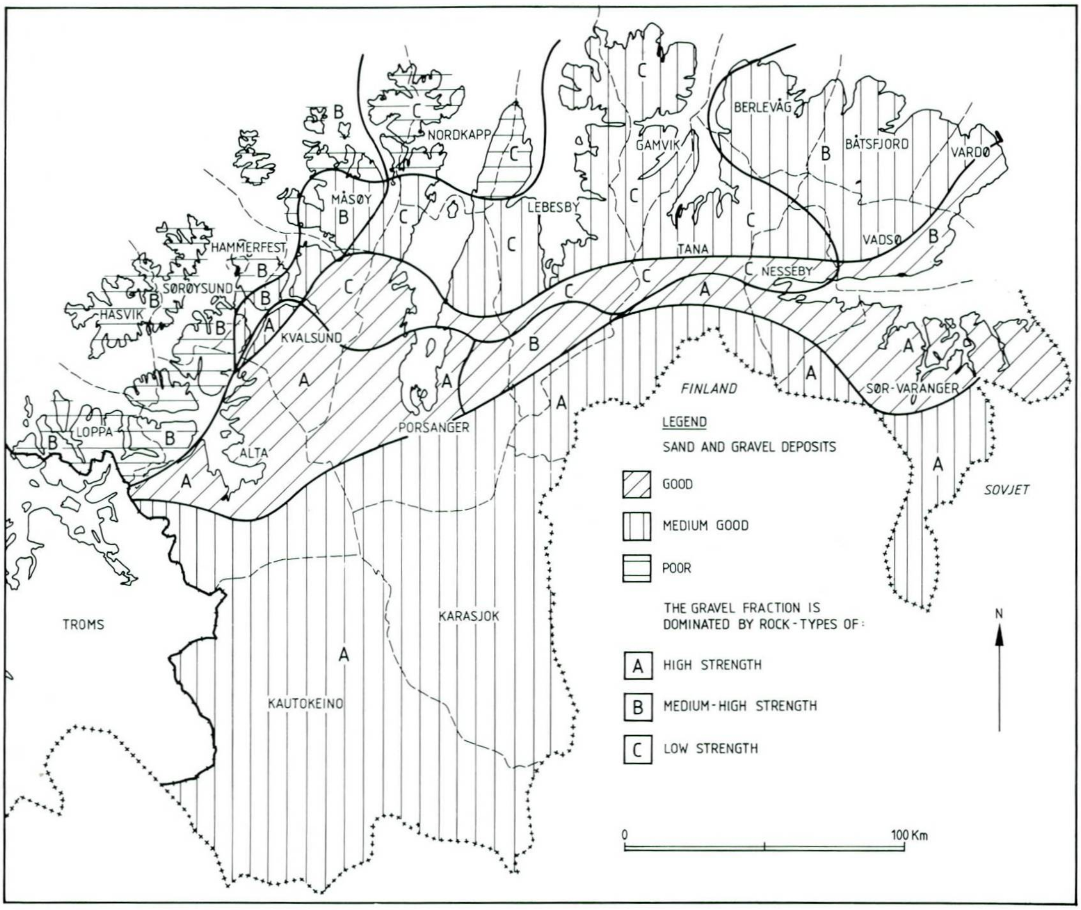

Fig. 5. Evaluation of sand and gravel deposits in Finnmark and the strength of rock-types in the gravel fraction. The evaluation of the deposits is done on the basis of the overall impression of their total volume and grain size, and they are classified as good, medium-good or poor. The strength of rock-types in the gravel fraction is determined using the Swedish Impact Test on gravel from the deposits (table 2) and is classified as high (A), medium-high (B) or low (C).

Bedrock Type	% of sampled rocks with strength: high	medium high	low	Total strenght	Number of samples (tests)
Basement complex	70	25	5	high (A)	45 (175)
Sedimentary rocks, partly metamorphosed	45	35	20	medium high (B)	35 (105)
Caledonian nappe rocks	45	25	30	low (C)	15 (45)
Plutonic rocks	-	-	-	medium high (B)	See text

Table 2. Results from the Swedish Impact Test of gravel in the fraction 8 - 11.2 mm from superficial deposits related to bedrock type and derivation of rock components. The total strength is the overall impression of the results listed to the left in the table.

derived from the basement complex occurs in the Alta, Kautokeino and Sør-Varanger areas and generally has a high strength (Bakkejord & Bergstrøm 1979, Bakkejord 1980, 1985c). In the Karasjok area, however, sampled gravel is mostly of medium-high or low strength because of the presence of some very poor rock-types, e.g. coarse-grained granulite (Nålsund et al. 1980). Gravel with components from the sedimentary rocks of Late Precambrian age occurs in the Vadsø and Vardø areas. This gravel has a relatively high degree of low-strength components which have a negative influence on the quality (Neeb 1979, Nålsund 1979). Gravel sampled from the Caledonian nappes in the Lebesby and Porsanger areas contains an even higher percentage of low-strength rocks than the sedimentary rocks mentioned above (Follestad et al. 1978, Statens Vegvesen 1982a, b). From the areas of plutonic rocks of Caledonian age there are too few samples to obtain any meaningful result. However, there are indications that the gravel components have approximately the same strength as the original source rock-types in Table 1.

Good sand and gravel deposits with rocks of high strength dominant in the gravel fraction are found in the west in Alta, Kvalsund and Porsanger, and to the east in parts of Tana and Sør-Varanger. These areas, which have nearly a half of the population of the county, carry a great surplus of sand and gravel.

With the exception of the Karasjok area, in the inner parts of Finnmark there are *medium-good or good deposits of sand and gravel which are dominated by rocks of high strength*. Because only about 10% of the total population lives here, the limited need is met by sand and gravel from actually within this area.

Medium-good or good sand and gravel deposits dominated by rocks of medium-high or low strength are found in the outer fjord areas and in the coastal areas from Kvalsund in the west to Vardø in the east. Locally, there are relatively good deposits of sand and gravel with a high content of rocks of high strength (for instance, quartzitic rocks). About 35% of the population lives in these areas and the need for sand and gravel here is relatively great. The population of Vardø and Vadsø is almost self-sufficient in sand and gravel for building purposes. However, in Nordkapp, Lebesby, Gamvik and Hammerfest it is necessary to import these materials.

Areas in the far west of the county have *poor deposits of sand and gravel dominated by rocks with medium-high or low strength*. In these areas, with some 10% of the population, it is necessary to import sand and gravel.

Acknowledgements

The author is grateful to engineering geologists Roar Nålsund and Peer-Richard Neeb, both from NGU, and engineering geologist Leif Rise from IKU, for their critical reading of the manuscript. Geologists Sarah J. Barnes from NGU and Sue Mollet from IKU have corrected the English text. Several draughtsmen, technicians and secretaries from NGU have helped in producing the final manuscript and illustrations. To all persons involved I express my thanks.

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Appendices

1. Definitions of superficial sediments containing sand and gravel

The definitions follow those appearing in a guide for descriptions of Quaternary maps made by Bargel et al.(1981).

Glaciofluvial deposits are superficial sediments which are transported and deposited by meltwater from glaciers. The sediments are commonly stratified and sorted by grain size and the main types are sand and gravel. The types of rocks and minerals in a sand and gravel deposit in a given region are deduced from the bedrock and the draining direction of glaciers, meltwater streams and normal streams.

Ice-marginal deposits (delta, sandur) are built up in front of the ice margin and consist of coarse-grained materials proximal to the glacier and fine-grained materials formed distally and at the base of the deposit.

Eskers are constructed in channels within or beneath glaciers and are elongated in the direction of ice movement. Eskers generally have a skin of coarse-grained sediment comprising sand, gravel, cobbles and boulders above a core of well-sorted sand or gravel. A large variation in grain size over short distances is characteristic of eskers.

Marine shore deposits are sediments washed up onto the shore by wave and stream activity. The deposits often lie as a cover upon other superficial sediments, but can also exist directly upon bedrock. The deposits are stratified and well sorted and the boundary with the other underlying superficial sediments is commonly gradational. As a rule, rocks with low strength are crushed to fines and washed to greater depths, while those with high strength remain in the sand, gravel and cobble fractions. The marine shore deposits are usually a few metres thick.

Fluvial deposits are accumulated after deglaciation and involve the burial, transportation and deposition, usually of sand and gravel , by stream water. Fluvial deposits are usually better sorted and have more well-rounded components than glaciofluvial deposits.

Tills are composed of material plucked up, transported and redeposited by glaciers. *Lodgement till* is unsorted till which is deposited directly from the base of the glacier. *Ablation till* is the sediment deposited during any of the processes by which snow and ice are lost from the glacier, for example during deglaciation or calving. This till is generally loosely packed and coarse-grained because the meltwater has washed the fines away. *Marginal moraines* are deposited at times when there is a halt in the advance of the glacier. The materials in parts of such moraines mostly consist of sand and gravel.

2. The idea of quality in connection with the use of sand and gravel

Research methods

The Geological Survey of Norway (NGU) has a model for sand and gravel investigations (Neeb 1981), which is divided into three parts:

Preliminary investigations aim to localize deposits and estimate their volume and quality. *Follow-up investigations* concentrate on important deposits and determine the probable volume of sand and gravel. Subsequent *detailed investigations* suggest the suitability of individual deposits for various purposes and give more accurate estimates of the volume and quality.

Surveys and mapping are undertaken after studying earlier investigations, Quaternary geological maps and aerial photographs. During fieldwork it is common to use probe drilling, shaft digging, sampling and different geophysical methods to decide the extent of the deposits and the variation in grain size with depth. Samples are tested in the laboratory for grain size, mechanical properties or strength, grain shape and fouling.

Grain size for material larger than 2 mm is determined by sieve analysis.

Strength and mechanical properties are given by the Swedish Impact Test which determines the amount of brittleness and flakiness, and the Abrasion Test which determines the degree of abrasion.

Fouling is usually caused by humus (organic remnants in the soil) and is determined by a colour classification when added to a NaOH solution. Other types of fouling, such as pyrite and clay content, are determined by a visual examination.

When examining sand and gravel for potential use in concrete production it is important to perform *solidarity tests* as well as measuring *the water requirements* and *plasticity*.

Road building

Specifications for sand and gravel in road building are given by Statens Vegvesen, Vegbyggingsnormaler, Håndbok -018 (1980).

The grain size of sand and gravel is one factor which will dictate where the material can be used in the road building process. Sand and gravel for road building processes should be placed inside the grain size limits shown in Fig. 4.

The positions in the road body and the expected traffic strain will specify what ranges of *strength or mechanical properties* the rocks or minerals in the sand and gravel should have.

Grain shape is especially important in the coarse-grained fraction (gravel and cobbles), since well-rounded material is more inclined to slip than angular material. Therefore, if the gravel material is well-rounded it is necessary to use a certain percentage of crushed material to obtain satisfactory stability in the road.

Fouling by humus and pyrite should be avoided.

Concrete

There are few specifications for sand and gravel in concrete. Some of them are given by Norges Standardiseringsforbund (1976), but most of the specifications listed below are given by Danielsen (1979).

The grain size of sand and gravel is especially important in concrete because the resultant product has to be easily worked or moulded and attain a certain solidarity. Grain-size limits for concrete sand are shown in Fig. 4.

There are no specific requirements for *the strength* for rocks in sand and gravel for use in concrete. However, weak rock fragments should not be present and the content of mica in the sand fraction should not be so high that the solidarity of the concrete is reduced (Danielsen 1979).

For coarse-grained particles, *the grain shape* decides the plastic quality. Crushed sand must have a higher degree of the finer fraction than natural sand and therefore the grain-size distribution curve has to diverge from the curve for natural sand and gravel material. The methods of crushing can also influence the grain shape.

Fouling by a surface cover of either clay, humus or pyrite should not occur.