NGU Report 97.193
Coastal quarrying, resource potential for
exporting from Nordland county

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REPORT

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Title:
Coastal quarrying, resource potential for exporting from Nordland county

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Summary:

Under the auspices of Nordlandsprogrammet, several initiatives have been taken to locate areas where natural conditions are present to establish large coastal aggregate plants. The investigations have been undertaken as a co-operative project between industrial partners, the Nordland County Authority and NGU. This report is a compilation of investigations carried out previously.

As the demands vary with regard to both how the material will be used and the European country concerned, it is difficult to make a common evaluation of the quality of the rock. As an overall assessment, the quality is considered to be poor for Råna, Kilheia, Velsvåg and Ursfjorden and very poor for Øyrfjellet in relation to the quality demands stipulated for building raw materials in England, Germany, France, the Netherlands, Belgium and Norway.

The analysis results show that the material from Øyrfjellet in Gildeskål is too poor to be used as building raw material. The rock quality for the samples taken in the other areas is on the borderline of what should be accepted as fulfilling the minimum demands for the establishment of large aggregate plants aimed at the export market in Europe.

The material is entirely suitable for delivery to the "offshore market" to support and cover pipelines and other installations.

For export to the USA, the quality of the material is adequate for use for road construction purposes, according to the information that is available regarding stipulated quality demands.

Key words: Engineering geology	Building raw materials	
Norwegian Impact Test	Abrasion	Ball mill
Los Angeles	Aggregate	Scientific report

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The results for the five areas that have been investigated in the boroughs of Ballangen (Råna), Flakstad (Kilheia), Gildeskål (Øyrfjellet), Leirfjord (Velsvåg) and Ursfjorden (Sømna) are summarised in the following table:

Criteria	Råna	Kilheia	Øyrfjellet	Velsvåg	Ursfjorden
Location	Favourable	Favourable	Favourable	Favourable	Favourable
Reserves	?Favourable	?Favourable	?Favourable	?Favourable	?Favourable
Sea depth/fjord width	Favourable	Favourable	Favourable	Favourable	Favourable
Climatic conditions	Unknown	Unknown	Unknown	Unknown	Unknown
Environmental aspects	Favourable	Favourable	Favourable	Favourable	Favourable
Rock type	Norite	Anorthosite	Granite	Porphyritic granite	Gabbro
Density	Less favourable	? Favourable	Favourable	Favourable	? Favourable
Bedrock homogeneity	Less favourable	Favourable	Favourable	Favourable	Favourable
Quality of bedrock	Moderate	Moderate	Very poor	Moderate	Moderate

Table 1.

For most areas of use, the density of the raw material should be as low as possible, preferably < 2.80 g/cm^3. In this respect, the density at Øyrfjellet and Velsvåg is favourable. It is somewhat high at Kilheia and Ursfjorden, and a little too high at Råna. For large-scale working, areas where the raw material is as homogeneous as possible are to be preferred. The norite in the Råna deposit shows variations in its mechanical properties that can be explained on the basis of mineralogical factors. The homogeneity of the bedrock is therefore assessed as being unfavourable in this area. The homogeneity in the other four areas is considered to be favourable.

As the demands vary with regard to both how the material will be used and the European country concerned, it is difficult to make a joint assessment of the quality of the rock. As an overall assessment, the quality is considered to be poor for Råna, Kilheia, Velsvåg and Ursfjorden and very poor for Øyrfjellet in relation to the quality demands stipulated for building raw materials in England, Germany, France, the Netherlands, Belgium and Norway.

The analysis results show that the material from Øyrfjellet in Gildeskål is too poor to be used as building raw material. The rock quality for the samples taken in the other areas is on the borderline of what should be accepted as fulfilling the minimum demands for the establishment of large aggregate plants aimed at the export market in Europe.

The material is entirely suitable for delivery to the "offshore market" to support and cover pipelines and other installations.
For export to the USA, the quality of the material is adequate for use for road construction purposes, according to the information that is available regarding stipulated quality demands.

1. PREFACE

The export of aggregates has been rising during the last decade. Several companies, both national and foreign ones, have shown considerable interest for finding new coastal deposits for export to a European market. There is considered to be a major potential for increased export of Norwegian aggregates, but the development will take place over time and in pace with the consumption and resource situation in the rest of Europe. Market research must be undertaken to clarify the opportunities for export for the individual aggregate plant and deposit. The location relative to the transportation distance and the quality of the rock product will be important factors [1],[2].

Against this background, the Geological Survey of Norway (NGU) wishes to undertake resource mapping to locate possible areas for extracting aggregates along the coast from Vest-Agder to Troms, in co-operation with local authorities, county councils, and Norwegian and foreign industrial concerns. It will primarily be southern parts of Norway that are of interest for export to the continent. NGUs intention is that suitable deposits shall be secured for future extraction, viewed in a long-term perspective. This must be seen in the light of ongoing coastal zone planning on parts of the Norwegian coast, which has the aim to protect areas from encroachment. It is important that areas that are suitable for extraction of aggregates be recorded and mapped at an early stage in order to avoid unnecessary conflicts in the future.

Trondheim, 11 December 1997
Main Project for Building Raw Materials

Peer-Richard Neeb
Project Manager

Eyolf Erichsen
Geologist

2. INTRODUCTION

Under the auspices of Nordlandsprogrammet, several initiatives have been taken to locate areas where natural conditions are present to establish large coastal aggregate plants. The investigations have been undertaken as a co-operative project between industrial partners, the Nordland County Authority and NGU. This report is a compilation of investigations carried out previously.

In 1992, in co-operation with Nikkel Olivin A/S, an investigation was undertaken in those parts of the Råna deposit in Ballangen which are most conveniently located for extraction of stone [3]. Side by side with ore-based mining operations, the company is currently operating a small quarry where stone is being extracted for crushing. The company has access to a large quay that has capacity to take ships of up to 80,000 tonnes.

In 1994-95, a preliminary round of consultations was undertaken in which 14 areas were assessed with a view to extraction operations (figure 1). This resulted in 4 areas being selected for follow-up field investigations. The areas investigated were Kilheia in Flakstad, Øyrfjellet in Gildeskål, Velsvåg in Leirfjord and Ursfjorden in Sømna [4].

The fieldwork was carried out by Eyolf Erichsen, Norodd Meisfjord and John Anders Stokke from NGU and Bjørge Brattli from NTNU.

3. METHODS

3.1 Selection of areas

For the sake of completeness, a general description is included clarifying the criteria on which the selection of new, potential areas for extracting aggregate is based. Table 2 lists some important criteria [5].

Criteria	Description
Location	Proximity to the sea, < 2-3 km
Reserves	Minimum 250 million tonnes
Sea depth/fjord width	Minimum 12 metres for ships of Panmax size, 300 m wide
Climatic conditions	Harbour and extraction site protected from bad weather
Environmental aspects	Is the plant open to view? Distance to housing; pollution
Density	Preferably less than 2.80 g/cm^3
Bedrock homogeneity	As homogeneous as possible
Bedrock quality	As good as possible; some minimum requirements must be met

Table 2. Criteria for large coastal aggregate plants.

NORDLAND

Resources for Coastal quarring

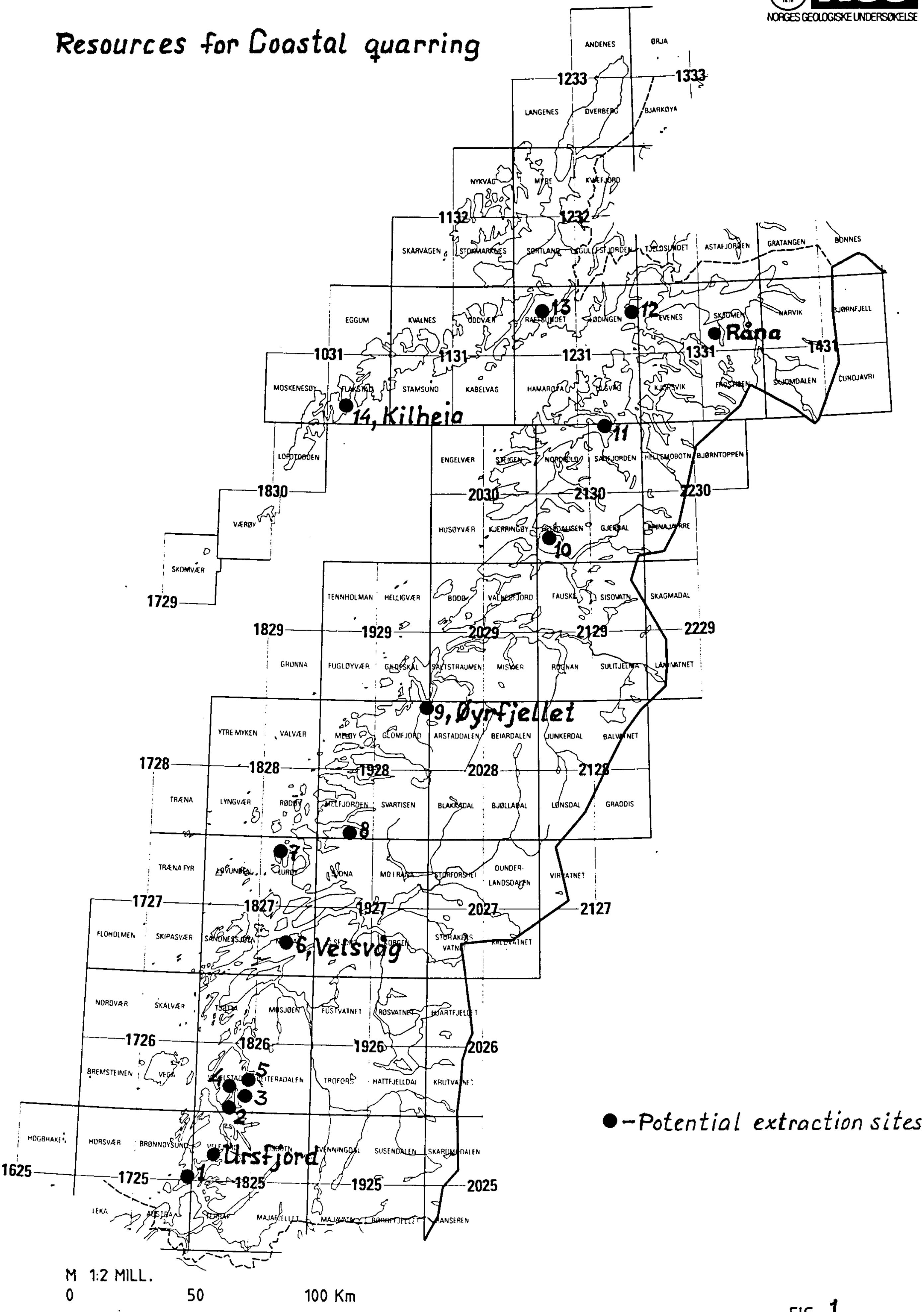


FIG. 1

When selecting new areas for extracting aggregate, the way the deposit will be worked will influence the location of the plant. Aggregate deposits are chiefly worked as open quarries. Occasionally, they are worked underground, in which case some criteria that have to be given priority when surface working is to take place can be ignored. Negative environmental consequences, such as spoiling the view, dust and noise, can be completely or more effectively screened when underground working takes place. An underground aggregate plant can be placed closer to a built-up area than an open quarry can.

Deposits of the size we are considering, having an annual production of > 3-5 mill. tonnes, will probably only be suitable for surface operation. Calculations have been made which show that aggregate deposits with an annual extraction in the order of 1 mill. tonnes may be competitive using underground working relative to surface working [6].

The resources required for large aggregate plants with an annual production in the order of 5 mill. tonnes are a minimum of 250 mill. tonnes (50 years operation) [5]. Large coastal aggregate plants will probably experience lower annual production during a starting-up phase, before gradually building up to full capacity. It is essential that the resources available are sufficient to enable production to be increased in the event of a future rise in demand. It may be mentioned that the first, and so far only, large coastal aggregate plant in Europe, Glensanda on the north-west coast of Scotland, has reserves of 450 mill. tonnes. The annual production is 5 mill. tonnes, with plans to raise it to 15 mill. tonnes.

A topographical map will provide useful information when the location of a new deposit, which it is envisaged will be worked as an open quarry, is being considered. It is important, to consider the mode of operation right from the start so that areas may be found where an intended quarry can be accommodated to the topography to avoid environmental problems, above all the scenery being spoilt. Other important aspects will be the conditions for building a good harbour, and that the maritime approaches and depth of the sea are satisfactory. The availability of other kinds of infrastructure, such as roads, power supply and settlements, may also be given priority. As regards the geology, areas with bedrock that can be assumed to have poor mechanical properties (in general, schistose, mica-rich rocks) and areas with a thick cover of superficial deposits should be avoided.

After several areas have been selected in accordance with the above criteria, it is natural to receive feedback to learn of any evident land-use or environmental conflicts. It is useful to have a round of consultation when contact should be taken with the Environmental Division of the County Governor's Office, the County Council and neighbouring local authorities. These bodies are in possession of information which may, at an early stage, exclude areas as being unfeasible for more detailed investigation. Examples of this kind of information will be agricultural and forestry interests, already recorded ancient monuments, and having consideration for natural and cultural landscapes.

For one of the projects, the entire coast of Nordland was assessed with a view to the establishment of large coastal aggregate plants. A total of 14 areas were selected on the basis of the above criteria (figure 1). A round of consultations was undertaken which gave NGU a constructive response, and which resulted in only 4 areas being judged as being of interest for follow-up field investigations. One of these areas was subsequently replaced by a new area in the same borough (Ursfjorden in Sømna).

3.2 Field investigations

Field investigations of new aggregate deposits consist of bedrock and engineering geology mapping. The objective is to map parameters that are important for extraction and production of aggregate. The results will provide an overview of recorded variations in the properties and quality of the bedrock to avoid unexpected surprises being encountered in a possible operating phase.

The geological mapping above all entails recording and delimiting rock types. Other important parameters are the grain size, texture and homogeneity of the rocks. Structures, the frequency and direction of joints, surface weathering, radioactivity and, not least, mechanical and physical parameters are also mapped.

Since geological maps are available for all the investigated areas, the fieldwork was primarily concentrated around locating suitable places to take samples for mechanical investigations. The geology was appraised, but only with a view to judging the homogeneity within the relevant extraction areas.

Investigation of mechanical and physical properties involves some sampling. The extent of the sampling depends on variations in the geology of the area and qualitative differences which can be recorded by surface mapping of the rocks. Sampling is undertaken by "small-scale blasting" on the surface down to a depth of 0.5 metres. To obtain sufficient material for the mechanical test analyses, about 60 kg are taken from each sampling site.

Core drilling may occasionally be needed to determine conditions at depth.

4. ANALYSES AND REQUIREMENTS OF BUILDING RAW MATERIALS

The following analyses have been carried out at NGU: density, the Norwegian Impact Test (brittleness, flakiness, degree of compaction) abrasion and Los Angeles. The Polished Stone Value (PSV test) has been carried out by Messrs. Sandberg, England and Celtest Ltd. in Wales. The distribution of the minerals has been approximately estimated by thin-section analysis performed by Harald Skålvoll at NGU and Bjørge Brattli at NTNU. Appendix A describes these laboratory methods.

All the areas have been sampled by hand-sized samples amounting to a total of about 60 kg. Prior to the mechanical testing, the samples were crushed using laboratory crushers under controlled conditions. The material was then sieved to the various grain fractions used for the different test methods. The demands placed on aggregates refer chiefly to material prepared in a full-scale crushing and screening plant. Investigations have, however, shown [7] that analysis results from samples taken from the production, "production samples", may deviate considerably from virgin samples taken in the field, also called "geological specimen samples". The production samples will be dependent upon how well the material has been prepared in the crushing and screening plant. Mechanical testing of geological specimen samples gives a more neutral evaluation of the "inherent properties" of the rock as compared with production samples. When preparation in an aggregate plant is optimal, it is assumed that the analysis results for production samples will be comparable with the results of geological specimen samples crushed under controlled laboratory conditions.

Material intended to be used as aggregate in Norway must fulfil the demands of the Norwegian Impact Test and the abrasion method. In the Norwegian Impact Test, a stone category is estimated on the basis of values determined for brittleness and flakiness. For some areas of use, demands are also placed on resistance to wear (Wear), or the ball mill value (Bm). It is intended that the newly introduced ball mill method will replace the abrasion method. Appendix C summarises the current quality requirements for Norwegian aggregates. Table 3 gives a simplified summary of the Norwegian requirements for aggregates for use in road construction.

In general, the demands placed by roads with a high traffic load should be fulfilled, whereas those for roads with little traffic must be met if a deposit is to be of interest for extraction. The Norwegian Impact Test, abrasion method and ball mill method are also standard techniques in the other Nordic countries, except that testing is undertaken on somewhat different grain fractions.

Area of use	Type of road	St. categ.	Abr.	Wear	Bm
Surface	Road with specially high traffic load, ADT > 5000	≤ 1	≤ 0.40	≤ 2.0	≤ 6.0
"	Road with high traffic load, ADT 5000 - 15000	≤ 2	≤ 0.45	≤ 2.5	≤ 9.0
"	Road with moderate traffic load, ADT 3000 - 5000	≤ 2	≤ 0.55	≤ 3.0	≤ 11.0
"	Road with moderate traffic load, ADT 1500-3000	≤ 3	≤ 0.55	≤ 3.5	≤ 13.0
"	Road with little traffic, ADT < 1500	≤ 3	≤ 0.65	-	-
Foundation		≤ 4	≤ 0.75	-	-
Sub-foundation		≤ 5	≤ 0.75	-	-

Table 3.

Demands for stone category (St. categ.), abrasion value (Abr.), resistance to wear (Wear) and ball mill value (Bm) depending on the area of use. The table is simplified and is based on Appendix C.

Various testing methods are used elsewhere in Europe, but they often express the same mechanical loads as those resulting from the Norwegian and Nordic methods. Comparison shows that the correlation between the various testing methods is sometimes good [8]. The on-going CEN work (Comité Européen de Normalisation) has led to standardisation of the methods that are to apply for all EU/EFTA countries. The ball mill, Los Angeles and PSV are all approved as "CEN methods". Appendix D summarises the quality requirements for aggregates for some European countries. Table 4 gives a simplified summary of the requirements for aggregates for road construction purposes in some European countries.

In general, the demands for roads with a high traffic load should be fulfilled, whereas those for roads with little traffic must be met if a deposit is to be of interest for extraction.

Even though no demands are placed on the specific gravity of the rock, expressed as density, it should neither be too low nor too high (preferably < 2.80 g/cm^3). For certain purposes, such as large blocks for use in dykes, as heavy ballast, as material for covering oil pipelines on the sea floor, etc., demands on a minimum specific weight may be placed, but these are exceptional cases. The market share for special products with a high specific weight is relatively small.

For the USA market, locally available material will be given primary consideration before import of aggregates, almost irrespective of demands. The demands stipulated for asphalt surfaces vary from state to state and within different regions. This is partly because of variations in climate, availability of materials and traffic loads. The U.S. Department of Transportation, Federal Highway Administration has issued a recommendation that certain criteria should be followed in each state [9]. In order that a particular material can be used for asphalt surfaces it should have a Los Angeles value that is less than 45. For use for foundations and sub-foundations, it is expected that the demands that are stipulated will be less strict.

Country	Area of use	Type of road	LA	PSV
	Road surface	Motorways, special demands	< 16	> 65
England	"	Roads with normal traffic loads	< 25	> 55
	"	Roads with little traffic	< 30	> 45
	Foundation and sub-foundation		< 35	-
	Road surface	Motorways, special demands	< 15	> 55
Germany	"	Roads with normal traffic loads	< 20	> 50
	"	Roads with little traffic	< 30	> 43
	Foundation and sub-foundation		< 40*	-
	Road surface	Motorways, special demands	< 15	> 50
France	"	Roads with normal traffic loads	< 20	> 50
	"	Roads with little traffic	< 25	> 40
	Foundation and sub-foundation		< 30	-
	Road surface	Motorways, special demands	?	> 65
Netherlands	"	Roads with normal traffic loads	?	> 53
	"	Roads with little traffic	?	> 48
	Foundation and sub-foundation		?	-
	Road surface	Motorways, special demands	?	?
Belgium	"	Roads with normal traffic loads	?	> 50
	"	Roads with little traffic	?	?
	Foundation and sub-foundation		?	-

* Demand depends on rock type

Table 4.

Demands regarding the Los Angeles value (LA) and the Polished Stone Value (PSV) for some European countries depending on the area of use. The table is simplified and is based on Appendix D.

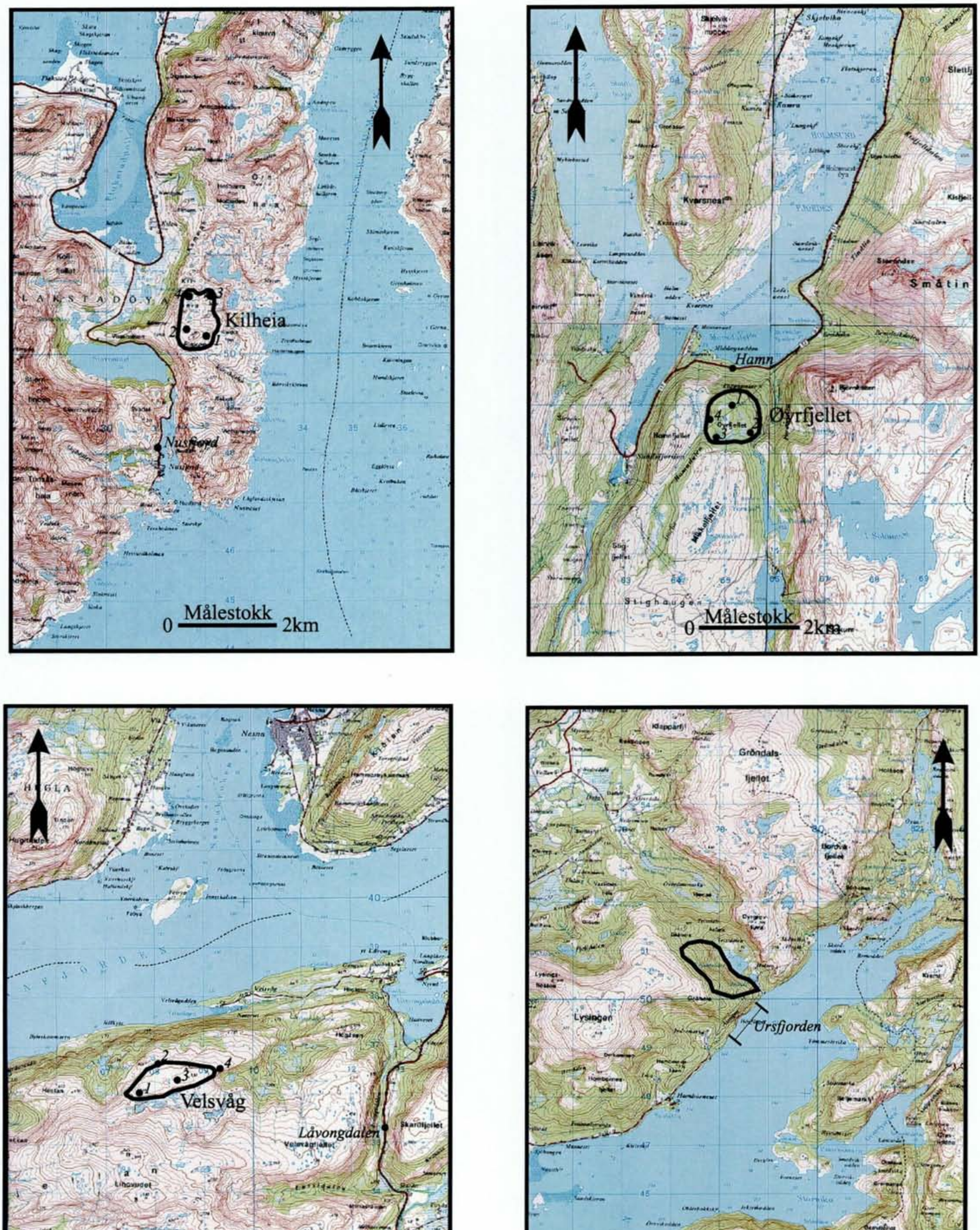
5. RESULTS

5.1 Opportunities for extraction

Table 5 gives a joint appraisal of some important criteria for new extraction sites for aggregates in the five areas (figure 2 and 3, see section 3.1 and Table 2).

Criteria	Råna	Kilheia	Øyrfjellet	Velsvåg	Ursfjorden
Location	Favourable	Favourable	Favourable	Favourable	Favourable
Reserves	?Favourable	?Favourable	?Favourable	?Favourable	?Favourable
Sea depth/fjord width	Favourable	Favourable	Favourable	Favourable	Favourable
Climatic conditions	Unknown	Unknown	Unknown	Unknown	Unknown
Environmental aspects	Favourable	Favourable	Favourable	Favourable	Favourable

Table 5.


Kilheia
Nusfjord
0 Målestokk 2km
Hamn
Øyrfjellet
0 Målestokk 2km
Velsvåg
Låvongdalen
0 Målestokk 2km
Ursfjorden
0 Målestokk 2km

Figur 2.

Figure 3.

5.2 Brief summary of bedrock geology

The geology within all the five areas is well documented through previous geological mapping [10-18]. The dominant rock type in the areas that have been investigated is given in Table 6.

	Råna	Kilheia	Øyrfjellet	Velsvåg	Ursfjorden
Rock type	Norite	Anorthosite	Granite	Porphyritic granite	Gabbro

Table 6.

5.3 Results of analyses

Representative analysis values for the five areas investigated are given in Table 7.

	Råna	Kilheia	Øyrfjellet	Velsvåg	Ursfjorden
Density	3.14	2.84	2.61	2.75	2.89
Degree of compaction	2	1	1	1	1
Brittleness	43.7	49.6	59.5	50.9	44.2
Flakiness	1.29	1.29	1.32	1.33	1.33
Stone category	2	3	5	3	2
Abrasion	0.67	0.58	0.81	0.62	0.67
Wear	4.4	4.1	6.2	4.4	4.5
Ball mill value	-	15.3	-	15.3	16.3
Los Angeles value	29.1	28.4	43.5	25.3	24.8
PSV	60	49	-	52	52

Table 7. Mechanical and physical properties.

Statistics from NGUs Aggregates Register show that samples from Nordland on the whole have poorer mechanical properties than other parts of the country. Part of the explanation for this may be that Nordland rocks are more prone to surface weathering. This will negatively affect samples blasted from the surface zone. As a control measure, reference samples were taken, preferably in rock cuts and at greater depths below the surface.

In Råna, surface weathering is extreme in some places. Most samples from the area show far poorer mechanical properties than those cited in Table 7. The reason why the other samples are poorer is not primarily surface weathering. The variation can be explained in terms of mineralogy. The norite chiefly consists of the minerals plagioclase and pyroxene. Plagioclase has a negative effect in that both the brittleness and abrasion values increase with rising contents of plagioclase. Pyroxene displays the opposite effect, since its mechanical properties become better as the content of this mineral rises.

The surface weathering at Kilheia is substantial. Despite this, there is little difference in the mechanical properties between the samples blasted from the surface and the reference sample taken in a fresh road cut. The samples blasted within the potential extraction site are therefore considered to be representative for the quality that can be expected at depth.

The results from Øyrfjellet show poorer analysis values than is usual for this type of rock. Substantial surface weathering may be present and it may be questionable whether the reference sample was taken sufficiently deeply beneath the surface.

Little mechanical variation exists between the samples blasted from within the potential extraction site at Velsvåg, thus implying that the material is homogeneous. The reference sample taken in a road cut in Låvongdalen shows better results and it is these values that are cited in Table 7. It is assumed that the blasted samples are somewhat influenced by their position at the surface and are therefore poorly representative.

Only one sample was taken in the area at Ursfjorden, and that came from a road cut. According to the statistics from the Aggregates Register, the analysis results are within the range that is usual for this type of rock nationally. In general, there will be little variation in the mechanical properties of plutonic rocks, but if the grain size of the rock varies, changes in the mechanical properties must be expected. Fine-grained plutonic rocks usually give better results than coarse-grained ones. As the grain size of this particular sample is relatively coarse, it is unlikely that poorer mechanical properties will be attained than this sample gives. Even though more samples have not been taken within the potential extraction area, the road-cut sample is believed to be representative for the area.

5.4 Use as building raw material

If the results in Table 7 are regarded as valid for what can be expected to be attained within the five areas, a suitability evaluation can be made relative to the requirements stipulated by some European countries for road construction purposes and concrete (Table 8, see also Tables 3 and 4).

The material is entirely suitable for delivery to the "offshore market" to support and cover pipelines and other installations.

For export to the USA, the quality of the material is adequate for use for road construction purposes, according to the information that is available regarding stipulated quality demands.

Country	Area of use	Type of road	Råna	Kilheia	Øyrfjellet	Velsvåg	Ursfjorden
England	Road surface	Motorway, special demands	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable
	"	Normal traffic load	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable
	"	Light traffic load	Suitable	Suitable	Unsuitable	Suitable	Suitable
	Foundation and sub-foundation		Suitable	Suitable	Unsuitable	Suitable	Suitable
Germany	Road surface	Motorway, special demands	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable
	"	Normal traffic load	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable
	"	Light traffic load	Suitable	Suitable	Unsuitable	Suitable	Suitable
	Foundation and sub-foundation		Suitable	Suitable	Unsuitable	Suitable	Suitable
France	Road surface	Motorway, special demands	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable
	"	Normal traffic load	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable
	"	Light traffic load	Unsuitable	Unsuitable	Unsuitable	Unsuitable/Suitable	Suitable
	Foundation and sub-foundation		Suitable	Suitable	Unsuitable	Suitable	Suitable
Netherlands	Road surface	Motorway, special demands	Unsuitable	Unsuitable	?/Unsuitable	Unsuitable	Unsuitable
	"	Normal traffic load	? / Suitable	?/Unsuitable	?/Unsuitable	?/Unsuitable	?/Unsuitable
	"	Light traffic load	? / Suitable	? / Suitable	?/Unsuitable	? / Suitable	? / Suitable
	Foundation and sub-foundation		? / Suitable	? / Suitable	?/Unsuitable	? / Suitable	? / Suitable
Belgium	Road surface	Motorway, special demands	?	?	?	?	?
	"	Normal traffic load	? / Suitable	? / Suitable	?/Unsuitable	? / Suitable	? / Suitable
	"	Light traffic load	? / Suitable	? / Suitable	?/Unsuitable	? / Suitable	? / Suitable
	Foundation and sub-foundation		? / Suitable	? / Suitable	?/Unsuitable	? / Suitable	? / Suitable
Norway	Road surface	Specially high traffic load	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable
	"	High traffic load	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable
	"	Medium traffic load <5000	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable
	"	Medium traffic load <3000	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable
	"	Low traffic load	Unsuitable	Suitable	Unsuitable	Suitable	Unsuitable
	Foundation		Suitable	Suitable	Unsuitable	Suitable	Suitable
	Sub-foundation		Suitable	Suitable	Suitable	Suitable	Suitable
All countries	For concrete		Suitable	Suitable	Suitable	Suitable	Suitable

Table 8. Suitability evaluations for road construction purposes and concrete in a number of European countries.

6. OVERALL APPRAISAL OF THE RESULTS

To appraise the quality of the rocks, a verbal ranking has been undertaken in Table 10. This ranking is based on the suitability evaluation for road construction purposes and concrete (Table 8) in accordance with the following classification:

Quality of rock	Suitability evaluation
Very good	Suitable for all road construction purposes and for concrete
Good	Suitable for at least roads with normal and high traffic loads, and for concrete
Moderate	Suitable for at least roads with light traffic loads, and for concrete
Poor	Suitable for foundations and sub-foundations, and for concrete
Very poor	Unsuitable for road construction purposes and concrete

Table 9.

Country	Råna	Kilheia	Øyrfjellet	Velsvåg	Ursfjorden
England	Moderate	Moderate	Very poor	Moderate	Moderate
Germany	Moderate	Moderate	Very poor	Moderate	Moderate
France	Poor	Poor	Very poor	Very poor - Poor	Moderate
Netherlands	? Good	? Moderate	Very poor	? Moderate	? Moderate
Belgium	? Good	? Good	Very poor	? Good	? Good
Norway	Poor	Moderate	Very poor - Poor	Moderate	Poor
QUALITY OF ROCK	Moderate	Moderate	Very poor	Moderate	Moderate

Table 10. Appraisal of bedrock quality based on suitability evaluations for road construction purposes and concrete in a number of European countries

Because requirements vary with regard to both the area of use and the European country concerned, it is difficult to give an overall appraisal of the quality of the rock types.
For instance, a particular rock type may be perfectly suitable for foundations and sub-foundations and roads with low traffic loads, but unsuitable for the surface layer (poor resistance to wear). Bearing this reservation in mind, the quality of the rock is appraised in accordance with Table 10 as being very poor at Øyrfjellet and moderate at Råna, Kilheia, Velsvåg and Ursfjorden.

For most uses, raw material should have as low a density as possible, preferably < 2.80 g/cm^3. The density at Øyrfjellet and Velsvåg is thus favourable. At Kilheia and Ursfjorden, it is somewhat high, and at Råna it is a little too high.

For large-scale working, areas with raw material that is as homogeneous as possible are to be preferred. Based on the density analysis and the degree of compaction following the Norwegian Impact Test, along with the geology in the five areas investigated, the homogeneity is considered to be specially favourable at Kilheia, Velsvåg and Ursfjorden.

Owing to poor exposure, it is difficult to evaluate Øyrfjellet, but based on the rock type which occurs in the area it is assumed that the homogeneity is favourable here, too. Since some mineralogical differences have been recorded in the geology within the Råna deposit, which influence the mechanical properties, this area is assumed to be less homogeneous.

For the establishment of large-scale working, the area at Øyrfjellet is considered to be without interest because of the quality of the rock. The quality of the rock in the other four areas, too, is on the borderline of what should be accepted as the minimum requirement. The results are summarised in Table 11.

Criteria	Råna	Kilheia	Øyrfjellet	Velsvåg	Ursfjorden
Location	Favourable	Favourable	Favourable	Favourable	Favourable
Reserves	?Favourable	?Favourable	?Favourable	?Favourable	?Favourable
Sea depth/fjord width	Favourable	Favourable	Favourable	Favourable	Favourable
Climatic conditions	Unknown	Unknown	Unknown	Unknown	Unknown
Environmental aspects	Favourable	Favourable	Favourable	Favourable	Favourable
Rock type	Norite	Anorthosite	Granite	Porphyritic granite	Gabbro
Density	Less favourable	? Favourable	Favourable	Favourable	? Favourable
Bedrock homogeneity	Less favourable	Favourable	Favourable	Favourable	Favourable
Quality of bedrock	Moderate	Moderate	Very poor	Moderate	Moderate

Table 11.

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*** Norwegian Impact Test (brittleness and flakiness)**
*** Abrasion**
*** Resistance to wear**
*** Ball mill**
*** Los Angeles**
*** Polished Stone Value (PSV)**
*** Thin section**

Norwegian Impact Test (brittleness and flakiness)

The ability of stone to resist mechanical impact stress can be determined by, for instance, the Norwegian Impact Test. This method is widely used in the Nordic countries (the way the test is carried out varies somewhat from country to country) and can to some extent be compared with the British 'aggregate impact test', the German 'Schlagversuch' and the American 'Los Angeles test'.

The Norwegian Impact Test consists of the crushing of a specific fraction, 8.0-11.2 mm, of gravel or aggregate of known grain shape in a drop apparatus. The apparatus consists of a mortar in which the test material is exposed to the impact of a 14 kg weight falling 20 times from a height of 25 cm. The proportion of the test material whose grain size after crushing is less than the minimum grain size of the original fraction, in this case 8.0 mm, is called the uncorrected brittleness value (S_0). This value is corrected for the degree of compaction in the mortar after the impact, permitting the **brittleness value (S_8)** to be calculated.

The average grain shape of the material is expressed by the **flakiness value**, which is a physical property indicating the relationship between the mean width and thickness of the grains. The flakiness test is performed as part of the Norwegian Impact Test and is determined on the same sieved grain-size fraction as the brittleness value. Flakiness verifications may, in addition, be made on any fractions desired. The width is determined on a sieve with a square mesh and the thickness on a sieve with a rectangular mesh. The method is used for both natural gravel and aggregate.

The results of the Norwegian Impact Test may vary from laboratory to laboratory, but the apparatus used has been reasonably well standardised since 1988. Unless otherwise stated, the brittleness value is given as an average of three separate measurements.

The material is usually tested twice in the drop apparatus. The brittleness value for the repeated impact, the repeated impact value, expresses the resistance of the material to repeated impact stress. The repeated impact value often reflects the improvement in quality which can be achieved by employing several stages of crushing in a crushing mill.

Stone is classified into stone categories based on the results of the Norwegian Impact Test. Five categories are recognised, depending on the brittleness and flakiness values.

Stone category	Brittleness	Flakiness
1	≤ 35	≤ 1.45
2	≤ 45	≤ 1.50
3	≤ 55	≤ 1.50
4	≤ 55	≤ 1.60
5	≤ 60	≤ 1.60

Classification of stone materials according to the Norwegian Impact Test. Stone category 1 is best and 5 is worst.

The brittleness and flakiness results may vary, depending on how the material has been sampled and handled prior to the Norwegian Impact Test itself. It is either collected as geological-specimen samples (hand-sized specimen of rock), or taken from a specific fraction prepared in a crushing mill (production sample).

Hand-specimen sampling is often employed when new areas that are of interest for extracting rock are being investigated. The sample is usually taken from a blasted road cut, or is blasted from a rock exposure. In both cases, the material will be exposed to crushing in connection with the blasting. Occasionally, hand-specimen samples are taken without them having been exposed to blasting. This occurs, for example, when a sample is taken from a scree, or struck directly off an exposure with a sledgehammer. In such cases, the rock must lack surface weathering. Hand specimens are always crushed in laboratory mills before undergoing the Norwegian Impact Test itself.

Hand-specimen sampling may also be carried out in an aggregate plant, but it is generally of greater interest to investigate the quality of the material after it has been through the crushing and screening plant (production samples). In the crushing plant, it is usual to crush the material in several stages. This improves its quality because it attains a more cubic grain shape (lower flakiness value), and also gives a better brittleness value. This processing effect depends to some extent on the type of rock.

Production samples must be handled in accordance with the following guidelines:

a) For screened material with a stated upper grain size of less than 22 mm
the Norwegian Impact Test is performed on the 8.0-11.2 mm fraction screened from the product concerned, provided that that fraction comprises at least 15% of the product. If this requirement cannot be fulfilled, the Norwegian Impact Test is performed according to alternative b).

b) For screened material with a stated upper grain size in excess of 22 mm
the Norwegian Impact Test is performed on the 8.0-11.2 mm fraction of the product concerned sieved from material crushed in the laboratory.

In addition, in the case of production samples, verification of flakiness must be undertaken on the coarse fraction of plant-produced material in one of the following fractions: 11.2-16.0 mm, 16.0-22.4 mm, 22.4-32.0 mm, 32.0-45.2 mm or 45.2-64.0 mm. A fraction must be chosen which corresponds to at least 15% of the product and which is as close as possible to the stated upper grain-size limit of the product. Material that is produced must maintain a flakiness value > 11.2 mm.

Abrasion

Abrasion, or the **abrasion value**, expresses the abrasive resistance to wear or resistance to scratching, of the material. The abrasion method is a Nordic method (the way the test is carried out varies somewhat from country to country) evolved from the British aggregate abrasion test. It is chiefly used for quality appraisal of aggregate for asphalt wearing surfaces on roads with an annual daily traffic (ADT) load in excess of 1500 vehicles. Maximum abrasion values have also been introduced for aggregate to be used for roadbase and sub-base courses.

A representative selection of aggregate grains in the 11.2-12.5 mm fraction is cast on a square plate (10x10 cm) which is pressed with a given weight against a rotating disc carrying a standard grinding powder. The wear, or abrasion, is defined as the volume loss of the sample expressed in cubic centimetres.

The following classification is used:

< 0.35	**very good**
0.35-0.45	**good**
0.45-0.55	**moderate**
0.55-0.65	**poor**
> 0.65	**very poor**

Resistance to wear

The brittleness, flakiness and abrasion values are measured to determine the suitability of stone as aggregate for asphalt road surfaces. The resistance of the material to wear from studded tyres, called the resistance to wear (WR value) is expressed as the product of the square root of the brittleness value (S_8) and the abrasion value.

The following classification is used:

< 2.0	**very good**
2.0-2.5	**good**
2.5-3.5	**moderate**
3.5-4.5	**poor**
> 4.5	**very poor**

Ball mill

The ball mill method, like the abrasion method, expresses the resistance to wear of the stone. It has been introduced as a Nordic method in connection with the European standardisation programme for aggregates (CEN/TC 154). It is designed to determine the resistance of aggregate to wear deriving from studded tyres. The method should in due course replace the abrasion method.

Briefly, the method is as follows. 1 kg of stone in the 11.2-16.0 mm fraction is rotated in a drum for 1 hour at 5400 revolutions per hour together with 7 kg of steel balls and 2 litres of water. The drum has a specific shape and is equipped with three devices which raise and mix its contents as it rotates. The stone is exposed to both impact and wear, but mainly wear. After the rotation period, the material is wet sieved and dried. After weighing, the proportion that passes through a 2 mm square-mesh sieve is calculated. This expresses the wear, and is termed the **ball mill value (K_m).**

The following classification is used:

≤ 7.0	**category A**
≤ 10.0	**category B**
≤ 14.0	**category C**
≤ 19.0	**category D**
≤ 30.0	**category E**
No demand	**category F**

Category A is best and category F worst.

Los Angeles

The Los Angeles test expresses the ability of material to resist both impact and wear. The method is originally American, but has been in use for many years in several European countries, for instance by the Norwegian State Railways (NSB) in Norway. It can be performed using the standard American procedure, ASTM C131 (fine aggregate) and ASTM C535 (coarse aggregate), or the new European CEN procedure prEN 1097-2, §4.

When the CEN procedure is used, 5 kg of stone in the 10.0-14.0 mm fraction are rotated in a drum together with 11 steel balls. The inside of the drum is equipped with a steel plate which, as the drum revolves, lifts the material and the steel balls up before dropping them again. After about 15 minutes and 500 revolutions, the material is removed, wet sieved and dried. After weighing, the proportion that passes through a 1.6 mm square-mesh sieve is calculated. This expresses the mechanical load and is called the **Los Angeles value** (the **LA value**).

The following classification is used:

≤ 15.0	**category A**
≤ 20.0	**category B**
≤ 25.0	**category C**
≤ 30.0	**category D**
≤ 40.0	**category E**
≤ 50.0	**category F**
No demand	**category G**

Category A is best and category G worst.

Polished Stone Value (PSV)

PSV is a British method used for recording the resistance to polishing of aggregates that are to be used in road surfaces. In central Europe, it is desirable to have road surfaces with a high resistance to friction to avoid them becoming slippery. This is not a problem in Nordic countries because the studded tyres used in winter roughen the surface of the aggregate in the surface layer.

The test procedure requires that 35 to 50 particles of a specific grain fraction, < 10 mm in a square-mesh sieve and > 7.2 mm in a rectangular-mesh sieve are cast on a convex, rectangular sheet (90.6 x 44.5 mm). 12 test sheets (4 for each sample) and 2 control sheets are mounted on a road wheel that is itself mounted vertically on a polishing machine. The wheel rotates for 3 hours at 315-325 revolutions per minute. It is loaded by a wheel consisting of compact rubber that is rotated in the opposite direction from the road wheel.

Water and grinding powder are applied to the rubber wheel. After the test sheets have been in the polishing machine for the allotted time, the polishing resistance is measured with a pendulum apparatus. A pendulum arm is brushed across the test sheet giving a reaction on a calibrated scale. This reaction is the friction coefficient, stated as a percentage and also called the PSV value.

The following classification is used:

≥ 68.0	category A
≥ 62.0	category B
≥ 56.0	category C
≥ 50.0	category D
≥ 44.0	category E
No demand	category F

Category A is best and category F worst.

Thin section

The term thin section is used for a thin slice of a rock that is glued to a glass slide. This forms the basis for the microscopic determination of minerals and their relative occurrence. When polarised light passes through the transparent slice, which is usually approximately 0.020 mm thick, the various minerals will be identifiable in the microscope owing to their characteristic optical properties.

The distribution of the minerals, along with the visual appraisal of structures in the terrain, form the basis for deciding the rock type. The microscopic examination also permits the study of internal textures, the shape and size of mineral grains, alteration phenomena and the mode of formation of the rock, etc.

Special textures can be observed, such as microfractures between the minerals, or rod-shaped feldspar grains which function as a kind of armour in an otherwise granular groundmass (ophitic texture). Foliation is another term which is often used in rock descriptions. That a rock is foliated means that the constituent minerals have a preferred planar axial orientation, or are concentrated in narrow, parallel layers or laminae. The grain size of the minerals is divided on the following scale:

< 1 mm - fine grained
1-5 mm - medium grained
> 5 mm - coarse grained

A thin section usually covers about 5 square centimetres. The result of one thin-section analysis is therefore rarely fully representative of the rock.

Road building purposes

The requirements for crushed stone (made from crushed rock / aggregate) vary depending upon which course in the road structure the material will be used in. The road structure may be divided into five parts: filter course, sub-base, roadbase, base-course and surface course. The last two comprise the road surface itself. Crushed stone is an important component of the sub-base, roadbase and surface courses.

Stone of stone category 4 or better is required in the upper part of the sub-base, whereas its lower part requires category 5 or better. The flakiness value of material > 11.2 mm must be < 1.70. The abrasion value must be < 0.75.

The demands for the roadbase vary depending on the type of roadbase. The choice of roadbase depends on the average annual daily traffic load (ADT). Table 1 shows the requirements of the various types of roadbase course.

TYPE OF ROADBASE		ADT				
			300	1500	5000	15000
Crushed rock Cr	Stone category Flakiness value > 11.2 mm Abrasion value	3 1.55	3 1.55 (0.65)	3 1.55 (0.65)		
Compacted aggreg. Ca	Stone category Flakiness value > 11.2 mm Abrasion value	3 1.60	3 1.60 (0.65)	3 1.60 0.65	3 1.60 0.65	
Compaction aggreg. Cag	Stone category Flakiness value > 11.2 mm Abrasion value	3 1.50	3 1.50 (0.65)	3 1.50 0.65	3 1.50 0.65	
Asphalt-mixed aggreg. Aa	Stone category Flakiness value > 11.2 mm Abrasion value			4 1.60 (0.65)	3 1.55 0.65	3 1.55 0.65
Penetrated aggreg. Pa	Stone category Flakiness value > 11.2 mm Abrasion value		5 1.60 (0.75)	5 1.60 0.75	5 1.60 0.75	4 1.60 0.75
Cold aggreg. Coa	Stone category Flakiness value > 11.2 mm Abrasion value	4 1.60	4 1.60	3 1.55 (0.65)	3 1.55 0.65	
Cement-stabilised aggreg. Csa	Stone category Flakiness value > 11.2 mm Abrasion value			(5) 1.50	(5) 1.50	5 1.50

Shaded cells signify "not a usual area of use". ( ) = desirable abrasion values

Table 1
Requirements for maximum values for stone category and flakiness of material > 11.2 mm and for the abrasions value for material for a roadbase of crushed stone.

Three types of road surface can be distinguished: asphalt, gravel and concrete. Crushed rock is normally used in all three types of surface. The requirements for road surfaces are given in Table 2 a-c.

ASPHALT SURFACE		ADT					
			300	1500	3000	5000	15000
Cast asphalt, Ca	Stone category Flakiness value > 11.2 mm Abrasion value Resistance to wear Ball mill value					2 1.45 0.45 2.5* 9.0	1 1.45 0.40 2.0 6.0
Topeka, Top	Stone category Flakiness value > 11.2 mm Abrasion value Resistance to wear Ball mill value					2 1.45 0.45 2.5* 9.0	1 1.45 0.40 2.0 6.0
Skeleton asphalt, Ska	Stone category Flakiness value > 11.2 mm Abrasion value Resistance to wear Ball mill value				2 1.45 0.55 3.0 11.0	2 1.45 0.45 2.5* 9.0	1 1.45 0.40 2.0 6.0
Asphalt concrete, Ac	Stone category Flakiness value > 11.2 mm Abrasion value Resistance to wear Ball mill value			3 1.45 0.55 3.5 13.0	3 1.45 0.55 3.0 11.0	2 1.45 0.45 2.5* 9.0	1 1.45 0.40 2.0 6.0
Drain asphalt, Da	Stone category Flakiness value > 11.2 mm Abrasion value Resistance to wear Ball mill value			3 1.45 0.55 3.5 13.0	2 1.45 0.55 3.0 11.0	2 1.45 0.45 2.5* 9.0	
Asphalt gravel concrete, Agc	Stone category Flakiness value > 11.2 mm Abrasion value Resistance to wear Ball mill value	3 1.50	3 1.50 (0.65)	3 1.50 0.55 3.5 13.0			
Soft asphalt, Sa Soft drain asphalt, Sda	Stone category Flakiness value > 11.2 mm Abrasion value Resistance to wear Ball mill value	3 1.50	3 1.50 (0.65)	3 1.45 (0.55) 3.5 13.0			
Cold gravel, Cg, Cd	Stone category Flakiness value > 11.2 mm Abrasion value Resistance to wear Ball mill value	3 1.50	3 1.45 (0.65)	3 1.45 0.55 3.5 13.0			
Surface treatment, St DSt	Stone category Flakiness value > 11.2 mm Abrasion value Resistance to wear Ball mill value	3 1.50	3 1.45 (0.55)	3 1.45 0.50 3.5 13.0			
Surface treatment with gravel, Stg, DStg	Stone category Flakiness value > 11.2 mm Abrasion value	3 1.50	3 1.45				
Oil gravel, Og	Stone category Flakiness value > 11.2 mm Abrasion value	3 1.50	3 1.45				
Asphalt scum gravel, Asg	Stone category Flakiness value > 11.2 mm Abrasion value	3 1.50	3 1.50				

Shaded cells signify "not a usual area of use". ( ) = desirable abrasion values

* Stricter demands should be considered for ADT > 10,000

Table 2a
Requirements for maximum values for stone category, flakiness of material > 11.2 mm, abrasion value, resistance to wear and ball mill value for aggregates for asphalt surfaces.

GRAVEL SURFACES		ADT					
		300	1500	3000	5000	15000	
Gravel	Stone category Flakiness value > 11.2 mm	3 1.50					

Shaded cells signify "not a usual area of use".

Table 2b
Requirements for maximum values for stone category and flakiness of material > 11.2 mm for aggregates for gravel surfaces.

CONCRETE SURFACES		ADT					
		300	1500	3000	5000	15000	
Concrete, C70 - C90	Stone category Flakiness value > 11.2 mm Abrasion value					2 1.45 0.45	1 1.45 0.40
Concrete, C40 - C70	Stone category Flakiness value > 11.2 mm Abrasion value				3 1.45 0.55	2 1.45 0.45	2 1.45 0.40
Rolled concrete, C35 - C55	Stone category Flakiness value > 11.2 mm Abrasion value		3 1.45 (0.65)	3 1.45 0.55	3 1.45 0.55		

Shaded cells signify "not a usual area of use". ( ) = desirable abrasion values

Table 2c
Requirements for maximum values for stone category, flakiness of material > 11.2 mm and abrasion value for aggregates for concrete surfaces.

With a few exceptions, Table 2a, requirements for asphalt surfaces, may be simplified as shown in Table 3.

Property	Annual daily traffic (ADT)					
Stone category	1 - 3			1 - 2		1
Abrasion value	-	(≤0.65)	≤ 0.55		≤ 0.45	≤ 0.40
Resistance to wear	-		≤ 3.5	≤ 3.0	≤ 2.5*	≤ 2.0
Ball mill value	-		≤ 13.0	≤ 11.0	≤ 9.0	≤ 6.0

Figure in brackets indicates the desired value.

* Stricter demands should be considered for ADT > 10,000

Table 3
Requirements for stone category, abrasion value, resistance to wear and ball mill value for surface aggregates. **Exceptions in the table** concern asphalt concrete, which accepts up to stone category 3 for ADT < 5000 and surface treatments where the requirements for the abrasion value are £ 0.50 for ADT 1500-3000 and (£ 0.55) for ADT 300-1500.

Concrete purposes

Apart from the flakiness value, no specific demands have been stipulated for the mechanical properties of crushed aggregates for concrete. The flakiness value should be less than 1.45 for the 11.2-16.0 mm fraction. Experience has shown that flakiness depends more upon the crushing equipment and the crushing process than the mineral content and the texture of the rock.

In general, rocks intended for use for concrete should be "mechanically good" and contain as little mica as possible (the kind of mica is decisive, but preferably < 10%). An excessive content of certain sulphides (iron pyrites, pyrrhotite) is undesirable.

Manufacture of high tensile concrete calls for such high compactness that the aggregate constitutes the weak link. The demand on the mechanical properties is therefore greater, but no detailed quality criteria are available.

Silicic acid in quartz crystals, capable of dissolving alkalis, may react with the cement paste and result in concrete fracturing and expanding in volume. In recent years, a number of concrete constructions in Norway have been found to have been damaged by alkaline reactions (AR). The chemical reaction is extremely slow and only takes place under unfavourable conditions with high moisture and temperature stress, such as on bridges and dams. The damage is often not discovered before 15 to 20 years elapse. The detrimental reactions may be linked with the following <u>potentially</u> alkali-reactive rock types:

* Sandstone/greywacke/siltstone
* Mylonite/cataclasite
* Rhyolite/acid volcanic rocks
* Argillite/phyllite
* Quartzite (microcrystalline and fine grained)

In addition, the following are classified as <u>possibly</u> alkali reactive:

* Quartzite (fine grained/quartz schist)
* Fine-grained quartz-rich rocks
* Limestone with pelitic texture

This list of detrimental rocks is not final. New research continually leads to revisions.

Road building purposes

The following requirements apply in England:

Road construction		Testing method	Traffic load (cv/lane/day) 1500 6000		
Non-bonded		LA	< 35	< 30	< 25
		ACV	< 30	< 27	< 23
		AIV	< 30	< 27	< 23
		10% fines	> 100	> 115	> 130
Asphalt bonded	Surface dressing, pervious macadam	LA	< 25		< 16
		ACV	< 23		< 16
		AIV	< 23		< 16
		10% fines	> 130		-
	Dense wearing course	LA	< 30		< 25
		ACV	< 27		< 23
		AIV	< 27		< 23
		10% fines	> 115		> 130
	Roadbase and sub-base	LA	< 35		
		ACV	< 30		
		AIV	< 30		
		10% fines	> 100		
Cement bonded	Cement surface	LA	< 35		< 30
		ACV	< 30		< 27
		AIV	< 30		< 27
		10% fines	> 100		> 115
	Roadbase and sub-base	LA	< 35		
		ACV	< 35		
		AIV	< 35		
		10% fines	> 50		

Table 1.
Critical limiting values for some mechanical testing methods relative to the traffic load (cv/lane/day) and type of road construction

LA - Los Angeles, ACV - aggregate crushing value,
AIV - aggregate impact value, 10% fines - dry state.

<table>
<tr><th rowspan="2">Road surface</th><th colspan="5">Traffic load
(cv/lane/day)</th></tr>
<tr><th colspan="5">250 1000 1750 2500 3250 4000</th></tr>
<tr><td>Chippings</td><td>< 14</td><td colspan="2">< 12</td><td colspan="2">< 10</td></tr>
<tr><td>Wearing courses</td><td colspan="2">< 16</td><td colspan="2">< 14</td><td>< 12</td></tr>
</table>

Table 2.
Critical limiting values for aggregate abrasion value (AAV) relative to the traffic load (cv/lane/day) and road surface.

<table>
<tr><th rowspan="2">Road category</th><th rowspan="2">Proportion road length in England</th><th colspan="7">Traffic load (cv/lane/day)</th></tr>
<tr><th></th><th>250</th><th>1000</th><th>1750</th><th>2500</th><th>3250</th><th>4000</th></tr>
<tr><td>A1</td><td>< 0.1%</td><td>> 60</td><td>> 65</td><td>> 70</td><td colspan="4">> 75</td></tr>
<tr><td>A2</td><td>< 4%</td><td colspan="3">>60</td><td>> 65</td><td>> 70</td><td colspan="2">> 75</td></tr>
<tr><td>B</td><td>< 15%</td><td colspan="3">> 55</td><td colspan="3">> 60</td><td>> 65</td></tr>
<tr><td>C</td><td>< 81%</td><td colspan="7">> 45</td></tr>
</table>

Table 3.
Critical limiting values for the polished stone value (PSV) relative to the traffic load (cv/lane/day) and road category:

A1 - At traffic lights, pedestrian crossings and on dangerous stretches of road in built-up areas
A2 - At major crossroads, roundabouts, sharp bends and on steep inclines
B - Motorways, main roads, other roads with traffic loads > 250
C - Roads with light traffic loads (cv/lane/day < 250) and roads without risk of frictional accidents.

The following requirements apply in Germany:

	Number of vehicles weighing > 5 tonnes				
	>3000	3000-1500	1500-500	500-100	<100
Road category	I	II	III	IV	V
Asphalt road surfaces	18 (20)	18 (20)	18 (20)	22 (25)	26 (30)
Bonding course	18 (20)	18 (20)	22 (25)	26 (30)	26 (30)
Special uses	15 (15)	15 (15)	15 (15)	-	-

Table 4.
Limiting values for the Schlagversuch value (Los Angeles value) relative to the traffic load, road category and area of use. The Los Angeles values are not real, but have been calculated on the basis of the ratios between the two methods as they appear in Table 5.

The Schlagversuch values, the Los Angeles values and the Swedish impact test have been correlated (Høbeda 1981). On this basis and the categories valid for Europe, it is possible to prepare the following correlation table showing the limiting values for these methods:

Category (LA)	Los Angeles (LA)	Brittleness value	Schlagver such (SL)	Category
A	≤ 15	≤ 40	≤ 15	-
B	≤ 20	≤ 45	≤ 18	A/B
C	≤ 25	≤ 50	≤ 22	C
D	≤ 30	≤ 60	≤ 26	D/E
E	≤ 40	-	≤ 32	F
F	≤ 50	-	-	

Table 5.

	Number of vehicles weighing > 5 tonnes				
	>3000	3000-1500	1500-500	500-100	<100
Road category	I	II	III	IV	V
Asphalt road surfaces	> 50			> 43	
Special uses	> 55				

Table 6.
Proposal for limiting values for PSV relative to traffic load, road category and area of use

Rock type	Granite Syenite	Diorite Gabbro	Quartz porphyry Keratophyre Porphyrite Andesite	Basalt Dolerite	Limestone Dolomite	Greywacke Quartzite Vein quartz Quartz sandstone	Gneiss Granulite Amphibolite
Schlagversuch value	10 - 22	8 - 18	9 - 22	7 - 17	16 - 30	10 - 22	10 - 22

Table 7.
Permitted Schlagversuch values for roadbase material for some rock types.
Values vary between 7 and 30.

The following requirements apply in France:

ROADBASE AND SUB-BASE COURSES	TESTING METHOD	Number of vehicles weighing > 5 tonnes							
			75	100	150	300	500	600	1000
Asphalt gravel	Los Angeles	< 30			< 25				
Cement-stabilised gravel	Los Angeles	< 35		< 30					
Roadbase gravel	Los Angeles	≤ 30	≤ 25		≤ 20				

Table 8
Requirements for roadbase and sub-base courses courses for various traffic loads.

WEARING SURFACE	TESTING METHOD	Number of vehicles weighing > 5 tonnes							
		1000	75	100	150	300	500	600	
Surface treated	Los Angeles	-	< 25		< 20	< 15			-
	PSV	> 40	> 40		> 40	> 45			> 45
Asphalt concrete	Los Angeles	< 20							< 15
	PSV	> 50							> 50
Asphalt gravel	Los Angeles	< 30						< 25	
Cement-stabilised gravel	Los Angeles	< 35					< 30		
Roadbase gravel	Los Angeles	≤ 30	≤ 25						

Table 9.
Requirements for the wearing surface for various traffic loads

The following requirements apply in the Netherlands:

Road category	1 - 2	3	4 (Motorway)
PSV	≥ 48	≥ 53 (50)	≥ 65

Table 10.
Limiting values for PSV depending on road type.

The following requirement applies in Belgium: PSV > 50

For concrete:

The requirements placed on aggregates for concrete, including concrete for road building purposes, exist as proposals for European norms in prEN 12620:1996. If necessary, stipulations may be placed on a number of physical and mechanical properties. Only the stipulations for two properties will be cited here.

Grain shape for coarse aggregate

The flakiness index for aggregate > 4 mm, determined in accordance with prEN 933-3, is divided into the following categories, depending on what is necessary:

Flakiness index	Category
≤ 20	FI_A
≤ 35	FI_B
≤ 50	FI_C
No demands	FI_D

FI_A - Not normally required for concrete
FI_B - Normally required for crushed stone and gravel, slag and artificial aggregates
FI_C - Normally required for non-crushed sand and gravel
FI_D - Applies in cases where it has been shown that satisfactory concrete can be manufactured.

Los Angeles:

When necessary, demands may be placed on the Los Angeles value, which must be determined in accordance with prEN 1092-2. The following category divisions apply:

Los Angeles value	Category
≤ 20	LA_A
≤ 30	LA_B
≤ 40	LA_C
>40	LA_D

LA_A - Normally only required in special cases, such as where studded tyres are used.
LA_B - May be required for wearing surfaces and deck constructions exposed to high loads
LA_D - Applies in cases where it has been shown that satisfactory concrete can be manufactured