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Deliverable D4.1 Appendix

UNFC pilot case studies compiled as part of Mintell4EU WP4 (Appendix to Deliverable D4.1)

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UNFC application to sand and gravel resources in an Austrian pilot area

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Introduction

The United Nations Framework Classification (UNFC) for mineral resources was described in UNECE (2013 and 2019). Guidance for its application was provided by Lax et al. (2017) for mineral resources in Finland, Norway and Sweden. Guidance for social and environmental considerations when applying UNFC were drafted by EGRM (2020).

Previous UNFC application studies of mineral resources have focused mainly on ore deposits (UNECE, 2014). Hokka et al. (2020) applied the UNFC resource code to industrial mineral and industrial rock deposits and mines in Finland. Until now, the only published study on the application of UNFC to sand and gravel deposits was prepared by the Geological Survey of Norway (UNECE, 2020).

While the extent of ore bodies is mapped during exploration and mining, sand and gravel deposits are mapped in the course of traditional geological mapping. A very limited exploration phase, and no technical feasibility study, precede sand or gravel pit operations. The operations are usually started when, and where, demand arises due to a planned infrastructure project, and economic feasibility is usually given. Therefore, all the traditional criteria for deriving EFG codes need to be modified for classifying sand and gravel resources according to UNFC.

All previous UNFC application studies have in common that they assess the area around a mining site, either currently operating, recently closed or starting in the near future. In the present case study, an attempt is made to classify sand and gravel resources at a regional scale. Entire sediment accumulation bodies, such as river terraces stretching over tens of kilometres, are evaluated irrespective of past, current or future mining projects. A new set of criteria for deriving EFG codes is developed and applied to an area in Austria which is densely populated, rapidly developing, and where a high demand for sand and gravel coincides with numerous other, often conflicting, land use interests.

Description of the sand and gravel resources

Six stratigraphically different gravel units are present in the study area (Fig. 1). They all represent fluvial terraces deposited during the Pleistocene or Holocene. Regarding material quality, differences exist between these units with respect to grain size distribution and lithological composition, affecting the suitability as a resource. Due to the frequent occurrence of sandstone and crystalline components, the higher units (units 4 - 6) only offer material for road construction while the material of units 1 - 3 can be used for concrete (Tab. 1). With respect to quantity, the higher units reach greater gross average thickness (> 16 m) while the amount of sand intercalations is increased (> 30 %). In addition, the higher units are covered by thick layers (> 3 m) of loess. Net gravel thickness ranges between 8 and 13 m.

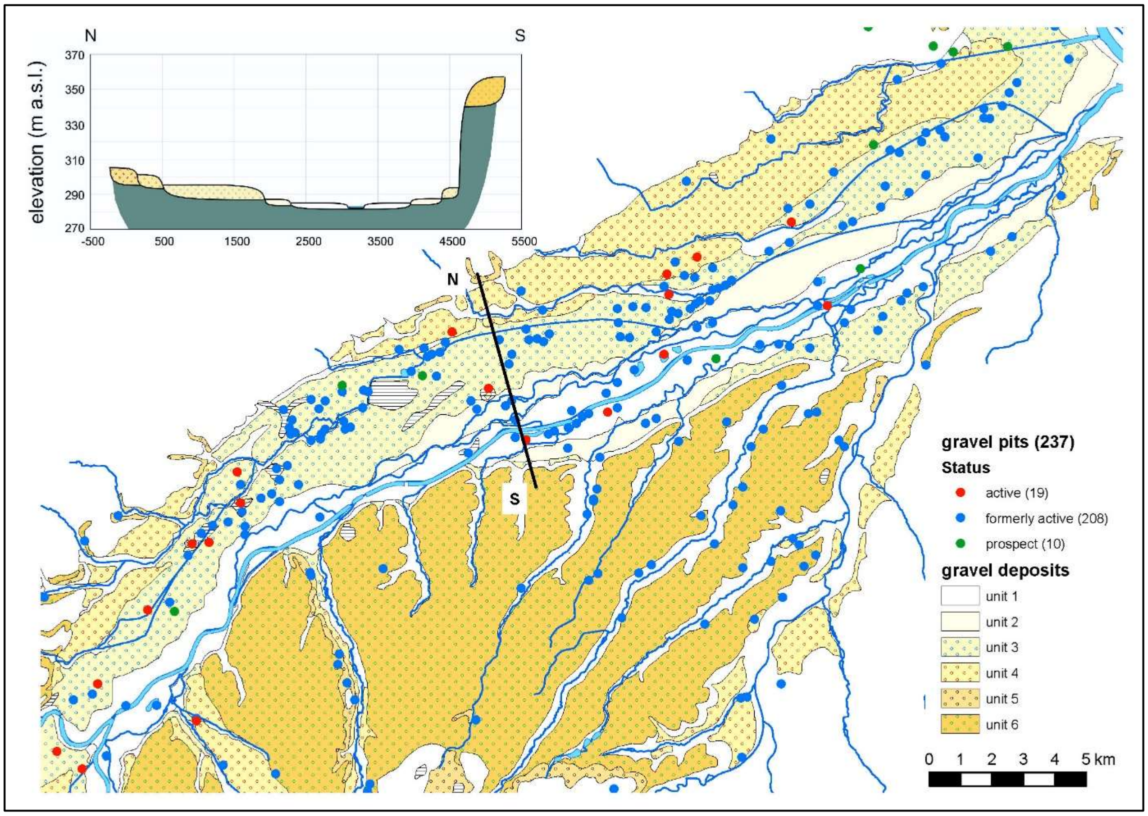

Fig. 1: Extent of Quaternary fluvial terraces in the study area (from Krenmayr & Schnabel 2006), schematic cross-section, location and number of gravel pits.

Data and Methodology

For the Austrian Mineral Resources Plan, the resource potential of sand and gravel deposits has been evaluated nationwide in a harmonised way (Pfleiderer et al., 2012). However, no international standard or reporting code has ever been used to classify sand and gravel resources in Austria. For the application of UNFC at a regional scale, a new, GIS-based methodology has therefore been developed which uses geological maps, borehole data, mining data and a wide range of spatial planning data such as zoning plans, environmental protection areas, cultural monument inventories, forests and water protection zones.

Data

Geological data: The surface extent of the gravel units was taken from digital geological maps. The units have been mapped at the scale of 1:25,000, facilitated by elevation models derived from airborne laser scanning. For the definition of three-dimensional extent, published models of the gravel base (Bieber et al., 2008; Flögl & Flögl, 1984; Kresser & Breiner, 1974) were used together with borehole data (data source: Land Oberösterreich - data.ooe.gv.at) (Fig. 2). A total of 2145 boreholes penetrate the gravel units in the study area. The borehole logs give information on overburden thickness, sand intercalations and depth-to-bedrock.

Tab. 1: Characterisation of gravel units in the study area (compiled from Schadler & Preitschopf, 1938; Kohl, 1998; Letouzé-Zezula et al., 1998; Rupp et al., 2011; van Husen & Reitner, 2011).

	unit 1	unit 2	unit 3	unit 4	unit 5	unit 6
sediment petrography	coarse gravel with sand layers, well rounded, well sorted, horizontally layered	coarse gravel with sand layers, well rounded, well sorted, horizontally layered	coarse sand-bearing gravel, well rounded, well sorted, weak layering	coarse sand-bearing gravel, not well rounded, poor sorting, weak layering, locally weakly conglomerated	coarse sand-bearing gravel, not well rounded, poor sorting, weak layering, partially conglomerated	coarse sand-bearing gravel, well rounded, poor sorting, weak layering, partially conglomerated
depositional environment	fluvial, meandering river	fluvial, meandering river	glaciofluvial, braided river	glaciofluvial, braided river	glaciofluvial, braided river	glaciofluvial, braided river
clast lithology	limestone and dolomite (80%), flysch sandstones (2%), quartz (18%)	limestone and dolomite (80%), flysch sandstones (2%), quartz (18%)	limestone and dolomite (83%), flysch sandstones (3%), quartz (14%)	predominantly flysch sandstones, some limestone and dolomite, almost no quartz or crystalline components	limestone, dolomite, and flysch sandstones; some quartz and crystalline components	limestone, dolomite, flysch sandstones, quartz and crystalline components
sediment cover	no loess cover, local overbank deposits (loam)	no loess cover, local overbank deposits (loam)	no loess cover	on average 4 m (up to 10 m) thick loess cover	on average 3 m (up to 8 m) thick loess cover	on average 6 m (up to 12 m) thick loess cover
gross average thickness (m)	10,4	9,21	13,77	16,2	16,4	20,4
net gravel thickness (%)	86	83	91	59	62	64
suitability	concrete & road construction	concrete	concrete & road construction	road construction	road construction	road construction
resource importance	supra-regional	supra-regional	supra-regional	mostly local, some regional	local	only local

Mining data: The gravel units have been mined at 227 active and formerly active pit operations within the study area (Fig. 1). Only 19 pits are still active today, most of them situated in units 1 and 3 (Tab. 2). The mining data shown in Figure 1 are taken from the interactive resource information system (IRIS) of the Geological Survey of Austria. They exist as point data and give no quantitative information on

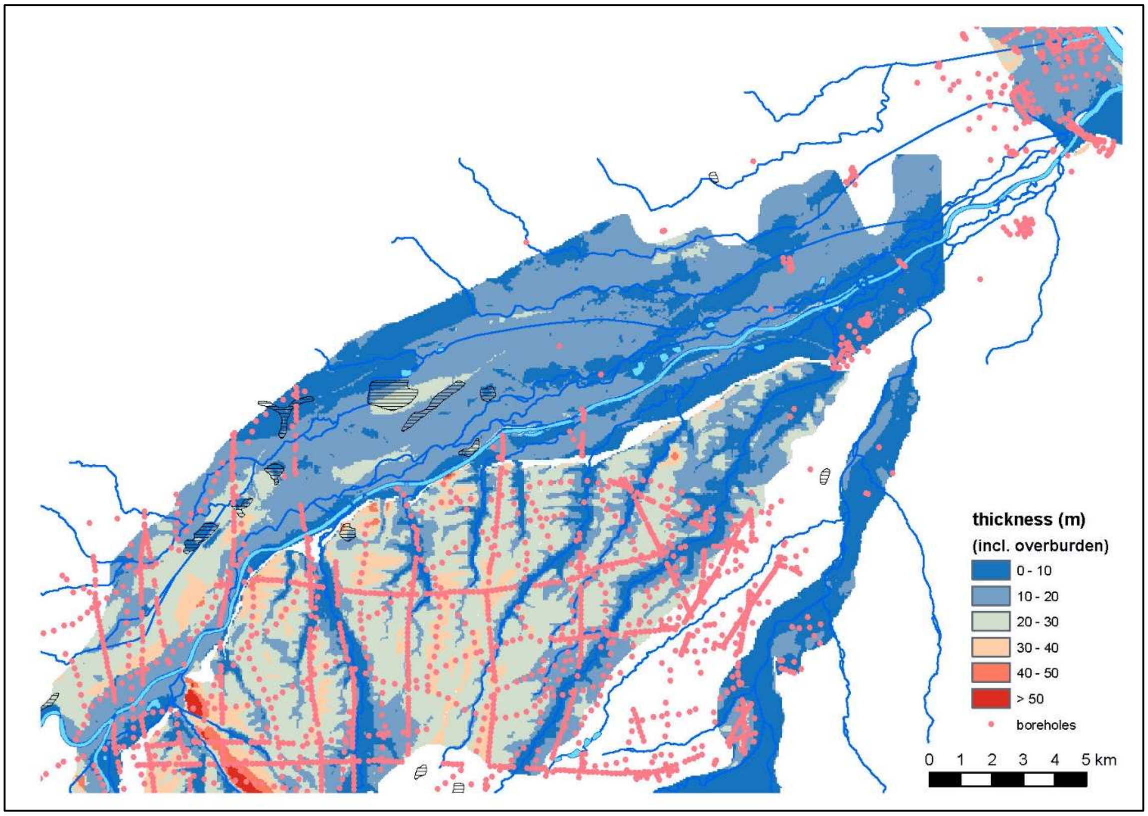

Fig. 2: Thickness models of gravel units (Bieber et al., 2008; Flögl & Flögl, 1984; Kresser & Breiner, 1974) and location of boreholes (Land Oberösterreich - data.ooe.gv.at).

the surface area or volume of pits. However, information exists on relative pit size as well as on the use of the material and the supply range. In addition, information on active mine sites exists in the mining information system BergIS, operated by the Directorate of Telecommunications, Postal Services and Mining (Federal Ministry of Agriculture, Regions and Tourism). This data set contains current mining rights including the corresponding mining areas.

Tab. 2: Data on gravel pit operations.

	unit 1	unit 2	unit 3	unit 4	unit 5	unit 6
# of pits	42	8	116	23	8	40
# of active pits	5	0	11	3	0	0
relative pit size	some relatively big pits	medium and small pits	some relatively big pits	few big pits	medium and small pits	only small pits

<u>Zoning data</u>: Building land (and designated building land), recreational areas, roads and railway lines were taken from zoning plans. Building land includes residential, industrial, and business buildings as well as cottages, schools, nurseries, hospitals, churches, cemeteries, waste sites, parking garages and alike. Recreational areas include parks, playparks, sport areas, swimming pools, campsites, golf courses, equestrian facilities and alike. Federal and provincial laws protect the vicinity of buildings and traffic routes prescribing minimum distances. These distances were used to buffer the zoning data.

Environmental data include ecological areas, natural monuments, game passageways, national nature protection areas, national parks, Natura2000 areas and Ramsar areas. As natural monuments exist as point data, a buffer of 300 m, comparable to the protection zone around buildings, was calculated.

Forestry data considered here represent forests of special importance acting e.g. as protection against avalanches, debris flows or rock falls, or serving recreational purposes.

Cultural data used here represent objects under monumental protection such as historical or cultural monuments. As these data exist as point data, a buffer of 300 m, comparable to the protection zone around buildings, was calculated.

Spatial plans specify "negative zones" within the study area where sand and gravel mining is unwanted. These zones are defined in order to protect (a) against emissions resulting from excavation or transport of sand and gravel, (b) forests within largely deforested areas, (c) rivers and meadows inhabited by rare species and (d) important aquifers. In addition, regional plans define "green zones" as areas which cannot be reassigned, i.e. where land use change is prohibited.

Spatial plans may additionally specify areas where extraction of precious mineral resources is given priority to other land uses. These safeguarded areas may be legally instituted or informally considered as areas where mining permit applications are given preference in case of conflicts of interest. Within the study area, spatial plans do not include safeguarded areas.

Water: Among data on groundwater, only water protection zones (zones I, II and III) were used for this study.

Data availability

Geological maps of the Geological Survey of Austria (GBA) are available as a web map service or visible in a web viewer (Tab. 3). Vector data can however not be downloaded and are only accessible to GBA staff. Thickness models were taken from publications listed in the library catalogue of GBA (https://www.geologie.ac.at/en/services/library) and prepared for use in ArcGIS.

Borehole data in Austria are owned by the state governments who show the location of boreholes in online viewers. Within the study area, the respective state government additionally provides borehole logs in table format by clicking on individual boreholes in the web viewer (Tab. 3). The data sets cannot be downloaded. Most state governments however make borehole data available to GBA staff for internal use.

Mining data of GBA's interactive resource information system (IRIS) are owned and maintained by the Department of Mineral Resources and shown on the web viewer of the GBA homepage (Tab. 3). The data set on sand and gravel can be downloaded. Active mining areas listed in BergIS are available as a web map service, vector data cannot be downloaded.

The remaining data are publicly available and can be downloaded free of charge thanks to INSPIRE and the open government data initiative. The creative commons licence CC BY 4.0 obliges any user to name the respective Austrian State Government as the data owner.

Table 3 lists the data types, sources and accuracies for geological, mining, zoning, environmental, forestry and cultural data, spatial plans and water protection zones.

Tab. 3: Data types, sources and accuracies.

	data type	source	maximum scale permitted for presentation
geological maps	polygons	web viewer: https://gisgba.geologie.ac.at/gbaviewer/?url=https://gisgba.geologie.ac.at/arcgis/rest/services/KM50/AT_GBA_KM50_GE_LS99/MapServer	1:10,000
		web map service: https://gisgba.geologie.ac.at/arcgis/services/KM50/AT_GBA_KM50_GE_LS99/MapServer/WMSServer?	1:10,000
borehole data	points	https://doris.ooe.gv.at/viewer/(S(scdgxuobmfjijxqlowuj1acp))/init.aspx?ks=alk&karte=wage	1:500
mining data	points	web viewer (mining site archive): https://geolba.maps.arcgis.com/apps/webappviewer/index.html?id=ef8095943a714d7893d41f02ec9c156d	no limit
	polygons	web map service (active sites): https://inspire.lfrz.gv.at/000503/wms?version=1.3.0&request=GetCapabilities&	
building land	polygons	https://www.land-oberoesterreich.gv.at/119788.htm	1:1,000
roads	lines	https://www.land-oberoesterreich.gv.at/119788.htm	1:1,000
railway lines	lines	https://www.land-oberoesterreich.gv.at/119788.htm	1:1,000
recreational areas	polygons	https://www.land-oberoesterreich.gv.at/119788.htm	1:1,000
ecological areas	polygons	https://www.land-oberoesterreich.gv.at/119788.htm	1:1,000
natural monuments	points	https://www.land-oberoesterreich.gv.at/119788.htm	1:1,000
game passageways	polygons	https://www.land-oberoesterreich.gv.at/119788.htm	1:1,000
national nature protection areas	polygons	https://www.land-oberoesterreich.gv.at/119788.htm	1:1,000
national parks	polygons	https://www.land-oberoesterreich.gv.at/119788.htm	1:1,000
Natura2000 areas	polygons	https://www.land-oberoesterreich.gv.at/119788.htm	1:1,000
Ramsar areas	polygons	https://www.land-oberoesterreich.gv.at/119788.htm	1:1,000
protective forests	polygons	https://www.land-oberoesterreich.gv.at/119788.htm	1:1,000
cultural monuments	points	https://www.land-oberoesterreich.gv.at/119788.htm	1:2,000
spatial plan - negative zones	polygons	https://www.land-oberoesterreich.gv.at/119788.htm	1:20,000
spatial plan - green zones	polygons	https://www.land-oberoesterreich.gv.at/119788.htm	1:10,000
water protection zones	polygons	https://www.land-oberoesterreich.gv.at/119788.htm	1:2,000

Methodology of defining the E, F and G-axis

The definitions of E-, F- and G-axis categories are given in Tab. 4 (UNECE, 2019). Any newly developed methodology needs to assure that results are compliant with these definitions.

E-axis: The traditional criteria for E-axis classification are economic viability, social acceptance and the likelihood of the mining project to be permitted by mining authorities. For the classification of gravel resources at a regional scale, this approach was imitated by distinguishing between permitted areas, safeguarded areas, conflict areas and legally prohibited areas.

Safeguarded areas are set aside by spatial planners specifically for future mining. In these areas, no social conflicts or environmentally negative consequences are expected. Planned gravel pit operations are virtually certain to be granted a mining permit. Therefore, these areas are classified as E1.

Tab. 4: Definitions of E-, F- and G-axis categories (UNECE, 2019).

Category	Definition
E1	Development and operation are confirmed to be environmentally-socially-economically viable.
E2	Development and operation are expected to become environmentally-socially-economically viable in the foreseeable future.
E3	Development and operation are not expected to become environmentally-socially-economically viable in the foreseeable future or evaluation is at too early a stage to determine environmental-socioeconomic viability.
E3.1	Estimate of product that is forecast to be developed, but which will be unused or consumed in operations.
E3.2	Environmental-socio-economic viability cannot yet be determined due to insufficient information.
F1	Technical feasibility of a development project has been confirmed.
F2	Technical feasibility of a development project is subject to further evaluation.
F3	Technical feasibility of a development project cannot be evaluated due to limited data.
F4	No development project has been identified.
G1	Product quantity associated with a project that can be estimated with a high level of confidence.
G2	Product quantity associated with a project that can be estimated with a moderate level of confidence.
G3	Product quantity associated with a project that can be estimated with a low level of confidence.
G4	Product quantity associated with a prospective project, estimated primarily on indirect evidence.

Outside conflict areas, gravel pits are also considered socially acceptable and likely to have no negative environmental effects. However, because the granting of a permit is less certain, these areas are classified as E2. Inside conflict areas, environmental or social conflicts are to be expected but can potentially be resolved, either by careful choice of the pit location of by compensating for negative effects. These areas are *a priori* classified as E3.1 but can be given E2 if an impact analysis is performed and results are positive (cf. chapter 'Discussion').

In certain areas, mining is either prohibited by law or permits are *de facto* never granted. The latter may be due to a high societal value or to some cultural monument, ecosystem or habitat worth protecting. In any case, these areas are classified as 3.2.

The information, which of the spatial planning data listed in Table 3 constitute conflict areas or *de facto* bans for mining, needs to be provided by local or regional planners. Within the study area, ecological areas, green zones, Natura2000 areas and game passageways are considered possible conflict areas, whereas *de facto* banned areas include highly sensitive game passageways (type I and II), important forests, negative zones and areas around cultural or natural monuments. Legally excluded according to the Mining Act are building land, designated building land, recreational areas, roads and railway lines (all including buffer zones) as well as water protection zones, national parks and national protection zones.

F-axis: The F-axis code reflects the maturity of a mining project. Basis for the classification are the existence and outcome of prefeasibility and feasibility studies. However, such studies are usually not performed for gravel pits as excavation and processing never pose a technical challenge. Therefore, different criteria have been defined here for deriving the F-axis code of gravel resources at a regional scale. The criteria include the existence of legal prohibition areas and the distance to potential consumers.

Areas, where mining is legally prohibited and no mining project will ever mature, are classified as F4. Outside these areas, it is inherently difficult to forecast whether a gravel pit operation in a given area is to be expected in the foreseeable future. Demand for sand and gravel is driven by activity in the construction industry. Therefore, the proximity to markets is proposed here as an indicator for the likelihood of a gravel pit operator to seek a mining permit. Close to conurbations and designated enlargement areas, any gravel deposit can potentially become a desired resource. Beyond an average distance of 30 km to the consumer, the transport of gravel becomes too expensive and traffic related environmental pressure too strong for gravel pit planners to pursue a permit in Austria (Weber, 2012). Consequently, any area within a 30 km distance to the markets is classified as F2, otherwise as F4. Within the densely populated study area, the proximity to markets never exceeds 30 km.

If an application for a mining permit has already been filed, the F-axis code becomes F1. However, this information does not systematically reach the Geological Survey in Austria. Therefore, only active pits were classified as F1 in the present study.

Table 5 summarizes the proposed derivation of E- and F-axis codes.

Tab. 5: Allocation of E- and F-axis codes for gravel resources at a regional scale.

active pit	permitted area	**E1**		**F1**
around active pit / around former pit / no pit	safeguarded areas	**E1**	• application pending: • near market: • >30 km to market:	**F1** **F2** **F4**
	outside conflict areas • mining likely without conflict • no negative environmental effects • socially acceptable	**E2**	• application pending: • near market: • >30 km to market:	**F1** **F2** **F4**
	inside conflict areas • negative environmental effects to be compensated • social acceptance to be negotiated	**E3.1 / E2***	• application pending: • near market: • >30 km to market:	**F1** **F2** **F4**
	inside legal (or *de facto*) ban	**E3.2**		**F4**

* E2 is given if an impact analysis is performed and results are positive.

G-axis: The G-axis code reflects the degree of confidence regarding the geological knowledge of the resource. Prior to gravel pit operations, detailed exploration studies including systematic drilling campaigns, are hardly ever carried out and gravel excavation is often started without a high level of confidence. To assess the volume of gravel deposits, the accuracies of surface extent and of thickness need to be considered. For fluvial terraces or alluvial fans, geo-morphology is normally used to delineate the surface extent of sediment deposits. Digital elevation models derived from airborne laser scanning allow a high accuracy (tens of centimetres) of mapping. The error becomes negligible when the lateral extent of the units reaches tens of kilometres. Therefore, the critical factor is the accuracy of thickness estimates. For large deposits, the error associated with estimating gravel thickness can directly be translated into the G-axis code (Fig. 3).

Fig. 3: Allocation of G-axis codes based on the error associated with estimating gravel thickness.

The thickness models shown in Fig. 2 do not contain any information on model uncertainty. Therefore, borehole logs were used to derive a thickness error. The discrepancy between log data and models was quantified at each borehole and an average error derived within each gravel unit. Areas within the model extent, but without borehole information, were classified as G4, otherwise the average error was used to derive the G-axis code according to Fig. 3.

Methodology of calculating volumes

Within the extent of thickness models (Fig. 2), thickness was derived for each EFG zone, i.e. for the polygons with a given EFG code, using the zonal statistics tool in ArcGIS. This was carried out for each gravel unit separately. Thickness values were then corrected for overburden and sand intercalations derived from borehole log data (see net gravel thickness in Tab. 1). Total volumes were calculated for each EFG zone by multiplying thickness by surface area. An additional correction factor of 0.9 was applied to take into account an estimated volume loss of 10 % due to incomplete zoning data (e.g. pylons for electric power cables, wind turbines, gas pipelines etc.).

Outside the extent of thickness models, information from the nearest boreholes was used to derive an average thickness for each polygon. The same steps as within the extent of thickness models (determination of net gravel thickness, calculation of volume, correction for volume loss) were then carried out.

Reporting the total volume of sand and gravel resources per EFG code was performed separately for each suitable end-use of the material. To obtain the resources of sand and gravel potentially used for concrete, volumes within gravel units 1, 2 and 3 were added together (cf. Tab. 1). For road construction, the numbers of units 1, 3, 4, 5 and 6 were combined.

Results

Fig. 4 shows the distribution of conflict zones, of legally prohibited and of currently permitted areas within the extent of gravel deposits. Of the total surface area (387 km²), 75 % are off-limits, 1 % represents possible conflict areas and 1 % is currently mined. In 23 % of the area, potential mining is considered likely to proceed without conflict. It is important to note, that this result does not replace, nor pre-empt the outcome of, any permitting procedure. A site-specific evaluation will still be required for any mining permit procedure.

The result of allocating E-, F- and G-axis codes according to Tab. 5 and Fig. 3 is shown in Fig. 5. For each EFG zone, total volumes are given in Tab. 6. Volumes within active mining areas (EFG code 111) represent total extractable volumes before mining. These numbers still need to be reduced by the amount of already extracted material. Information on already extracted volumes however does not systematically reach the Geological Survey in Austria. Annual update of these numbers can therefore not be performed.

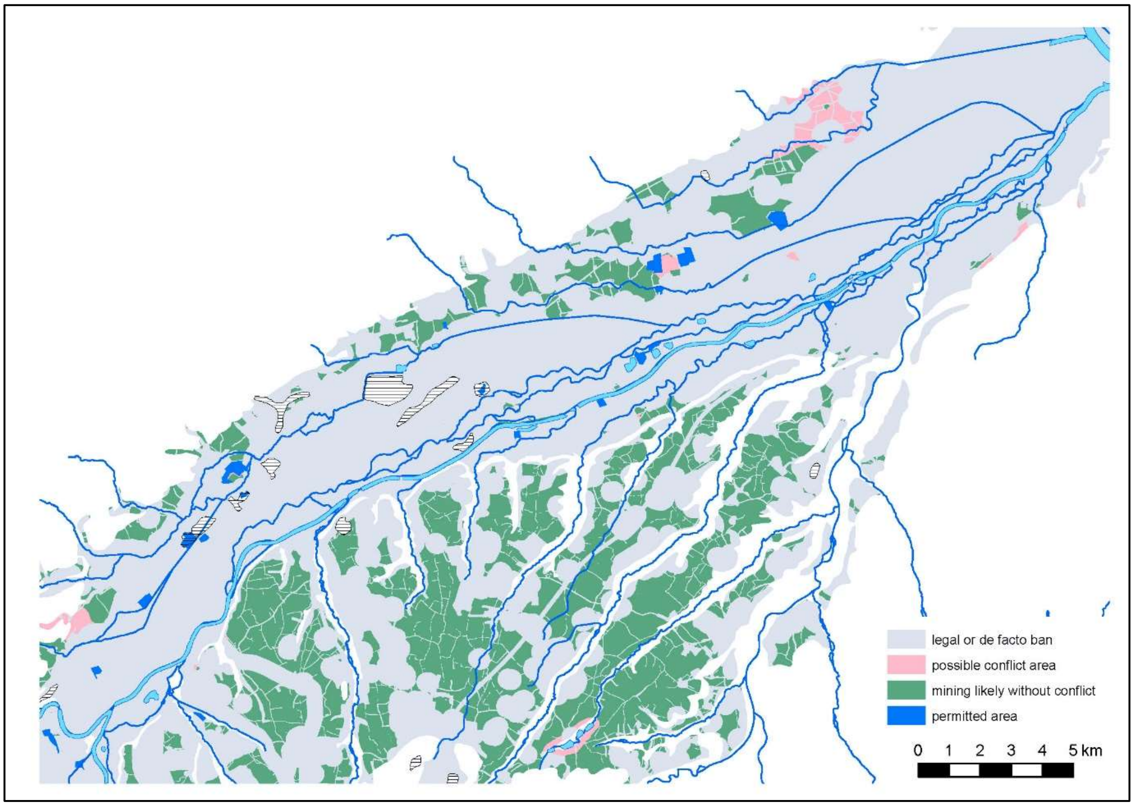

Fig. 4: Areas currently permitted for mining, conflict and conflict-free areas, and zones with a legal or *de facto* ban for gravel mining within the extent of gravel deposits.

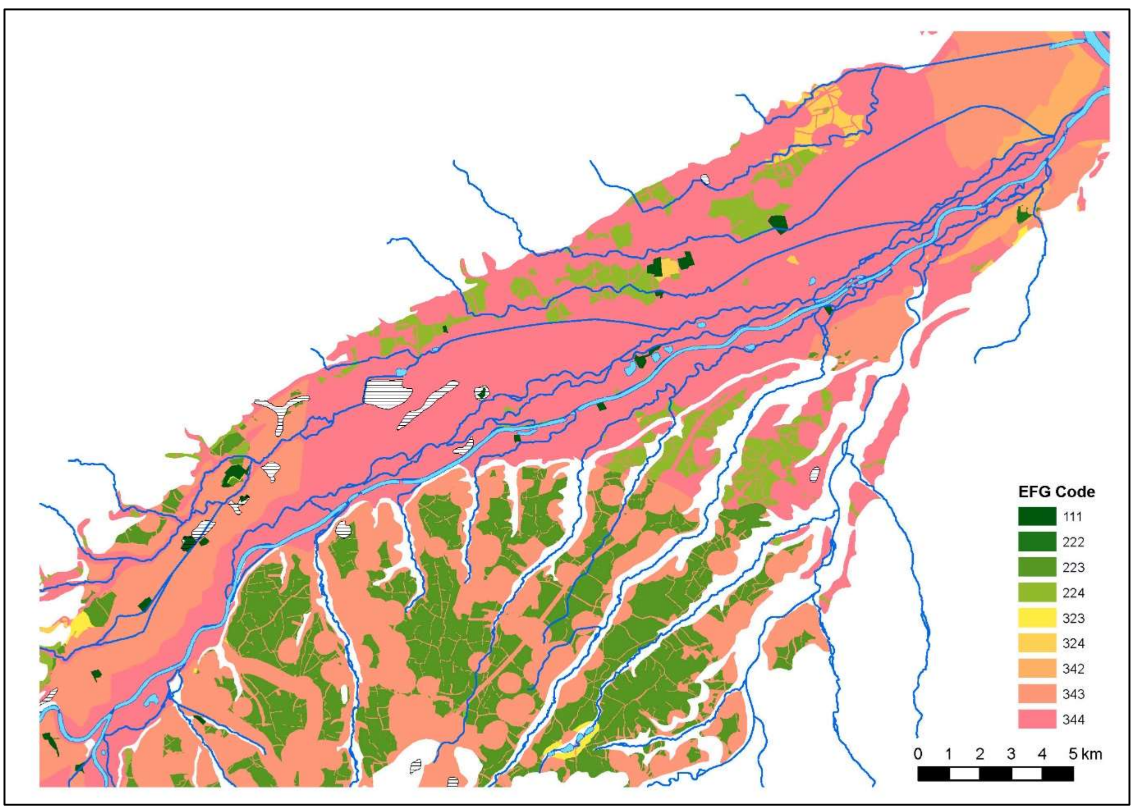

Fig. 5: Distribution of EFG codes within the extent of gravel deposits.

Tab. 6: Volumes of sand and gravel resources suitable for concrete and for road construction (in million m^3).

EFG	material suitable for concrete	material suitable for road construction
111	13*	17*
222	1	0
223	8	859
224	27	173
323	1	8
324	3	24
342	48	0
343	512	1477
344	1080	1237

* Numbers need to be reduced by already extracted volumes.

Discussion

For the application of UNFC to sand and gravel resources at a regional scale, the traditional measures (profitability assessments, technical feasibility studies, exploration campaigns) to derive EFG codes are not appropriate. The present case study develops a new methodology to classify entire sand and gravel deposits according to UNFC, and nevertheless obtain results which comply with the original definitions of EFG categories.

The surface extent of sand and gravel deposits is taken from geological maps as a starting point. Information on thickness is added from borehole logs or subsurface models but can also be taken from any other database specifying vertical extent. Such data are then used on the one hand to calculate volumes and on the other hand to quantify uncertainties and derive the G-axis code. If no data are available, volumes cannot be quantified and the resource not classified. However, geological survey organisations (GSO's) generally have access to such data and are therefore particularly well suited to implement the approach.

Within the study area, two types of thickness data exist, subsurface models and borehole logs. In this special case, thickness values from borehole data were considered as true (or observed) values and modelled thickness as predicted. The deviations between the two data sets were used to quantify geological confidence (G-axis). If only borehole data are available, volumes can still be calculated but the G-axis codes need to be derived differently. Uncertainty is then mainly a function of borehole density and geological variability (Lelliot et al., 2009). The top of a fluvial terrace is usually flat and constant, but the base can vary by several meters over short distances (tens of meters) due to erosion gullies. However, experience from exploited gravel pits shows that such gullies are narrow, few and far between in the study area and thus have a limited effect on the uncertainty of calculated volumes.

For the derivation of the E-axis code, the approach relies on spatial planning data to identify zones where mining is legally prohibited (or *de facto* never permitted), likely to encounter social or environmental conflicts, likely to proceed without conflict, or even given preference to other land use interests. Active mining areas are then added to these zones. Due to INSPIRE, the required data are largely public domain and the developed approach should be feasible in any European country. However, in order to implement the approach, geological surveys need to consult with spatial planners or permitting authorities. Only they can inform on *de facto* banned areas, where mining permits will generally not be granted.

F-axis codes are derived here based on three aspects: (a) presence of legally (or *de facto*) banned areas, (b) proximity to markets and (c) pending applications for mining permits. While the first two aspects can easily be accounted for in a GIS project, the third aspect may pose a challenge to geological surveys. In Austria, there is no regular data exchange between permitting authorities and the Geological Survey and this information cannot be factored into the derivation of F-axis codes.

Within areas of conflict, scoring systems exist to resolve environmental or social issues by weighing the importance of the sand and gravel resource for the supply of construction material against negative consequences for the society, the environment or for natural resources (Rogaland Fylkeskommune, 2006; Letouzé-Zezula et al., 1993). On one hand, marks are given in favour of gravel mining depending on the suitability, importance and location of the resource. On the other hand, points are deducted depending on the impact of excavation and transport on the local community, the value of the land, on biodiversity, landscape, cultural heritage, agriculture, forestry and water supply. A positive total score would lead to the classification of the resource as F2 (Tab. 5). However, this type of conflict resolution should be performed by spatial planners, ideally in cooperation with geologists.

Finally, total volumes of the sand and gravel resources per EFG code are proposed here to be listed separately for each suitable end-use of the material. In the present study, information on resource suitability was extracted from mining data. It can however also come from any other data source describing potential uses of the material. Geological surveys are generally well positioned to gain access to such data.

Accurate information on volumes within active mining areas (EFG code 111) requires data on (annually) extracted quantities to be accessible. In Austria, such data are not open to geological surveys, leading to imprecise numbers (Tab. 6). For the other EFG zones, the accuracy of resource volumes will depend on the precision of the geological map and, most critically, on the accuracy of thickness data. The precision of spatial planning data (Tab. 3) is generally higher than geological information and will not negatively impact on the overall results.

Correcting for sand intercalations using a constant correction factor for each gravel unit (net gravel thickness in Tab. 1), assumes lateral homogeneity within the gravel units. In addition, material quality aspects such as lithological composition are assumed here to be unvarying. However, map polygons are mostly delineated on the basis of geo-morphology, and petrographical variations within any one polygon cannot be excluded. The assumption of homogeneity of gravel units in the study area was made on the basis of genetic origin and is not supported by hard data.

Conclusions

This case study attempts to classify sand and gravel deposits according to UNFC. It presents a new, GIS-based approach and a new set of criteria for deriving EFG codes at a regional scale, irrespective of past, current or future mining projects. The results are compliant with current UNFC definitions of E-, F- and G-axis categories. The methodology largely relies on spatial planning data which due to the INSPIRE directive should be generally accessible in any EU country. Additional geological data required, such as geological maps or borehole logs, are commonly available at geological survey organisations which makes this approach particularly well suited for implementation by these organisations.

It remains to be confirmed by geological surveys in other EU countries, whether the approach is transferable, feasible across Europe, and perhaps even recommendable as a guideline or common way to classify sand and gravel resources. At least the proposed quantification of geological confidence (G-axis) and the distinction between legal ban areas, possible conflict areas, conflict-free areas and safeguarded areas - and the resulting E- and F-axis code allocation - are expected to be transferable and of general help when applying UNFC to sand and gravel deposits at a regional scale.

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This case study was performed in close collaboration with the Norwegian Geological Survey. The author is grateful to Henrik Schiellerup, Kari Aasly and her team who contributed substantially to the development of the method, as well as to Holger Paulick and Robert Supper (Geological Survey of Austria) who facilitated a 1-month work placement for the author to pursue this study in Norway. Special thanks go to Heide Birngruber (Government of Upper Austria, Department of Land Use Planning and Regional Development) for guidance on the classification of spatial data.

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UNFC Case study – phosphates, Belgium

Introduction/Background

Define the resource

National phosphate mineral deposit database and primary information sources linked to the database

Methodology

Before this project, there was no phosphate database or classification available for Belgium, nor at national or regional level. In coordination with the GeoERA frame project, a review of Belgian phosphate deposits was done, based on available literature and new sample analysis.

Did you use bridging from CRIRCSO-compliant data? No prior classification existed.

How have data been gathered? Amongst the sources, the ProMine/M4EU databases was used as a starting point, with the global geological settings reviewed from historical publications (Notholt et al., 1979, Robaszynski, 1989). Recent work by Jacquemin et al., 2018, provided new insight on the associated CRM linked to phosphates deposits, with new geochemical analysis.

What kind of data have been used? New resource localisations have been made by hand, looking at bibliographic record. The new geochemical data was directly taken from a recent study (Jacquemin et al., 2018). Current state of the deposits, state of permits, and future use was checked through contacts with regional authorities and Belgian phosphates experts.

Phosphates deposits of Belgium

Phosphate rock occurs in Belgium in beds of phosphatic chalk (Upper Cretaceous age) situated along the Haine and Senne valleys near Mons, Hainaut Province, which have accounted for most of the past Belgian production of phosphate rock. Other phosphate chalks occurrences are also found in the Liege Province along the Meuse valley between Liege and Namur.

In addition, phosphatic nodules associated to oolithic iron formation occur in various parts of Belgium in sediments of Jurassic, Tertiary and Quaternary age, for example, in the Antwerp Province and in the extreme southern part of Luxembourg Province. None of the occurrences in Belgium has been of economic interest since the Second World War. However, waste phosphatic chalk arising from former washing operations was recovered from dumps until 1968 at Ciply near Mons for direct application to the soil. The phosphate fertilisers for the country's intensive agricultural needs is therefore based on imports of phosphate rock obtained almost entirely from abroad. (Notholt et al., 1979; Jacquemin et al., 2018).

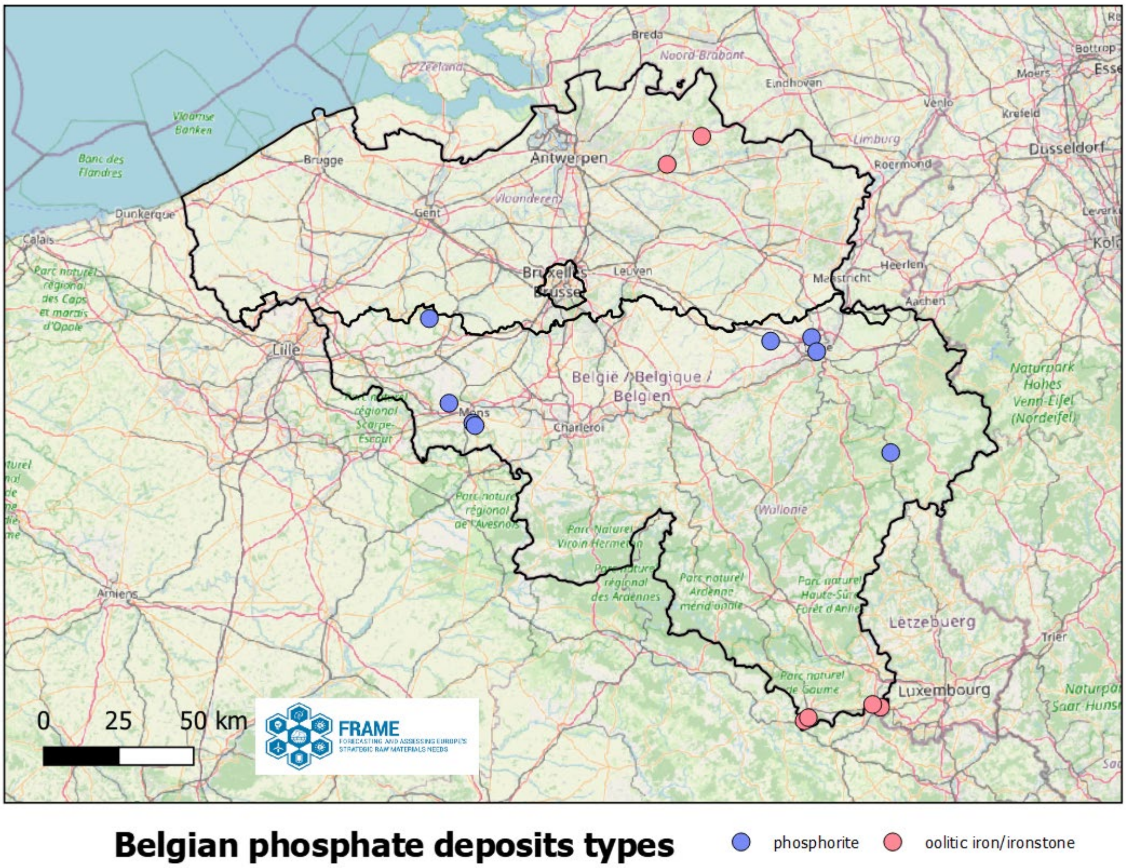

Figure 1 : Belgian phosphates deposits identified in this study

UNFC classification

From the bibliography review, we identified 14 relevant deposits for phosphates in Belgium (discarding anecdotic phosphates mineral descriptions. These phosphates deposits range from occurrences-sized to large deposits. 6 are linked to Early Jurassic (oolithic) ferruginous deposits and 8 are linked to phosphorites Deposits (mostly Cretaceous – chalk, also Paleogene – clay, one Cambrian occurrence)

Deposits areas were not mapped, volumes and resource calculations made by Jacquemin et al. were used for the phosphatic chalk of the Mons basin (‘Ciply Chalk’). This deposit is the only one that have been recently studied for its associated REE potential, with samples analysis from a borehole (Hyon borehole) and an underground quarry (la Malogne). Both phosphates exhibit REE enrichments, with total REE average concentration of 350ppm for the Hyon borehole samples and 660ppm for the La Malogne quarry samples.

The phosphatic Mons basin has an area of about 23 km². The phosphatic chalk generally exceeds 20 m in thickness and in some places up to 76 m. Resources were evaluated at 960Mt tons of phosphatic chalk at a grade comprised between 5 and 10% P_2O_5 (Robaszynski and Martin, 1988).

Given the European-level estimated potential for REE, the Mons deposit was rated E2, and all other E3 (not considered for development). All deposits were rated F4 as no mining project is under consideration (as we are aware of in 2021). The Mons and Liège deposits were rated G1,2,3 because of the available literature, all other were rated G4.

Additional Questions:

What have you learned from this work? First contact with UNFC code system and resource estimation in general.

What kind of challenges have you experienced during this work? Lack of data (only one deposit studied) and need of dedicated workforce. Categorising into UNFC was however straightforward in this case because no plan for future studies or exploitation is foreseen.

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UNFC application to aggregates (limestone; gravel and sand) resources in the Croatia, Koprivnica- Križevci County case study

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Introduction/Background

The United Nations Framework Classification (UNFC) for Fossil Energy and Mineral Resources (UN, 2010) is a global system of reporting of fossil energy and mineral reserves and resources developed under a mandate from the UN Economic and Social Council and serviced by the Expert Group on Resource Classification (EGRC) of the United Nations Economic Commission for Europe (UNECE). UNECE is the UN regional Commission for North America, Europe (including all EEA member states), CIS countries, Turkey and Israel. The UNFC is not mandated by the UN but on consensus (both at the ECOSOC and UNECE levels) as a voluntary system of reporting. It is not enforced through an international treaty or similar legally binding instrument.

UNFC is capable of meeting the requirements for application at national, industrial and institutional level, as well as to be successfully used for international communication and trans-national assessments. It should be emphasised that UNFC provides no guidance on data quality or validation, or on methods or formats of reporting.

The UNFC consists of a three-dimensional system with the following three axes: Geological Assessment, Feasibility Assessment and Economic viability.

The process of geological assessment is generally conducted in stages of increasing details. The typical successive stages of geological investigation i.e., reconnaissance, prospecting, general exploration and detailed exploration, generate resource data with a clearly defined degrees of geological assurance. These four stages are therefore used as geological assessment categories in the classification. Feasibility assessment studies form an essential part of the process of assessing a mining project.

The typical successive stages of feasibility assessment i.e., geological study as initial stage followed by prefeasibility study and feasibility study/mining report are well defined.

The degree of economic viability (economic or sub economic) is assessed in the course of prefeasibility and feasibility studies. A prefeasibility study provides a preliminary assessment with a lower level of accuracy than that of a feasibility study, by which economic viability is assessed in detail. It is a three-digit code-based system, the economic viability axis representing the first digit, the feasibility axis the second digit and the geologic axis the third digit.

The three categories of economic viability have codes 1, 2 and 3 in decreasing order, similarly the three categories of feasibility study have also codes 1, 2 and 3 while the four stages of geological assessment are represented by 4 codes i.e., 1 (detailed exploration), 2 (general exploration), 3 (prospecting) and 4 (reconnaissance). Thus, the highest category of resources under UNFC system will have the code (111) and lowest category the code (334).

The United Nations Framework Classification (UNFC) for mineral resources was described in UNECE (2013 and 2019). Guidance for its application was provided by Lax et al. (2017) for mineral resources in Finland, Norway and Sweden. Guidance for social and environmental considerations when applying UNFC were drafted by EGRM (2020).

Previous UNFC application studies of mineral resources have focused mainly on ore deposits (UNECE, 2014). Hokka et al. (2020) applied the UNFC resource code to industrial mineral and industrial rock deposits and mines in Finland. Until now, the only published study on the application of UNFC to sand and gravel deposits was prepared by the Geological Survey of Norway (UNECE, 2020).

While the extent of ore bodies is mapped during exploration and mining, the aggregates deposits are mapped in the course of traditional geological mapping. A very limited exploration phase, and no technical feasibility study, precede the aggregates pit operations. The operations are usually started when, and where, demand arises due to a planned infrastructure project, and economic feasibility is usually given. Therefore, all the traditional criteria for deriving EFG codes need to be modified for classifying sand and gravel resources according to UNFC.

All previous UNFC application studies have in common that they assess the area around a mining site, either currently operating, recently closed or starting in the near future. In the present case study, an attempt is made to classify of the aggregates resources at a regional (county) scale. In Koprivnica - Križevci County the -aggregates resources include limestone and gravel and sand. The geological potentiality of the aggregate's resources derived from geological maps to the scale 1:100 000 of Croatia. A new set of criteria for deriving EFG codes is developed and applied to an area in county which is mostly obtained from spatial plan data (conflict zones, of legally prohibited and of currently permitted areas within the extent of the aggregates deposits). Using polygons with geological potential of the aggregate's resources and basic tools in ArcGIS, an EFG code was derived and assigned for each polygon of geological potential for the entire county.

Description of the aggregate's resources

Table 1 lists the geological units with basic characteristics of lithological features very suitable for the exploitation of the aggregates (Croatian Geological Survey, 2015), while data on active exploitation fields and exploration areas and current exploitation of aggregates are taken from the Mining and Geological Study Koprivnica -Križevci County (2015).

Table 1. Geological units with basic characteristics of lithological features very suitable for the exploitation of aggregates (Croatian Geological Survey, 2015)

No *	Geological unit	Area sq km	Active pits or quarry
1	Pont	160.73	1
5	Loess	148.17	1
4	Bed sediment	266.12	3
2	Aeolian sediment	176.98	2
6	IV. terrace	55.36	2
7	Marsh sediment	130.44	5
9	III. terrace	29.34	2
8	I. and II. terrace	245.34	19
12	Clast with volcanics	6.48	1
14	Kalnik breccia	1.62	1

The geological units listed in Table 1 are suitable for the aggregates. Many other types of rocks and sediments that occur in the county are not listed in Table 1 because they are not favourable for the exploitation of the aggregates. Most deposits (39 locations) of the aggregates are observed in I. and II. terrace, also the locations of the aggregates are represented in other geological units (Aeolian sediment, 4th terrace, bed sediments, marsh sediment - the most represented after the 1st and 2nd alluvial terrace).

The geology of Koprivnica-Križevci County is described on geological map sheets and explanation notes Koprivnica (Hećimović, 1987a and b) and Đurđevac (Šimunić et al., 1990; Šimunić et al., 1991) to the scale 1:100 000 (Figure 1). Cretaceous clastic deposits with volcanic are the oldest primary rocks that form in the County. They were discovered in the central part of the Kalnik Mountains, where they extend in an east-west direction. They consist of irregular alterations of rocky sandstones, shales, and dark-plate limestones and corneas. Towards the east and west, they "sink" under the sediments of the Lower Miocene, and appear in the valleys of the streams. Basic igneous rocks were discovered in the Kalnik area, and consist of parts of spilitized diabase's and spilites, and less often lava and tuff. These volcanic are synchronous with deep-water Cretaceous clasts, meaning that they are "imprinted" in unconsolidated sediments or spilled on the seabed. The deposits of aggregates stand out in the chalk.

Sediments from the Eocene epoch occur in the County, in the form of Kalnik breccia. The Kalnik Eocene breccias form the southern ridge of the Kalnik Mountains. The southern ridge, about 30 km long and up to 500 m wide, extends in an east-west direction. The base part of Kalnik breccia is dominated by carbonate mega breaks consisting of large blocks of Triassic limestone and dolomite, whose dimensions exceed tens of cubic meters. In the top parts of that breccia, unrounded blocks of Cretaceous ore limestones are incorporated, as well as blocks of deep-water limestones, the so-called scales. Rounded blocks of dark brown Palaeocene limestone also occur very rarely. The breccias are bulky, so their true thickness has not been determined. In the Kalnik hills near the village of Vojnovec in Kalnik breccia, a quarry was opened in which the breccia is exploited as a technical-building stone. Tertiary deposits are presented by technical-building stone, construction sand and gravel, coal, geothermal energy and hydrocarbons. Quaternary deposits cover most of the County, but due to the lack of conductive fossils they are not divided by stratigraphic but by lithogenic classification. The Pleistocene includes formations of river (sands and gravels of IV and III terraces) and river-lake (proluvial clasts), and lake-marsh and aeolian type of sedimentation (loess and lesoid sediments). They are most widespread on the eastern and southern slopes of the Kalnik hills, in the Križevci depression and on Bilogora. Holocene deposits are divided into the following genetic types: Sands and gravels II. and I. terraces, alluvial-proluvial deposits, alluvium of streams and riverbeds of the Drava and aeolian sands and marsh sediments. Deposits of construction sand and gravel, as well as brick clays occur as Quaternary deposits.

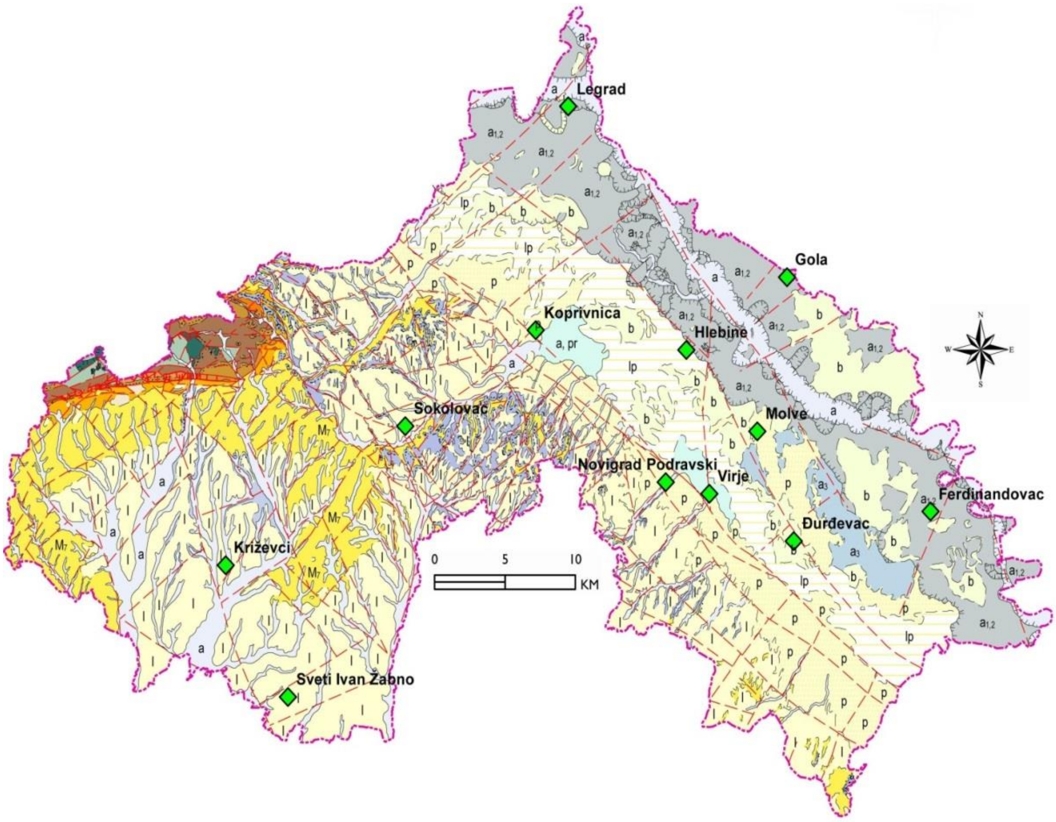

Figure 1 Geological map of the Koprivnica - Križevci County (source: Mining and Geological Study Koprivnica -Križevci County (2015))

Data and Methodology

The resource potential of the aggregates (limestone; gravel and sand) resources deposits for Koprivnica - Križevci County case study has been evaluated in the Mining and Geological Study Koprivnica - Križevci County (2015). However, no international standard or reporting code has ever been used to classify the aggregates (limestone; gravel and sand) resources in the Koprivnica - Križevci County. For the application of UNFC at a regional (county) scale, a new GIS-based methodology has therefore been developed which uses geological maps, mining data and a wide range of spatial planning data such as zoning plans, environmental protection areas, cultural monument inventories, forests and water protection zones.

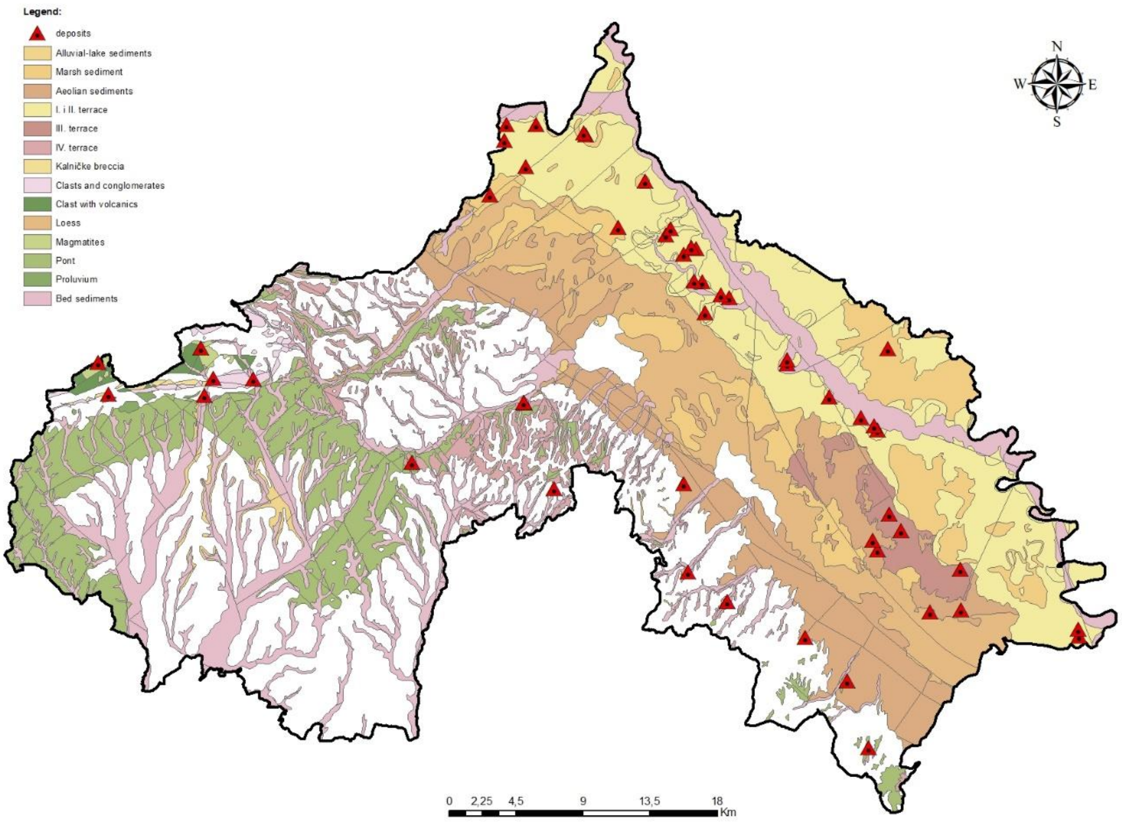

Figure 2 Geological areas with potential for explorations and exploitations of aggregates (limestone; gravel and sand) resources with aggregates deposists in Koprivnica - Križevci County

Data

Geological data: The surface extent of the aggregates units was taken from digital geological maps. The units have been mapped at the scale of 1:25,000.

Mining data: The aggregates units have been mined at 52 active and formerly active pit or quarries operations within the study area (Table 1 and Figure.2). Only 39 pits or quarries are still active today, most of them situated in I. and II. terrace (Table 1). The mining data shown in Figure 2 are taken from the public WEB GIS portal of the unique information system of mineral resources (JISMS) https://jisms.gospodarstvo.gov.hr/#/maps or from mineral resources information system of the Croatian Geological Survey.

Spatial plans: Building land (and designated building land), recreational areas, roads and railway lines were taken from zoning plans. Building land includes residential, industrial, and business buildings as well as cottages, schools, nurseries, hospitals, churches, cemeteries, waste sites, parking garages and alike. Recreational areas include parks, playparks, sport areas, swimming pools, campsites, golf courses, equestrian facilities and alike. State laws protect the vicinity of buildings and traffic routes prescribing minimum distances. These distances were used to buffer the zoning data. Spatial plans may additionally specify areas where extraction of precious mineral resources is given priority to other land uses. These safeguarded areas may be legally instituted or informally considered as areas where mining permit applications are given preference in case of conflicts of interest. Within the study area, spatial plans do not include safeguarded areas.

Water: Among data on groundwater, only water protection zones (zones I, II and III) were used for this study.

Environmental data include ecological areas, natural monuments, game passageways, national nature protection areas, national parks, Natura2000 areas. As natural monuments exist as point data, a buffer of 300 m, comparable to the protection zone around buildings, was calculated.

Forestry data considered here represent forests of special importance acting e.g., as protection against avalanches, debris flows or rock falls, or serving recreational purposes.

Cultural data used here represent objects under monumental protection such as historical or cultural monuments. As these data exist as point data, a buffer of 300 m, comparable to the protection zone around buildings, was calculated.

Methodology of defining the E, F and G-axis

The definitions of E-, F- and G-axis categories are given in Tab. 2 (UNECE, 2019). Any newly developed methodology needs to assure that results are compliant with these definitions.

E-axis: The traditional criteria for E-axis classification are economic viability, social acceptance and the likelihood of the mining project to be permitted by mining authorities. For the classification of aggregates resources at a regional (county) scale, this approach was imitated by distinguishing between permitted areas, safeguarded areas, conflict areas and legally prohibited areas. Safeguarded areas are set aside by spatial planners specifically for future mining. In these areas, no social conflicts or environmentally negative consequences are expected. Planned aggregates pit or quarries operations are virtually certain to be granted a mining permit. Therefore, these areas are classified as E1.

Table 2 Definitions of E-, F- and G-axis categories (UNECE, 2019).

Category	Definition
E1	Development and operation are confirmed to be environmentally-socially-economically viable.
E2	Development and operation are expected to become environmentally-socially-economically viable in the foreseeable future.
E3	Development and operation are not expected to become environmentally-socially-economically viable in the foreseeable future or evaluation is at too early a stage to determine environmental-socioeconomic viability.
E3.1	Estimate of product that is forecast to be developed, but which will be unused or consumed in operations.
E3.2	Environmental-socio-economic viability cannot yet be determined due to insufficient information.
F1	Technical feasibility of a development project has been confirmed.
F2	Technical feasibility of a development project is subject to further evaluation.
F3	Technical feasibility of a development project cannot be evaluated due to limited data.
F4	No development project has been identified.
G1	Product quantity associated with a project that can be estimated with a high level of confidence.
G2	Product quantity associated with a project that can be estimated with a moderate level of confidence.
G3	Product quantity associated with a project that can be estimated with a low level of confidence.
G4	Product quantity associated with a prospective project, estimated primarily on indirect evidence.

Outside conflict areas, aggregates pit or quarries are also considered socially acceptable and likely to have no negative environmental effects. However, because the granting of a permit is less certain, these areas are classified as E2. Inside conflict areas, environmental or social conflicts are to be expected but can potentially be resolved, either by careful choice of the pit location of by compensating for negative effects. These areas are *a priori* classified as E3.1 but can be given E2 if an impact analysis is performed and results are positive.

In certain areas, mining is either prohibited by law or permits are *de facto* never granted. The latter may be due to a high societal value or to some cultural monument, ecosystem or habitat worth protecting. In any case, these areas are classified as 3.2.

Within the study area, ecological areas, green zones, Natura2000 areas and game passageways are considered possible conflict areas, whereas *de facto* banned areas include highly sensitive game passageways (type I and II), important forests, negative zones and areas around cultural or natural monuments. Legally excluded according to the Mining Act are building land, designated building land, recreational areas, roads and railway lines (all including buffer zones) as well as water protection zones, national parks and national protection zones.

F-axis: The F-axis code reflects the maturity of a mining project. Basis for the classification are the existence and outcome of prefeasibility and feasibility studies. However, such studies are rarely or poorly performed and briefly described for aggregates pit or quarries as excavation and processing never pose a technical challenge. They exist but are not in compliance with UNFC regulation. Therefore, different criteria have been defined here for deriving the F-axis code of aggregates resources at a county scale. The criteria include the existence of legal prohibition areas.

Areas, where mining is legally prohibited and no mining project will ever mature, are classified as F4. Outside these areas, it is inherently difficult to forecast whether a gravel pit operation in a given area is to be expected in the foreseeable future. Demand for aggregates resources is driven by activity in the construction industry. Therefore, the proximity to markets is can be proposed here as an indicator for the likelihood of a gravel pit operator to seek a mining permit.

If an application for a mining permit has already been filed, the F-axis code becomes F1. However, this information does not systematically reach the Croatian Geological Survey. Therefore, only active pits were classified as F1 in the present study. Table 3 summarizes the proposed derivation of E- and F-axis codes.

Table 3 Allocation of E- and F-axis codes for gravel resources at a county scale.

active pit or quarry	permitted area	**E1**		**F1**
around active pit / or quarry around former pit / or quarry no pit or quarry	safeguarded areas	**E1**	•	**F1- F2 F4**
	outside conflict areas • mining likely without conflict • no negative environmental effects • socially acceptable	**E2**	•	**F1- F2 F4**
	inside conflict areas • negative environmental effects to be compensated • social acceptance to be negotiated	**E3.1 / E2***	•	**F1- F2 F4**
	inside legal (or *de facto*) ban	**E3.2**		**F4**

* E2 is given if an impact analysis is performed and results are positive.

G-axis: The G-axis code reflects the degree of confidence regarding the geological knowledge of the resource. Aggregates pit and quarries operations require detailed exploration studies including systematic drilling campaigns, and they are performed in varying degree and aggregates excavation is started with a different level of confidence. To assess the volume of aggregates deposits, the accuracies of surface extent and of thickness need to be considered. The four stages of geological assessment are represented by 4 codes i.e., 1 (detailed exploration), 2 (general exploration), 3 (prospecting) and 4 (reconnaissance). Areas without borehole information, were classified as G4 (Fig.3).

Figure 3 Allocation of G-axis codes based on the geological confidence

Results

A GIS-based methodology and reclassification has been developed which uses geological maps and a wide range of spatial planning data such as zoning plans, environmental protection areas, cultural monument inventories, forests and water protection zones.

The result of allocating E-, F- and G-axis codes according to Tab. 3 and Fig. 3 is shown in Fig. 4 and 5, and Tab. 4 and 5. The distribution of permitted areas, possible conflict areas, area in which mining likely without conflict and legal or de facto ban areas of the aggregates in Koprivnica - Križevci County has been shown on Fig.4

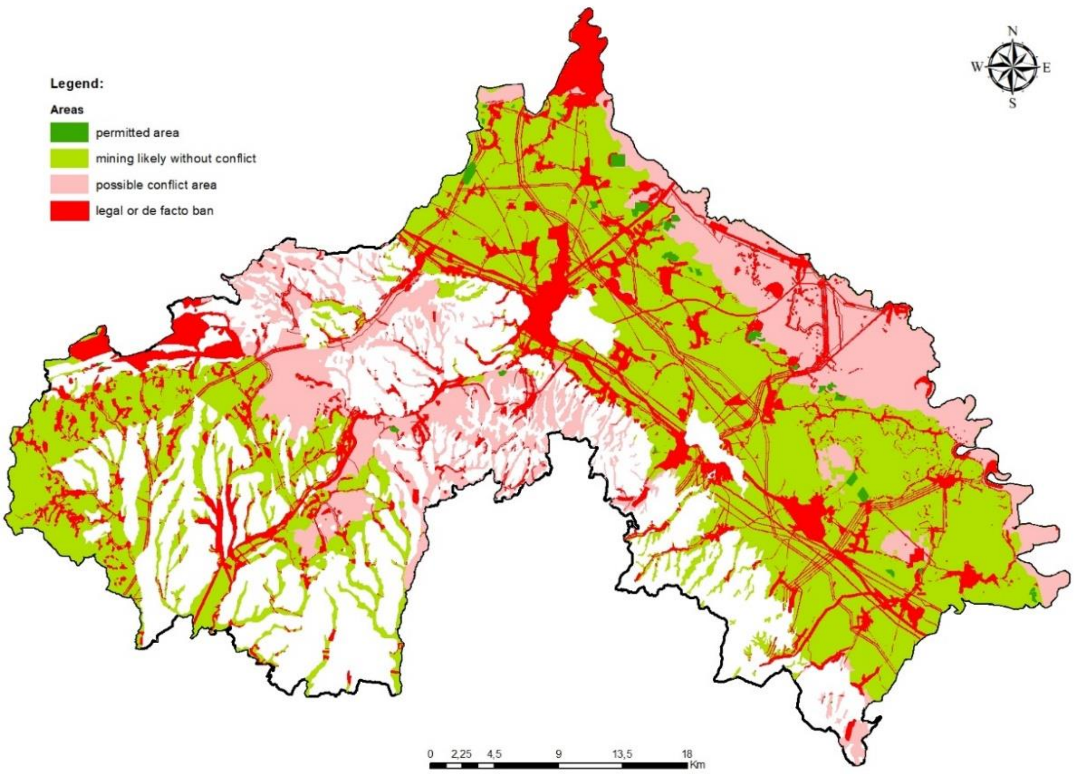

Figure 4 Areas currently permitted for mining, conflict and conflict-free areas, and zones with a legal or de facto ban for aggregates in Koprivnica - Križevci County

The resource potential of the aggregates (limestone; gravel and sand) resources areas for Koprivnica - Križevci County occupy more than 70% of the total area (1242 km²). Less than 30% of the area is not suitable for aggregates in the county (white colour in Fig. 4 and 5).

Of the total surface area (1242 km²) aggregates resources in the Koprivnica - Križevci County less than 1% are permitted area (0,67%) or deposits that are currently performed by mining, than 54% are area in which potential mining is considered likely to proceed without conflict, than 24% are possible conflict area and more than 20% are legal or de facto ban according to state or regional laws or spatial plans in more levels.

The distribution of EFG codes for stone aggregate resources in Koprivnica - Križevci County is shown in Fig. 5., EFG code 111 represent permitted area or deposits that are currently performed by mining (blue colour), EFG code 222 -224 represent area in which potential mining is considered likely to proceed without conflict (green colour), EFG code 323 -324 represent possible conflict area (yellow and orange colour), EFG code 343 -344 represent legal or de facto ban areas (reddish colour).

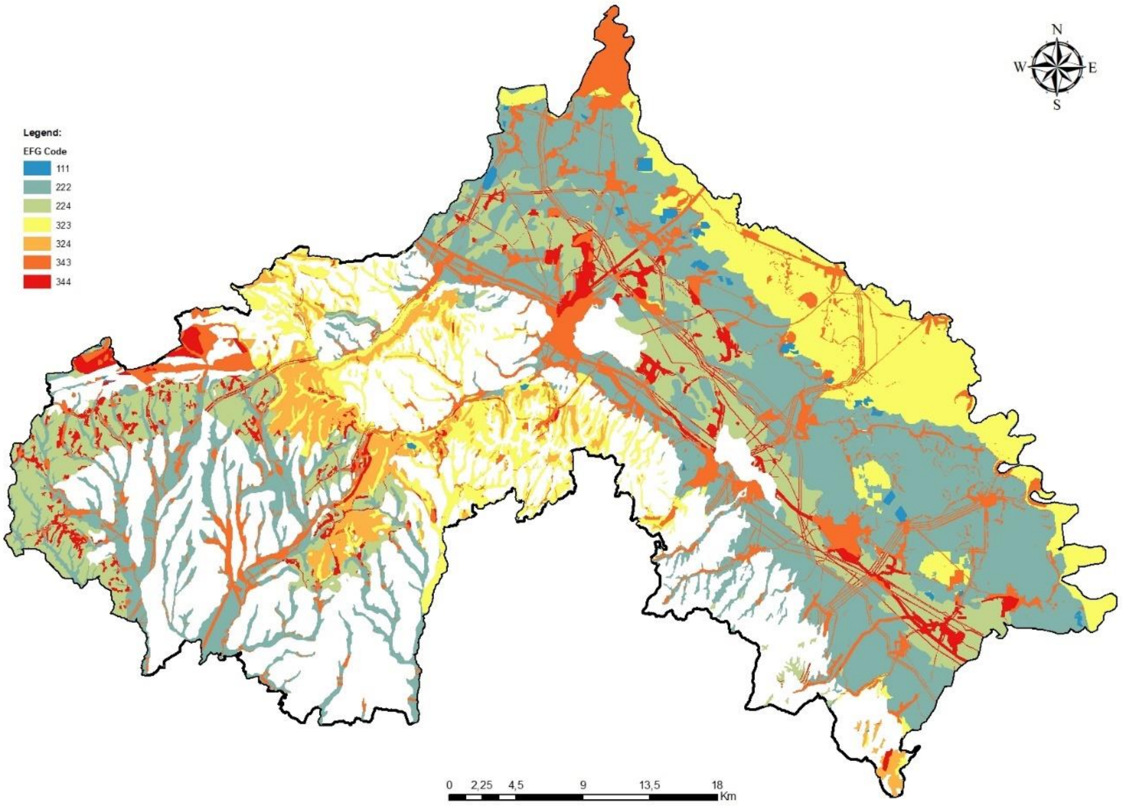

Figure 5 Distribution of EFG codes for aggregates resources in Koprivnica - Križevci County

Distribution of EFG codes for stone aggregates resources in Koprivnica - Križevci County can be divided into two dominant mineral resources crushed stone aggregates and gravel and sand. Also, such areas can be divided into areas more or less suitable for exploration and exploitation of such mineral resources the conclusion about that comes to us from the knowledge of the geological structure of the area. Tab 4. shows the EFG codes with areas in square kilometres (km^2) and percentages (%) that they cover for the entire county or for the area of geological potential of these mineral resources and a description of the EFG according to the spatial planning documentation.

Table 4 Distribution of EFG codes for aggregates resources in Koprivnica - Križevci County

Types of mineral resources (MR)	Area km ²	Area (%) MR	Area (%) County	EFG Code	EFG description
Crushed stone aggregates	0,06	0,005	0,003	111	permitted area
	1,06	0,08	0,06	222	mining likely without conflict
	3,87	0,31	0,22	323	possible conflict area
	9,79	0,79	0,56	343	legal or de facto ban
Crushed stone aggregates Total	**14,78**	**1,19**	**0,85**		
Gravel and sand	7,94	0,64	0,45	111	permitted area
	487,54	39,18	27,89	222	mining likely without conflict
	243,71	19,59	13,94	323	possible conflict area
	175,12	14,07	10,02	343	legal or de facto ban
Gravel and sand Total	**914,30**	**73,48**	**52,31**		
Less suitable crushed stone aggregates	0,04	0,005	0,003	111	permitted area
	0,60	0,05	0,03	224	mining likely without conflict
	0,39	0,03	0,02	324	possible conflict area
	5,44	0,44	0,31	344	legal or de facto ban
Less suitable crushed stone aggregates Total	**6,47**	**0,52**	**0,37**		
Less suitable gravel and sand	0,33	0,03	0,02	111	permitted area
	193,36	15,54	11,06	224	mining likely without conflict
	55,83	4,49	3,19	324	possible conflict area
	59,14	4,75	3,38	344	legal or de facto ban
Less suitable gravel and sand Total	**308,66**	**24,81**	**17,66**		

As shown in Tab. 5, EFG code 111 represent permitted area or deposits that are currently performed by mining cover 0,04% of entire county, EFG code 222 -224 represent area in which potential mining is considered likely to proceed without conflict cover around 3,14 % of entire county, EFG code 323 -324 represent possible conflict area cover around 1,4 % of entire county, EFG code 343 -344 represent legal or de facto ban areas cover around 1,15 % of entire county.

Table 5 The aggregate distribution in the area and percentages of EFG codes for aggregates resources in Koprivnica - Križevci County

EFG Code	Description	Area km ²	Area (%) MR	Area (%) County
111	permitted area	8,37	0,67	0,04
222	mining likely without conflict	488,59	39,28	2,25
224	mining likely without conflict	193,96	15,59	0,89
323	possible conflict area	247,58	19,90	1,14
324	possible conflict area	56,22	4,52	0,26
343	legal or de facto ban	184,91	14,86	0,85
344	legal or de facto ban	64,58	5,19	0,30

Discussion

For the application of UNFC to the aggregates resources at a regional (county) scale, traditional measures (profitability assessments, technical feasibility studies, exploration campaigns) to derive EFG codes are not appropriate. The present case study develops a new GIS methodology which reclassifies the entire aggregates resources deposits according to UNFC, and nevertheless obtains results which comply with the original definitions of EFG categories.

We have used simple tools ESRI GIS software, such as vectors of different data on which reclassification was performed in order to determine EFG categories. For better and more comprehensive analyses it is necessary to more sources of data and opportunities that give ESRI software to get through raster or other spatial analysis.

The surface extent of aggregates resources deposits is taken from geological maps as a starting point. Geological survey organisations (GSO's) generally have access to such data and are therefore particularly well suited to implement the approach.

The G-axis code reflects the degree of confidence regarding the geological knowledge of the resource. Aggregates pit and quarries operations require detailed exploration studies including systematic drilling campaigns, and they are performed in varying degree and aggregates excavation is started with a different level of confidence

For the derivation of the E-axis code, the approach relies on spatial planning data to identify zones where mining is legally prohibited (or *de facto* never permitted), likely to encounter social or environmental conflicts, likely to proceed without conflict, or even given preference to other land use interests. Active mining areas are then added to these zones. Due to INSPIRE, the required data are largely public domain and the developed approach should be feasible in any European country. However, in order to implement the approach, geological surveys need to consult with spatial planners or permitting authorities. Only they can inform on *de facto* banned areas, where mining permits will generally not be granted.

F-axis codes are derived here based on two aspects: (a) presence of legally (or *de facto*) banned areas, and (b) pending applications for mining permits. While the first aspect can easily be accounted for in a GIS project, the second aspect may pose a challenge to geological surveys. In Croatia, there is regular data exchange between permitting authorities and the Geological Survey upon request.

Within areas of conflict, scoring systems exist to resolve environmental or social issues by weighing the importance of the aggregates resources for the supply of construction material against negative consequences for the society, the environment or for natural resources. On one hand, marks are given in favour of aggregates mining depending on the suitability, importance and location of the resource. On the other hand, points are deducted depending on the impact of excavation and transport on the local community, the value of the land, on biodiversity, landscape, cultural heritage, agriculture, forestry and water supply. A positive total score would lead to the classification of the resource as F2 (Tab. 5). However, this type of conflict resolution should be performed by spatial planners, ideally in cooperation with geologists.

Conclusions

This case study attempts to classify aggregates deposits according to UNFC. It presents a new, GIS-based approach and a new set of criteria for deriving EFG codes at a county scale, irrespective of past, current or future mining projects. The results are compliant with current UNFC definitions of E-, F- and G-axis categories. The methodology largely relies on spatial planning data which due to the INSPIRE directive should be generally accessible in any EU country. Additional geological data required, such as geological maps or borehole logs, are commonly available at geological survey organisations which makes this approach particularly well suited for implementation by these organisations.

It remains to be confirmed by geological surveys in other EU countries, whether the approach is transferable, feasible across Europe, and perhaps even recommendable as a guideline or common way to classify aggregates resources at regional (county) level. The distinction between legal ban areas, possible conflict areas, conflict-free areas and safeguarded areas - and the resulting E- and F-axis code allocation - are expected to be transferable and of general help when applying UNFC to aggregates deposits at a county scale.

We have proposed a new GIS methodology that is compatible with the UNFC for aggregate resources in which geological research organizations (GMOs) play a key role due to their position in geosciences and research then in national policies and to assist policy makers in decision making. This GIS methodology complements the UNFC at the regional (county) level in order to obtain high-resolution data for spatial planners, decision makers or investment investors, or in those fields where the UNFC is not sufficiently implemented.

It is important to emphasize that this work can be further improved and refined and it all depends on the quality of data available to geological surveys as an example of which is the work of Pfleiderer S. (2020), in which other variables are applied, such as the distance of the market from exploitation areas where deposits are located (< 30 km, greater distance higher price of final product), gravitational variables (larger cities in or outside the region itself; Zagreb and Koprivnica) that can further help in the reclassification of EFG codes as well as the volumes of the reserves themselves, which require numerous data from wells that are not so easy to reach in Croatia.

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UNFC Case study – Marine aggregates, Denmark

Introduction

Sand and gravel dredging in Denmark have through the last 50 years gone from near wild west conditions with almost no restrictions at all, to a law-based maritime planning system, integrated with EU environmental protection directives. The Danish Environmental Protection Agency (EPA) administrates environmental protection areas, dredging allowances, controls aggregate investigation projects, and support national sand and gravel mapping activities at sea. The Geological Survey of Denmark and Greenland (GEUS) performs national/regional aggregate mapping surveys for the EPA, the Danish Coastal Agency, as well as for dredging companies. GEUS maintains a national database and related GIS-map server of marine aggregate resource areas, with specific survey information on seismic data, sediment cores, sample analyses, and geological/environmental reports on specific areas. The resources are pt. classified on basis of geological knowledge, but increasing demands for maritime spatial planning underline the need for more advanced resource evaluations tools such as UNFC.

Danish marine aggregate resources

This study attempts to assign UNFC confidence values to known Danish marine aggregate resource areas, ranging from inferred resource areas (low data confidence) to measured resource areas (high data confidence). Also included are project areas encompassing active and inactive aggregate exploration and production areas from the Danish offshore area.

Danish aggregate resources are found widespread over the offshore area reflecting the close to 100% cover of loose quaternary deposits over Denmark. The aggregate resources are dominated by fine-coarse grained sand, but specific areas have larger occurrences of gravelly deposits. The resources are dominated by Holocene marine deposits, but meltwater deposits from the last and penultimate glacial-deglacial periods also occur. In addition, there is few areas with exposed loose sandy pre-quarternary deposits in the North Sea (Miocene sands) and by Bornholm (Late Cretaceous-Jurassic quartz sands). Danish marine aggregate resources are pt. classified on basis of data confidence (3 classes), geological deposit type (4 classes) and resource type (5 classes), cf. Figure 1.

The resource inventory used for this project is part of the national Danish marine raw material database MARTA hosted by GEUS. In addition, commercial areas (exploration and production) at different project maturity states are included.

MARTA includes information on aggregate area resources, survey data (shallow seismic lines and borehole data), sample analyses, available survey reports, surface sediments, as well as Natura-2000 habitat areas and geological/environmental reports. The GIS interface allow users to tick relevant information layers and to download most of the data (Figure 1). Apart from giving a 2D map view of known (measured) deposit extension and total volume, it also shows extent of potential deposits at lower certainty levels (indicated and inferred).

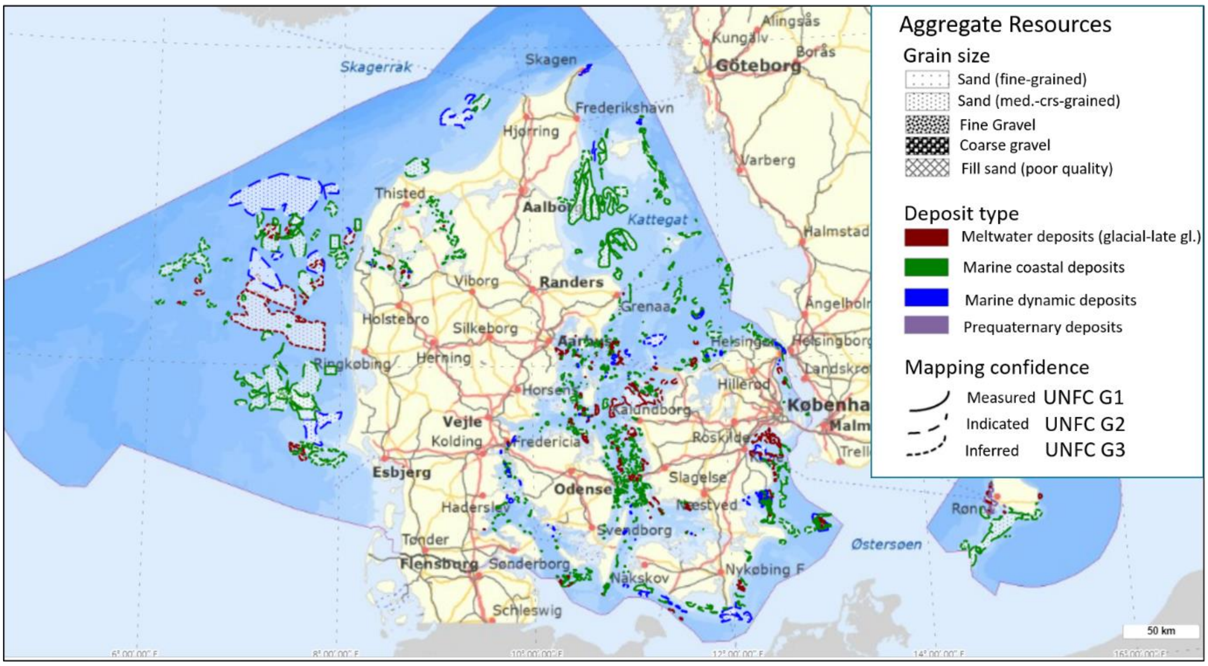

Figure 1 Distribution and classification of marine aggregate resources in Denmark.

The Danish aggregate exploration and active dredging areas are according to Danish law divided into five different types (Figure 2):

Exploration areas term areas where exploration for new aggregate dredging projects has been allowed by EPA. An evironmental report on impact of necessary survey activities are required. Also a public hearing period is required in relation to the Danish Maritime Authority, Danish maritime museums, Danish Navy, fishery organisations, and local/national environmental organisations.

Common areas are areas where active dredging takes place. All dregers with allowance are able to dredge aggregates with a m^3 fee in the area up to a yearly maximum amount for the specific area. The areas are partly specific areas where dredging has taken place for many decades, even before any regulations were established. The area itself and its allowed yearly and total dredging amount can be extended following a detailed geological and environmental impact study according to EPA's specifications.

Auction areas term areas where a specific dredging company following an auction has won the exclusive right to dredge aggregates up to a yearly maximum amount for a period of 10 years. In order to get allowance, detailed aggregate resource studies and an environmental impact study following EPA's specifications are required. The process typically takes 1,5-2 years.

Reservation areas are areas reserved for larger state infrastructure projects such as coastal protection (coastal nourishment), bridge and tunnel projects, and larger land reclamation (e.g.

harbour area) projects. The areas need further studies and project development before specific dredging areas (termed construction areas) can be defined.

Construction areas are areas where active dredging for larger state infrastructure or coastal protection projects takes place. Detailed aggregate resource studies and an environmental impact studies following EPA's specifications are required in order to get the allowance.

Figure 2 Danish marine aggregate project areas divided into 5 types.

Methodology

Data used are partly from the Danish marine raw material database MARTA (https://data.geus.dk/geusmap/?marta) as well as from EPA concerning administrative status, extent of exploration and production areas, as well as Natura-2000 protection areas and Danish Marine Strategy areas ([Miljøgis (mim.dk)](https://mim.dk)). The databases are publically available and data can be down-loaded and shown as tables and GIS shape files. Existing data concerning confidence level of geological knowledge are basically CRIRCSO-compliant, as the three levels used in the Danish marine raw material database corresponds to CRIRSCO levels for mineral resources: inferred, indicated, and measured.

Tables of basic ressource parameters (ID-no, area, thickness, volume (if existent), resource type, geological deposit type, and geological knowledge (data confidence) have been created and assigned to GIS shape files for each resource. Administrative boundaries, Natura-2000 areas, sea maps with addtional restricting parameters such as sea cables, navigation routes, wrecks, etc. have beed added to GIS project for evaluation of societal/environmental constraints on specific project areas/resource areas.

UNFC EFG-confidence levels have been allocated to each resource number based on considerations listed in the following section. GIS layers of restricted areas have been used to assist the classification with respect to environmental protection areas, wind farms, navigation, military, marine archaeology.

UNFC

In the following, parameters decisive for the definition of the UNFC EFG confidence levels for marine aggregates in Denmark are described (cf. Figure 3).

UNFC E-axis

Relative to most other raw materials, aggregates have in general a low value/weight ratio and therefore transport costs are a major factor influencing the logistics and value chain of aggregate dredging projects. Distance to land and nearest landing place where there is a demand for aggregates is a decisive element. From this follows, that a similar aggregate resource with respect to amount and quality that are situated in different parts of the Danish waters can have a quite different value. The different aggregate types with respect to grain size distribution and mineralogy have also quite different values. In Denmark there is a high demand for coarse gravel of good quality (low amorphous silica/flint content) for high grade concrete production. This means that it may be profitable to transport shiploads of coarse gravel many hundreds of kilometres (even as export products), whereas sand of lower value maximally can be transported about 30-40 km in order to be economically viable.

Environmental protection with respect to protected EU habitat types is an important element of evaluation of the E number of existing resource areas as well as the establishment of new aggregate dredging areas. New dredging areas will generally not be allowed within established habitat protection areas (Natura-2000 areas).

EU Marine Strategy Framework Directive aims to achieve good environmental status (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend. In context to this, a new law on maritime physical planning is about to be ratified in Denmark. The plan shall establih which sea areas that can contribute to a sustainable development of the energy sector, sea transport, fishery/aquaculture, aggregate dredging, and preservation and protection of the marine environment incl. the effects of climate changes. In the end, the plan will have the effect, that potential areas where new aggregate projects can be established will considerably diminish. This will affect the UNFC E number of many existing ressource areas.

Project areas approved for dredging and areas where active dredging takes place are termed E1. Project areas where exploration takes place and where approval of environmental study and and outcome of public hearing is underway are termed E2. The main part of the Danish resources where no action or development for dredging has taken place is termed E3.

UNFC F-axis

In comparison to higher value raw materials on land, the project development for marine aggregates is relatively simple and typically takes only a few years. The project development can be considered to be low-risk, as resources are situated close to the sea bed (no or very limited burial depth), and existing data may already reveal the general quality of the resource with good confidence. During exploration for aggregates in a given area, unexpected findings that could have influence on final approval of the project interest area could be fx. The discovery of specially protected marine habitats (e.g stone reefs, bubble reefs) or archaeological remains.

The exclusive dredging right areas which are assigned after an auction to the highest bidder may cause a certain element of project development uncertainty and stop further project development for a dredging company that may have defined and forwarded the specific auction area to DEPA. The auction winning company is however obliged to perform investigations of the area following standard DEPA legislation.

The approval process and procedures for all types of dredging areas in Denmark follows the legislation for marine raw materials administrated by DEPA. After approval of exploration area and survey environmental impact report by the authorities, investigation follows in three phases. A first screening phase (called Ia) is composed of a geophysical survey and optionally sediment coring. Hereafter follows a second survey phase (Ib) with detailed geophysical mapping and sediment coring of subarea(s) where suitable aggregates have been indicated during the first phase (incl. a 500 m surrounding zone). In this phase it is required that the distance between seismic lines is maximum 100 m in order to have full coverage of the seabed by side scan sonar. The third phase is an environmental survey (incl. underwater video) and environmental impact study with evaluation of biological habitats and influence of potential dredging activities. If existing data from a potential project area corresponds to the level of a phase Ia investigation, the demand for new phase Ia survey data may be waived, and the project development can be shortened.

In short, the main part of the Danish aggregate resource areas where no dredging takes place, can be termed F3. Quite a limited amount of areas is under exploration falling into the F2 category. Fully developed active dredging areas and fully developed exploration areas only missing the final environmental approval can in general be termed F1.

UNFC G-axis

Following the earlier description of the present classification of Danish marine aggregate resources based on geological knowledge, it follows that the translation to UNFC G-axis values is straight forward. In this sense G1 corresponds to measured resources, G2 to indicated resources, and G3 to inferred resources. None of the present Danish resources would fall into the G4 class terming resources only inferred by indirect data (e.g. a geological model for an area). Project areas mapped in connection to commercial exploration may contain very detailed supporting geological data. However, these data are often confidential, and therefore in some instances only G3-G2 confidence levels are assigned to the areas.

GIS mapping project

Resource areas and project areas has been assigned UNFC EFG-classes according to the above considerations. An UNFC GIS project has been established as shown in Figure 4 and Figure 5.

UNFC Classes defined by categories and subcategories						
Extracted	Sales Production					
	Non-Sales Production					
	UNFC Class	UNFC Subclass	Marine Aggregate Areas (DK)	UNFC minimum Categories		
				E	F	G
Known Deposit	Commercial	On Production	Common-, Auction -, and Construction area	1	1.1	1-3
		Approved for Development	Investigation area (approved)	1-2	1.1	1-2
		Justified for Development	Reservation areas	1-2	1.2 - 1.3	1-2
	Potentially Commercial	Development Pending	Investigation area under development	2-3	2.2 - 2.3	1-3
	Exploration projects	Development On Hold	Investigation area on hold	3.2	3.1 - 3.3	2-3
	Projects	Development Unclarified	Unused proven resources	2	2.1	1-2
		Development Not Viable	Resources in environmental protection zones	3	2-3	1-3
	Additional quantities in place (known deposits)		Proven ressources under thick cover (>1m)	3	3-4	1-2
Potential Deposit	Exploration projects	Prospect	Indicated resources	3.2	3.1 - 3.3	2-3
		Early Exploration	Inferred resources	3.3	3.2 - 3.3	3
		Play				
	Additional quantities in place (potential deposits)		Indicated/Inferred Resources under thick cover	3	3-4	2-3

Figure 3. UNFC classes and corresponding Danish marine aggregate resource areas and project areas.

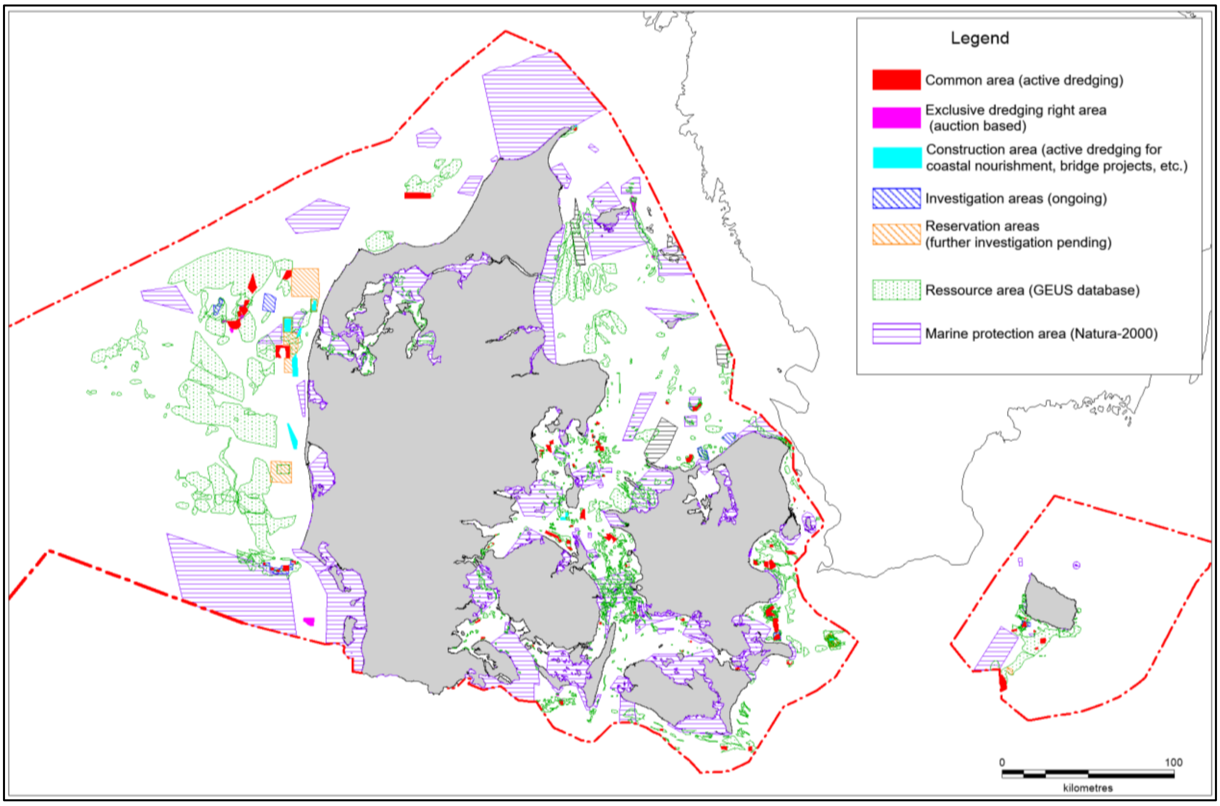

Figure 4 Aggregate resource areas, investigation areas, active and inactive dredging areas as well as Natura-2000 marine protection areas.

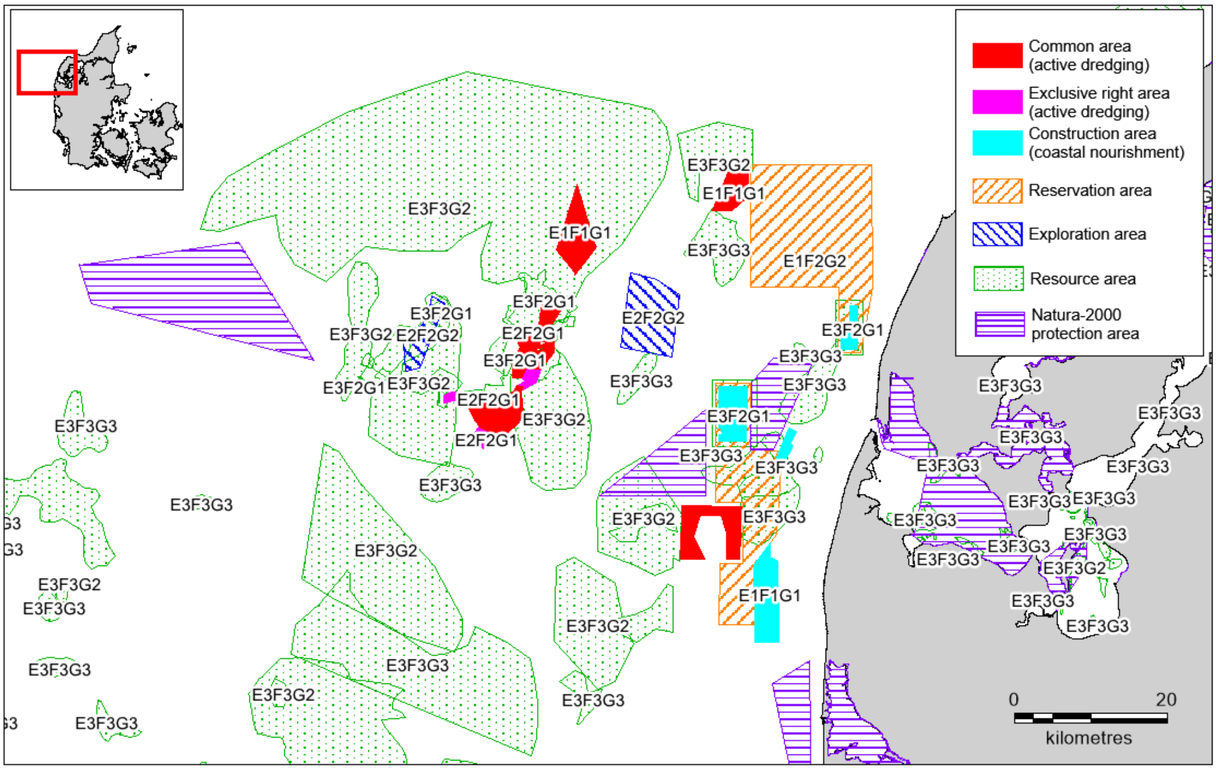

Figure 5 UNFC classifications of marine aggregate areas assigned to different types of project areas and resource areas in the northwestern part of Denmark.

Resource volumes

Resource volumes or area and average thickness are given for most of the Danish resources with a measured or indicated (G1-G2) level of geological knowledge. The volume uncertainty of measured resources is generally estimated to be about 20%. Volumes of inferred resources (G3) are mostly not given. However, based on the given resource areas, volumes can be calculated, assuming a fixed thickness.

Challenges

There are numerous challenges with respect to UNFC classification of marine aggregate resources that hitherto have only been classified with respect to geological knowledge. In international context, challenges are partly related to basic classification issues between EU countries of what type of material that can be termed a marine aggregate. Secondly, industry data on offshore aggregate resources mapped by dredging companies are mostly limited due to confidentiality. This means, that in some project areas where data density is very high, available data on geological knowledge may be quite limited.

The geological definition of marine sediment types that are classified as aggregate resources is treated different between EU countries, fx. filling sand for land reclamation is not included as an aggregate in some countries. Marine aggregates encompass sand, fine gravel and coarse gravel. Demands are often focussed on specific occurrences with a specific grain size composition and a mineralogical composition suitable for e.g. concrete. Therefore, classification of total ‘marine aggregates’ or ‘sand and gravel’ does not reveal volumes and location of market specific high grade (most valuable) resources.

Experience learned

This pilot study has shown that marine aggregate resources in Denmark in general can be allocated UNFC class values based on relatively simple prerequisites. It has been an advantage that a comprehensive database of marine aggregate resources already exists in Denmark. Commercial data of dredging areas may however be confidential.

The low value/weight relationship of aggregates makes transport costs to market a very important element of the socioeconomic E factor. In addition, marine environmental legislation and requirements concerning EU marine strategy planning are of increasing importance. Marine aggregates are relatively simple to map and to extract and therefore project development factor F are mostly related to legal requirements concerning environmental approval of projects. The geological knowledge factor G can be assigned to resources, where a corresponding division based on data confidence already exists.

This study underlines that aggregates occur in very different qualities with respect to grains size and mineralogy, making comparison of total aggregates without detailed background knowledge less valuable for decision makers.

References

Danish marine raw material database: https://data.geus.dk/geusmap/?marta

Danish Environmental Protection Agency: Miljoegis.mim.dk/cbkort?profile=miljoegis-raastofferhavet

Marine strategy framework directive: Law - EU Coastal and Marine Policy - Environment - European Commission (europa.eu)

UNFC Case study – Danish chalk and limestone resources

Introduction/Background

Chalk and limestone have been mined for ages in Denmark, e.g. for improving agricultural soils but also as construction stone. Today, most chalk and limestone are used in cement production, for soil improvement, in paint, paper and plastic production, and in other chemical products.

In Denmark, raw materials can only be exploited in designated excavation areas laid out by the Danish Regions with an excavation license in hand. Licenses are based on a national Raw Materials Law and are issued and enforced by the Danish Regions. The licenses include environmental requirements, terms on access, noise, dust, groundwater protection etc. Besides, mining companies must provide an economic guaranty for reconstruction of the mined area when abandoned.

In Denmark, chalk and limestone are mined in open pits only.

Define the resource

What kind of resource, location, situation, scale (project, local, regional or National) etc.

The following case study is national, covering Danish carbonates (see definition on the accessibility below)

The Danish carbonates are typically distinguished into two different types, depending on their age and lithology:

- Cretaceous chalk, a very fine grained (muddy) carbonate with a relatively low content of chert and variable but low clay content
- Danien limestone, variable grain size from mud, silt to sand and with a higher content of chert. One exception is the coral limestone, a very clean limestone type, primarily found in the southeastern part of Sealand.

The main part of the Danish subsurface contains several hundred of meters of carbonates of different geological ages, but in most places too deep to be exploited. This test case, based on the resource evaluation conducted by Ditlefsen et al (2015), only includes resources down to 25 m below surface and with less than 10 m overburden, see figure 1.

Chalk and limestone are, in terms of proved(measured) resources, the third largest group of Danish raw materials, only surpassed by salt, and sand & gravel. Chalk dominates with 91%, while limestone only stands for 9%. See table 1 for numbers on proved(measured), indicated and inferred resources. Gross numbers (inferred resources) are model-based calculations, based on a maximum mining depth of 25 mbsl. Net numbers take into account Natura2000 or other protected areas, build areas, infrastructure etc. although mining in specific cases might be possible.

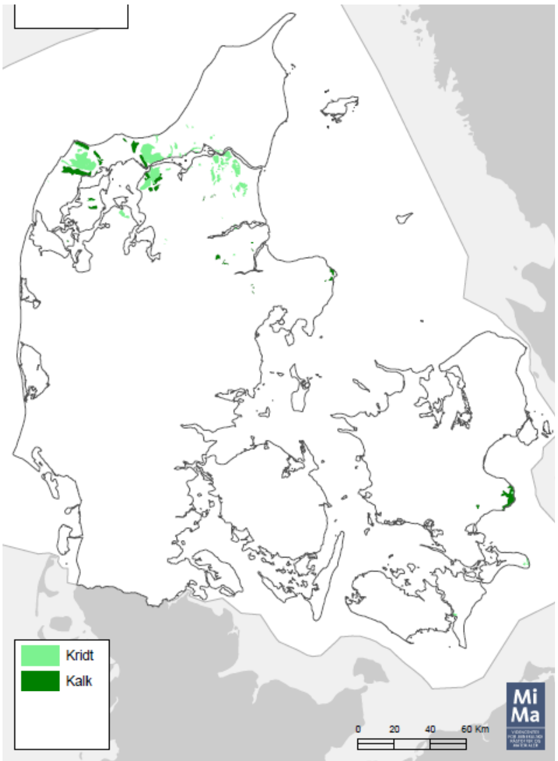

Figure 1: Mapped, accessible chalk (Kridt) and limestone (Kalk) resources in Denmark. Chalk is of Cretaceous origin while limestone is Danien. From Ditlefsen et al (2015)

Type	**Gross**			**Net**			**E**	**F**	**G**
	Chalk	Limestone	Total	Chalk	Limestone	Total			
Proven	27	266	293	27	266	293	1	1.1	1
Probable	14	75	89	14	75	89	1	1.1	2
Indicated	4,619	4,573	9,192	3,868	3,180	7,048	2	1.1 (1.2,1.3)	3
Total	4,660	4,914	9,574	3,909	3,521	7,430			

Table 1: Proved(measured), indicated and inferred chalk and limestone resources in Denmark. From Ditlefsen et al (2015). All numbers are in million m^3.

Methodology

How have data been gathered?

Data used in this test case was collected and published in 2015 by Center for Minerals and Materials (MiMa) at GEUS, see Ditlefsen et al (2015).

What kind of data have been used?

Information on volume and quality of raw material deposits of chalk and limestone are used in the following prioritized order (Ditlefsen *et al.* 2015):

- In the designated excavation areas, where the Region has estimated the resource, this information is used.
- For the resources where raw material mapping has been conducted, volume and quality are used from the reports
- In designated excavation areas without other information the volume is estimated based on geological maps and well data.
- In other areas where chalk and limestone is observed at the surface according to geological maps the volume is estimated based on the assumption that the resource is exploited to a depth of 25 m. In the well data base a search was made for wells where the chalk is found in the upper 10 m (less than 10 m overburden). The volume was then calculated from top chalk to 25 m below surface.

Availability of data sources

All the used data are available online (raw material plans from the Regions, well database, geological maps, geophysical surveys, reports etc., but interpretation was done by the team contributing to Ditlefsen et al (2015).

UNFC

Evaluation of data and areas, calculation of volumes.

The resources are classified based on the certainty on which they are determined, and they are divided into three levels; proven, probable and speculative

Proven resources are characterized by having sufficient data to give a sound estimate of volume and quality.

Probable resources are identified with geophysical methods and few wells, ore areas with many well data information.

Speculative resources are only interpreted based on geophysical methods, or very few wells.

<u>UNFC E-axis (Viability):</u>

E1: The Danish exploitation of limestone and chalk resources are assessed to be environmentally, socially and economically viable. All permits are in place for the current exploitation and can in most cases be extended in time or geographically, but this will be subject to an evaluation by the public authorities. Exploration and environmental impact are underlain municipal supervision, production must be reported to the respective municipalities, and mined areas must be reconstructed to a predetermined land use (farming, recreative, sportif etc.) when exploitation has ended.

E2: Some of the mapped resources not yet exploited fall into this category.

<u>UNFC F-axis (Technical feasibility and maturity):</u>

F1.1: The technical feasibility of the exploitation already taking place has been confirmed. Some resources not yet exploited fall into category F1.2 or even F1.3.

<u>UNFC G-axis (Confidence):</u>

G1-G2: Given the above described methods used for estimating the quantity of resources, it is our assessment that theses estimates have a high to moderate level of confidence.

Challenges

Describe possible challenges, harmonization issues and uncertainties. What is the quality of the data? Issues concerning availability of data?

Data access, the data arises from a specific report and are not necessarily available for GEUS.

Additional Questions:

What have you learned from this work?

Necessary to have a European/national strategy for Raw Materials to ensure alignment between countries on the same commodity types.

What kind of challenges have you experienced during this work?

Data access.

How can your work and experience be used into a UNFC guideline?

How can this case and your experience be used into the next deliverables and Milestones in Mintell4EU WP4:

D4.1 Case study review with practical guidelines/work flows and examples for applying UNFC to European mineral resources

D4.2 Report on harmonization issues, data gaps and challenges, reviewing also the quality of Pan-European aggregated inventories for selected commodities

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UNECE (2019). United nations Framework Classification for Resources. Update 2019. UNECE Energy Series 61

UNFC Case study – Cobalt, Finland

Introduction/Background

Define the resource

National mineral deposit database and primary information sources linked to the database

Methodology

The data was treated as follows:

1. All resource data in GTK deposit database are currently categorised into these classes: NA; Poorly estimated mineral resource, poorly documented (Mostly historic, but also includes a few more recent cases); Measured mineral resource; Indicated mineral resource; Inferred mineral resource; Measured and indicated mineral resource; Measured, indicated and inferred mineral resource; Indicated and inferred mineral resource; Proved ore reserves; Probable ore reserves; Proved and probable ore reserves.

Further, all these are first directly converted into UNFC categories, then checked according to reporting years and current holding of the deposits. This procedure has resulted in more realistic UNFC categories of all resources and reserves in the national deposit database.

2. The inspection of the data is team work: GTK experts knowing individual deposits, and their exploration history and status checked the data, reflecting the requirements of the CRIRSCO and UNFC codes.

Did you use bridging from CRIRCSO-compliant data? Yes

How have data been gathered? Information gathered from original mining and exploration company and Geological Survey of Finland reports into the national mineral deposit database.

What kind of data have been used? Data from original mining and exploration company and Geological Survey of Finland reports.

Availability of data sources: Availability for metal resources data is good, less so for most of the industrial minerals. Data on aggregates is not in the national mineral deposit database, as aggregates are in separate databases and are controlled by laws and permitting separate and different to metal and mineral deposit databases.

UNFC

Evaluation of data and areas, calculation of volumes: Figures as in the original reports used

Defining the E, F and G-axis: Easy and starightforward if CRIRCSO-compliant data is available. Also easy if can be coded into 3,3,4. Complicated and needs help from case study examples when not straightforward – more of that below.

What is considered as a regional resource, something that cannot be related to any individual deposit, we classify to 344. Essentially, this is based on GTK assessments on undiscovered mineral resources. The method and results of this work are summarised in Rasilainen et al. (2017). For cobalt there is an update in Rasilainen et al. (2020). Note that also cobalt data from some *deposits* (21,027 t Co) we have classified into 344; these are cases where the geological uncertainty is high due to very low data density.

Results Aggregated cobalt resources in Finland, classified according to the UNFC:

UNFC category	Cobalt tonnes
111	6,936
112	7,910
111+112	99,788
221	4,822
222	27,026
223	30,538
221+222+223	184,756
332	1,483
333	11,764
334	39,102
343	36,935
344	21,027
344	108,000*
Total	**580,086**

* Median value of undiscovered cobalt resources in Finland. Note that due to restrictions of the assessment method (lack of relevant reference data) undiscovered resources in the Talvivaara and Kevitsa type deposits could not be estimated.

Challenges

Pre-CRIRSCO reporting, high to low data density, feasibility done decades ago => need to use categories 331, 332, 333, 344.

Some commodities reported in an older but not in the latest resource. Alternatively, commodities may be reported with the same resource, but the technical feasibility study only considers the main metals and not the byproducts => Different UNFC categories in a deposit for individual commodities. This relates to cobalt resources for many deposits. This further means, e.g., a combination of 222 + 342 or 222 + 343 or 223 + 343 with the same tonnage for different commodities (222, 223 for the metals planned to be produced, 342, 343 for other commodities included in a resource). Value F4 is given when there is no information how that commodity could be extracted from that certain ore. Value E3 as the permitting in place or applied for does not include extraction of the commodity.

CRIRSCO-compliant resource >10 years ago, then the company left the prospect, the possible new owner has not released a new resource => Change from 221, 222, 223 to 321, 322, 323, respectively, or to 331, 332, 333 (= change from CRIRSCO-compliant to non-compliant resource!)

'Historic' resources: one needs to check the original reports and make one's mind on the quality of reporting and the data density.

A multi-lingual terminology dictionary, with focus in mineral resource codes, was found out to be a necessity, so we created a bi-lingual one. Obviously, such bi- or multi-lingual dictionaries (lexicons) are needed for each country.

Training should be organised in all countries, preferably also with the native languages, for all users to gain a full understanding of the UNFC code.

Additional Questions:

What have you learned from this work? A need for a good set of case studies to guide the classification. Also, quite a many UNFC class combinations are realistic, many more than what one might think from preliminary familiarisation of the UNFC code.

What kind of challenges have you experienced during this work? Lack of data and need of workforce. Categorising into UNFC is often not straightforward

How can your work and experience be used into a UNFC guideline? We have produced a guideline report with many case studies

How can this case and your experience be used into the next deliverables and Milestones in Mintell4EU WP4:

D4.1 Case study review with practical guidelines/work flows and examples for applying UNFC to European mineral resources

D4.2 Report on harmonization issues, data gaps and challenges, reviewing also the quality of Pan-European aggregated inventories for selected commodities

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UNECE 2019. United Nations Framework Classification for Resources, Update 2019. UNECE Energy Series 61. 20 p. Online: www.unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/publ/UNFC_ES61_Update_2019.pdf

UNFC Case study – Copper, Finland, with reference to the use of the code on all commodities

Introduction/Background

Define the resource

National mineral deposit database and primary information sources linked to the database.

Methodology

The data was treated as follows:

1. All resource data in GTK deposit database are currently categorised into these classes: NA; Poorly estimated mineral resource, poorly documented (Mostly historic, but also includes a few more recent cases); Measured mineral resource; Indicated mineral resource; Inferred mineral resource; Measured and indicated mineral resource; Measured, indicated and inferred mineral resource; Indicated and inferred mineral resource; Proved ore reserves; Probable ore reserves; Proved and probable ore reserves

=> Figures directly converted into UNFC categories

2. Resulting figures inspected as teamwork: GTK experts knowing individual deposits, and their exploration history and status checked the data, reflecting the requirements of the CRIRSCO and UNFC codes

=> Updated UNFC categories

Did you use bridging from CRIRCSO-compliant data? Yes

How have data been gathered? Information gathered from original mining and exploration company and Geological Survey of Finland reports into the national mineral deposit database.

What kind of data have been used? Data from original mining and exploration company and Geological Survey of Finland reports.

Availability of data sources: Availability for metal resources data is good.

UNFC

Evaluation of data and areas, calculation of volumes: Figures as in the original reports used

Defining the E, F and G-axis: Easy and starightforward if CRIRCSO-compliant data is available. Also easy if can be coded into 3,3,4. Complicated and needs help from case study examples whennot straightforward – more of that below.

Only what is considered as a regional resource, something that cannot be related to any individual deposit, we classify to 344. Essentially, this is based on GTK assessments on undiscovered mineral resources. The method and results of this work are summarised in Rasilainen et al. (2017).

Results Aggregated copper resources in Finland, classified according to the UNFC:

UNFC category	Copper tonnes
111	62123.6
112	352
111+112	735,280
221	100,074
222	824,850
223	977,754
222+223	64,350
221+222+223	1,305,920
331	346,107
332	33,836
333	103,493
334	688,273
344	9,669,000*
total	**14,911,413**

* Median value of undiscovered cobalt resources in Finland. Note that due to restrictions of the assessment method (lack of relevant reference data) undiscovered resources in the Talvivaara and Kevitsa type deposits could not be estimated.

resource!)

A typical case for an industrial mineral deposit held by a private (i.e., not listed) company: overall resource only given, only in an EIA => all goes into 1,2,2 or 1,3,3 (if active project or a mine, and permit granted) or 3,3,3 (if non-active and not permitted)?

Challenges

Pre-CRIRSCO reporting, high to low data density, feasibility done decades ago => need to use categories 331, 332, 333

Some commodities reported in an older but not in the latest resource; or Commodities reported with the same resource, but the technical feasibility study only considers the main metals and not the byproducts => Different UNFC categories in a deposit for individual commodities. This means, e.g., a combination of 222 + 342 or 222 + 343 or 223 + 343 with the same tonnage for different commodities (222, 223 for the metals planned to be produced, 342, 343 for other commodities included in a resource). Value F4 when there is no information how that commodity could be extracted from that certain ore. Value E3 as the permitting in place or applied for does not include extraction of the commodity.

CRIRSCO-compliant resource >10 years ago, then the company left the prospect, the possible new owner has not released a new resource => Change from 221, 222, 223 to 321, 322, 323, respectively, or to 331, 332, 333 (= compliant → non-compliant

Another typical case for an industrial mineral deposit held by a private company: no resource information at all available even when it is an active mine => no UNFC category can be given. So major issues exist especially with industrial mineral deposits.

'Historic' resources: one needs to see the original reports and make one's mind on the quality of reporting and the data density.

A multi-lingual terminology dictionary, with focus in mineral resource codes, was found out to be a necessity, so we created a bi-lingual one. Obviously, such bi- or multi-lingual dictionaries (lexicons) are needed for each country.

Training should be organised in all countries, preferably also with the native languages, for all users to gain a full understanding of the UNFC code.

Additional Questions:

What have you learned from this work? A need for a good set of case studies to guide the classification. Also, quite a many UNFC class combinations are realistic, many more than what one might think from preliminary familiarisation of the UNFC code.

What kind of challenges have you experienced during this work? Lack of data and need of workforce. Categorising into UNFC is often not straightforward

How can your work and experience be used into a UNFC guideline? We have produced a guideline report with many case studies

How can this case and your experience be used into the next deliverables and Milestones in Mintell4EU WP4:

D4.1 Case study review with practical guidelines/work flows and examples for applying UNFC to European mineral resources

D4.2 Report on harmonization issues, data gaps and challenges, reviewing also the quality of Pan-European aggregated inventories for selected commodities

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UNFC Case study – Gold, Finland

Introduction/Background

Define the resource

National mineral deposit database and primary information sources linked to the database

Methodology

The data was treated as follows:

1. All resource data in GTK deposit database are currently categorised into these classes: NA; Poorly estimated mineral resource, poorly documented (Mostly historic, but also includes a few more recent cases); Measured mineral resource; Indicated mineral resource; Inferred mineral resource; Measured and indicated mineral resource; Measured, indicated and inferred mineral resource; Indicated and inferred mineral resource; Proved ore reserves; Probable ore reserves; Proved and probable ore reserves.

Further, all these are first directly converted into UNFC categories, then checked according to reporting years and current holding of the deposits. This procedure has resulted in more realistic UNFC categories of all resources and reserves in the national deposit database.

2. The inspection of the data is team work: GTK experts knowing individual deposits, and their exploration history and status checked the data, reflecting the requirements of the CRIRSCO and UNFC codes.

Did you use bridging from CRIRCSO-compliant data? Yes

How have data been gathered? Information gathered from original mining and exploration company and Geological Survey of Finland reports into the national mineral deposit database.

What kind of data have been used? Data from original mining and exploration company and Geological Survey of Finland reports.

Availability of data sources: Availability for metal resources data is good, less so for most of the industrial minerals. Data on aggregates is not in the national mineral deposit database, as aggregates are in separate databases and are controlled by laws and permitting separate and different to metal and mineral deposit databases.

UNFC

Evaluation of data and areas, calculation of volumes: Figures as in the original reports used

Defining the E, F and G-axis: Easy and starightforward if CRIRCSO-compliant data is available. Also easy if can be coded into 3,3,4. Complicated and needs help from case study examples whennot straightforward – more of that below.

Only what is considered as a regional resource, something that cannot be related to any individual deposit, we classify to 344. Essentially, this is based on GTK assessments on undiscovered mineral resources. The method and results of this work are summarised in Rasilainen et al. (2017). For gold, there is an update in Rasilainen et al. (2020).

Results Aggregated gold resources classified according to the UNFC:

UNFC category	Gold tonnes
111	15.54
112	129.69
221	27.87
222	100.35
223	194.84
222+223	2.24
331	39.27
332	5.69
333	12.33
334	41.01
344	1,451*
Total	**2,030**

* Median value of undiscovered gold resources in Finland.

Challenges

Pre-CRIRSCO reporting, high to low data density, feasibility done decades ago => need to use categories 331, 332, 333, 343, 344.

Some commodities reported in an older but not in the latest resource. Alternatively, commodities may be reported with the same resource, but the technical feasibility study only considers the main metals and not the byproducts => Different UNFC categories in a deposit for individual commodities. This relates to gold resources for many deposits. This further means, e.g., a combination of 222 + 342 or 222 + 343 or 223 + 343 with the same tonnage for different commodities (222, 223 for the metals planned to be produced, 342, 343 for other commodities included in a resource). Value F4 is given when there is no information how that commodity could be extracted from that certain ore. Value E3 as the permitting in place or applied for does not include extraction of the commodity.

CRIRSCO-compliant resource >10 years ago, then the company left the prospect, the possible new owner has not released a new resource => Change from 221, 222, 223 to 321, 322, 323, respectively, or to 331, 332, 333 (= change from CRIRSCO-compliant to non-compliant resource!)

‘Historic’ resources: one needs to check the original reports and make one’s mind on the quality of reporting and the data density.

A multi-lingual terminology dictionary, with focus in mineral resource codes, was found out to be a necessity, so we created a bi-lingual one. Obviously, such bi- or multi-lingual dictionaries (lexicons) are needed for each country.

Training should be organised in all countries, preferably also with the native languages, for all users to gain a full understanding of the UNFC code.

Additional Questions:

What have you learned from this work? A need for a good set of case studies to guide the classification. Also, quite a many UNFC class combinations are realistic, many more than what one might think from preliminary familiarisation of the UNFC code.

What kind of challenges have you experienced during this work? Lack of data and need of workforce. Categorising into UNFC is often not straightforward

How can your work and experience be used into a UNFC guideline? We have produced a guideline report with many case studies

How can this case and your experience be used into the next deliverables and Milestones in Mintell4EU WP4:

D4.1 Case study review with practical guidelines/work flows and examples for applying UNFC to European mineral resources

D4.2 Report on harmonization issues, data gaps and challenges, reviewing also the quality of Pan-European aggregated inventories for selected commodities

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UNFC Case study – Graphite, Finland, with reference to the use of the code on all industrial minerals

Introduction/Background

Define the resource

National mineral deposit database and primary information sources linked to the database

Methodology

The data was treated as follows:

1. All resource data in GTK deposit database are currently categorised into these classes: NA; Poorly estimated mineral resource, poorly documented (Mostly historic, but also includes a few more recent cases); Measured mineral resource; Indicated mineral resource; Inferred mineral resource; Measured and indicated mineral resource; Measured, indicated and inferred mineral resource; Indicated and inferred mineral resource; Proved ore reserves; Probable ore reserves; Proved and probable ore reserves

Further, all these are first directly converted into UNFC categories, then checked according to reporting years and current holding of the deposits. This procedure has resulted in more realistic UNFC categories of all resources and reserves in the national deposit database.

2. The inspection of the data is team work: GTK experts knowing individual deposits, and their exploration history and status checked the data, reflecting the requirements of the CRIRSCO and UNFC codes.

Did you use bridging from CRIRCSO-compliant data? Yes

How have data been gathered? Information gathered from original mining and exploration company and Geological Survey of Finland reports into the national mineral deposit database.

What kind of data have been used? Data from original mining and exploration company and Geological Survey of Finland reports.

Availability of data sources: Availability for Industrial mineral resources data is highly variable, depending commodity.

UNFC

Evaluation of data and areas, calculation of volumes: Figures as in the original reports used

Defining the E, F and G-axis: Easy and starightforward if CRIRCSO-compliant data is available. Also easy if can be coded into 3,3,4. Complicated and needs help from case study examples when not straightforward – more of that below.

The general lack of industrial mineral resource data is also reflected in the graphite data. Only one deposit has reported resources at all.

Results Aggregated graphite resources in Finland, classified according to the UNFC:

UNFC category	Graphite tonnes
222	539,000
223	737,000
total	**1,276,000**

Challenges

Here, we only list the issues commonly and typically related to industrial minerals, where major issues indeed exist.

A deposit held by a private (i.e., not listed) company: overall resource only given, only in an EIA => all goes into 1,2,2 or 1,3,3 (if active project or a mine, and permit granted) or 3,3,3 (if non-active and not permitted)? In Finland, the common cases of this type are talc (-magnesite-nickel-cobalt) deposits.

Another typical case od a deposit held by a private company: No resource information at all available even when it is an active mine => no UNFC categorised resource can be given. In Finland, the common cases of this type are carbonate (-wollastonite) and industrial rock deposits.

Additional Questions:

What have you learned from this work? A need for a good set of case studies to guide the classification. Also, quite a many UNFC class combinations are realistic, many more than what one might think from preliminary familiarisation of the UNFC code.

What kind of challenges have you experienced during this work? Lack of data and need of workforce. Categorising into UNFC is often not straightforward

How can your work and experience be used into a UNFC guideline? We have produced a guideline report with many case studies

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UNFC Case study – application to peat resources in a Finnish pilot area

Teuvo Herranen, Geological Survey of Finland, teuvo.herranen@gtk.fi

Introduction and Background

The Geological Survey of Finland (GTK) has thus far studied 2.3 million ha of the total geological peatland area of Finland (5.1 million ha). GTK has studied Finnish peatlands since the second world war and more effectively after the energy crisis in the seventies. The big increase in research capacity occurred in the year 1981. The peat data generated in peat mapping has been saved in a peat database maintained by GTK. The database contains data on over 18 000 peatlands, totalling more than 1.78 million study and depth points. The resource potential of peat in Finland has been evaluated nationwide in a harmonised way by GTK (Lappalainen et al. 1984, Virtanen 2017a). Much of the data in database of GTK is publicly available in publications, reports, posters, maps, photos etc. (https://hakku.gtk.fi/en).

Samples have been taken over 19 000 sampling points for detailed laboratory analyses, of which over 1 800 are elemental analyses points. Most elements have been analysed from over 7 000 peat samples. The samples data covers over 9 900 individual peatlands throughout Finland and provides information on the background levels of elements in peat.

In Finland - there has been a nationwide project for studying peat reserves, which started in large scale in the year 1981 and ended in the year 2019. Peatlands at a minimum 20 ha were studied especially in the regions nearby major peat users in Finland. For a long time studies were done along mainlines and cross lines, which were normally 200–400 m apart. From the year 2011, has the so-called triangle grid net used, which gives a better areal scope of a peatland basin.

Define the resource

Our case study is about the peat resources, focusing on energy and horticultural peat resources, and on peat carbon storages. Our pilot area is the municipality of Kruunupyy, Ostrobothnia, Finland. GTK has studied 176 peatlands in Kruunupyy. The total peatland area studied is 14 984 ha. The studied peatlands contain a total of 178.28 million m^3 of peat *in situ*. The area deeper than 1.5 m covers 4 937 ha (33% of total peatland area studied) and contains 61% of the total peat quantity (107.86 million m^3) (Herranen 2010, 2011, 2012).

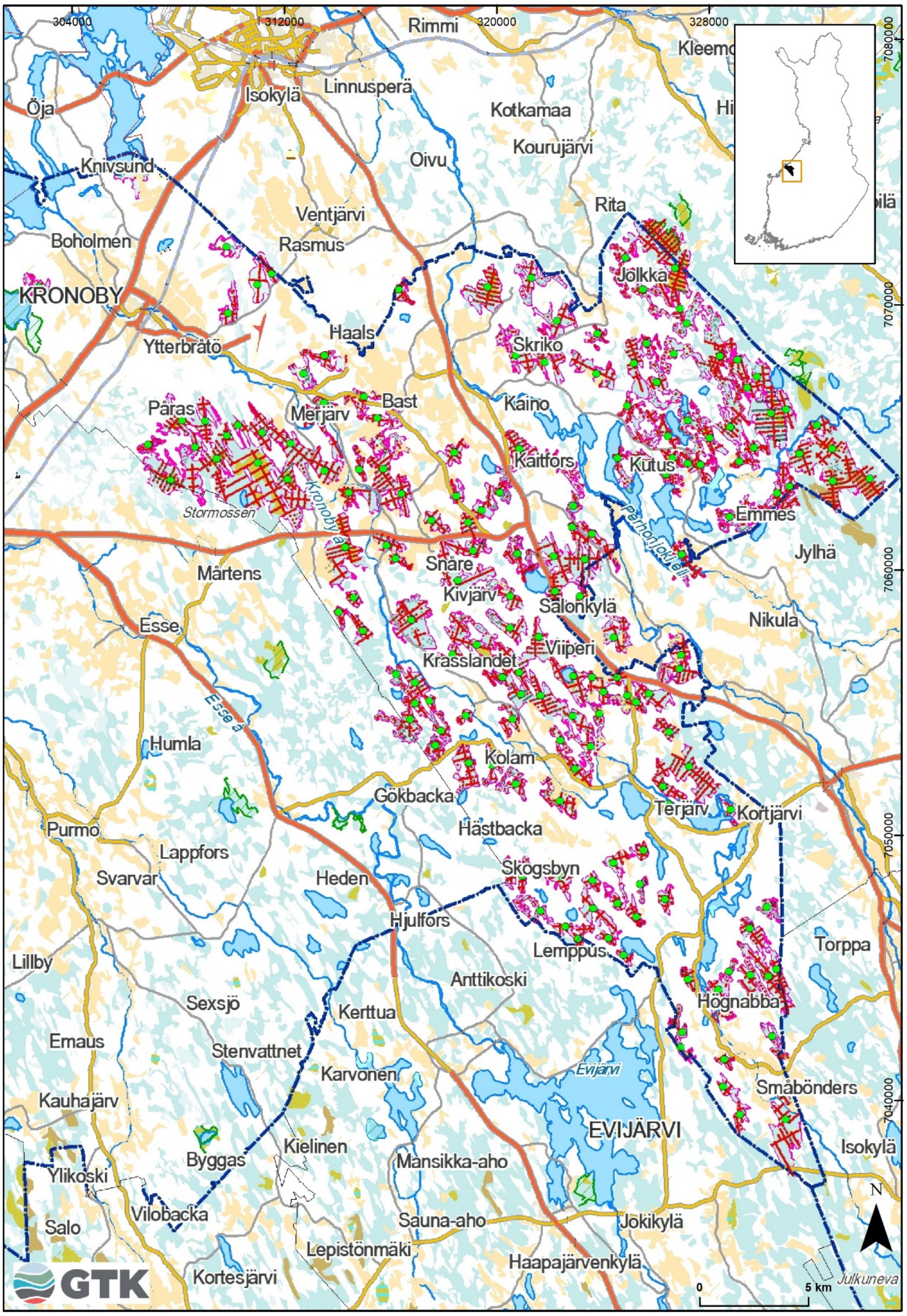

Fig. 1. The peatlands studied in Kruunupyy. Green points are focuses of the peatlands and red points study points. The peatlands have been studied along mainlines and cross lines.

Data and Methodology

The data was treated as follows:

1. All resource data is in GTK peat database

=> Resources are directly converted into UNFC categories

2. Resources inspected as teamwork: GTK experts checked the data, reflecting the requirements of UNFC codes

=> Updated UNFC categories

Did you use bridging from CRIRCSO-compliant data? No, as there is no CRIRSCO-compliant reporting on peat resources for the area.

How have data been gathered? The information was gathered from the peat database and reports of Geological Survey of Finland. The peat mapping in the field has been mainly done during years 1975–2019.

What kind of data have been used? Data from peat database and reports of Geological Survey of Finland.

Availability of data sources: Availability of peat resources data is good.

Table 1. Data types, sources and accuracies.

OPEN ACCESS	DATA	SOURCE
GEOLOGICAL MAPS	polygons	https://www.gtk.fi/en/services/data-sets-and-online-services-geo-fi/map-services/
PEAT RESOURCES	points	https://gtkdata.gtk.fi/Turvevarojen_tilinpito/index.html
NATURE CONSERVATION AREAS	polygons	https://www.syke.fi/fi-FI/Avoin_tieto/Paikkatietoaineistot/Ladattavat_paikkatietoaineistot
NATURA2000 AREAS	polygons	https://www.syke.fi/fi-FI/Avoin_tieto/Paikkatietoaineistot/Ladattavat_paikkatietoaineistot
GROUNDWATER AREAS	polygons	https://www.syke.fi/fi-FI/Avoin_tieto/Paikkatietoaineistot/Ladattavat_paikkatietoaineistot
REPORTS	publications	https://hakku.gtk.fi/en/reports
ACID SULFATE SOILS	polygons	https://gtkdata.gtk.fi/hasu/index.html

UNFC

Evaluation of data and areas, calculation of volumes: Evaluation of data in the original reports used

Methodology of defining the E, F and G-axis

The UNFC classification code is principles-based system and based on three-dimensional presentation where category definitions are the building blocks of the system (Fig. 2).

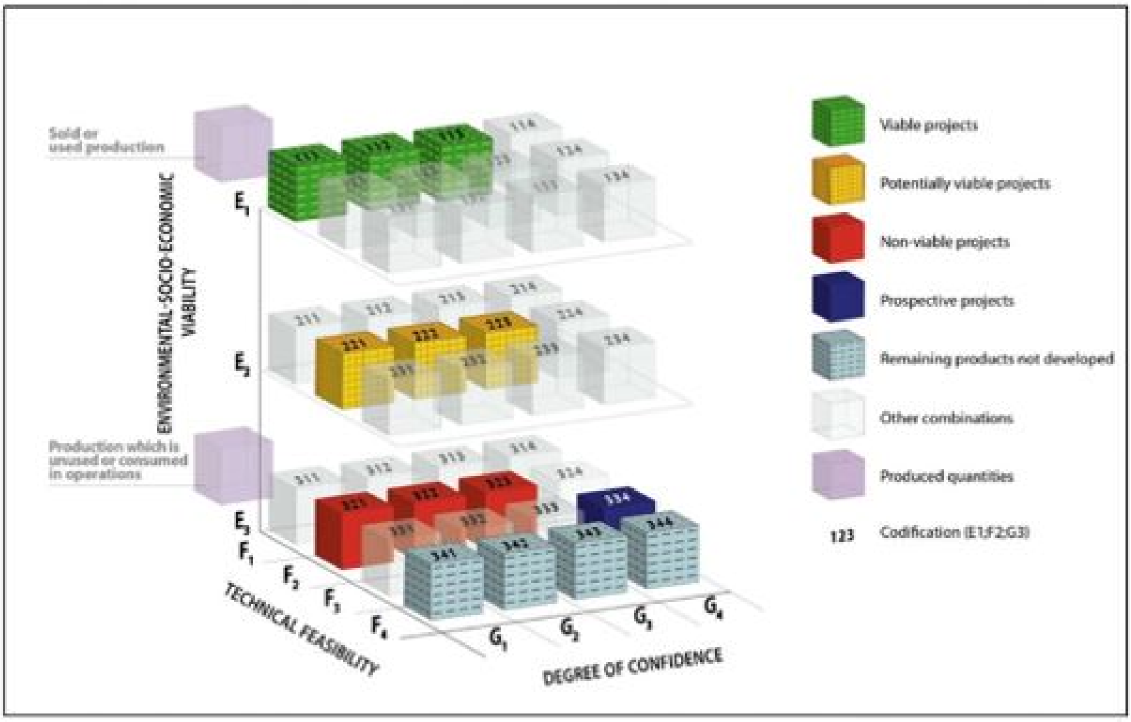

Fig. 2. UNFC-2019 Classification

The definitions of E-, F- and G-axis categories are given in Tab. 2 (UNECE, 2019). Because these definitions are best suitable for the classification of ore and mineral resources, we have been forced to allocate these definitions to various factors that affect to defining the UNFC- code to peat resources.

<u>E-axis</u>: The traditional criteria for E-axis classification are economic viability, social acceptance and the likelihood of the mining project to be permitted by mining authorities. For the classification of peat resources at a regional scale, this approach was imitated by taking in to account permitted areas, areas suitable for production, conflict areas, accuracy of the study, analyses data, natural state of the peatland, rare mire complex types, conservation areas, groundwater areas, distance to waterway, ash content, carbon accumulation, acid sulphate soils and black schists.

The value of E-axis and especially the environmental viability of the development and operation of a peatland depends largely on political decisions. The usage of peat as energy is now diminishing because of the large amount of carbon dioxide released into the air, when peat is burned. We need, however, to base the classification on the present situation, that is the calculated resources in reports and the national strategy of the sustainable usage and conservation of mires and peatlands in Finland. Many other factors have also to be taken into consideration when defining the E-values of peatlands.

Some peatlands in the pilot area are permitted production areas. Most peatlands in the pilot area are evaluated suitable for peat production.

In context with the national strategy of the sustainable usage and conservation of mires and peatlands in Finland was the scale for the classification of the natural state of peatlands published, The classes

0–2 can be used for peat production and the classes 3–5 not (Ministry of Agriculture and Forestry of Finland 2012).

Mire complex types are classified according their frequency, and regionally rare ones should be preserved. In Finland there is a lot of peatlands in Natura2000 program and in the basic program of peatland conservation.

Groundwater areas can prevent peat production. Distance to waterway is an important factor affecting to the condition of stream waters.

The classification of the same factors in the case of peat carbon storage is quite different, as we see in table 4. Carbon storage of peat diminishes, when peat production proceeds. Carbon accumulation is more efficient in raised bogs than in aapa mires. Many factors, which affect to the usage of peat to peat production do not affect to peat carbon storage at all.

<u>F-axis</u>:

Most factors in table 3 affect only little or not at all to the technical feasibility of peatlands to peat production. The situation is quite similar with the factors affecting to peatlands as carbon storages (tab. 4).

It is technically more demanding to produce peat inside conflict areas than outside conflict areas. It is a common opinion, that it is not economical to transport peat over 100 km to consumption place.

According to operation manual of the peat studies the study is enough accurate, if there is at least 3 study points/10 hectares and 6 depth points/10 hectares.

Analyses data is important for as accurate evaluation of peat resource as possible. Natural state of the peatland describes the acceptability of the peat production. An unchanged peatland demands a little bit more preparation work compared to a peatland, which is mostly or totally drained.

Groundwater areas near or in the immediate vicinity bring also technical challenges and costs for peat production as well as waterways near or in the immediate vicinity of the production area.

High ash or sulphur content of peat dilutes the quality of peat as energy or horticulture resource. Acid sulphate soils and black schists also affect negatively to the quality of peat and can make it technically difficult to produce peat.

Tab. 2: Definitions of E-, F- and G-axis categories (UNECE, 2019).

Category	Definition
E1	Development and operation are confirmed to be environmentally-socially-economically viable.
E2	Development and operation are expected to become environmentally-socially-economically viable in the foreseeable future.
E3	Development and operation are not expected to become environmentally-socially-economically viable in the foreseeable future or evaluation is at too early a stage to determine environmental-socioeconomic viability.
E3.1	Estimate of product that is forecast to be developed, but which will be unused or consumed in operations.
E3.2	Environmental-socio-economic viability cannot yet be determined due to insufficient information.
F1	Technical feasibility of a development project has been confirmed.
F2	Technical feasibility of a development project is subject to further evaluation.
F3	Technical feasibility of a development project cannot be evaluated due to limited data.
F4	No development project has been identified.
G1	Product quantity associated with a project that can be estimated with a high level of confidence.
G2	Product quantity associated with a project that can be estimated with a moderate level of confidence.
G3	Product quantity associated with a project that can be estimated with a low level of confidence.
G4	Product quantity associated with a prospective project, estimated primarily on indirect evidence.

Table 3. Allocation of E- and F-axis codes for horticultural and energy peat production resources in Finland.

Active production area	permitted area	E1		F1
Suitable for production		E1	near market	F1
		E1	>100 km to market	F2
Outside conflict areas	no negative environmental effects	E1	near market	F1
	socially acceptable	E1	>100 km to market	F2
Inside conflict areas	negative environmental effects to be compensated	E3.1	near market	F2
	social acceptance to be negotiated	E3.1	>100 km to market	F3
Accuracy of the study	good	E1		F1
	scattered	E2		F2
Analyses data	yes	E1		F1
	no	E2		F2
Natural state of the	class of natural state 0–1	E1		F1
peatland	class of natural state 2	E2		F1
	class of natural state 3–5	E3		F2
Rare mire complex types	no	E1		F1
	yes	E3		F1
Conservation areas	no	E1		F1
	yes	E3		F1
Groundwater area	not near	E1		F1
	near	E2		F2
	immediate vicinity	E3		F4
Distance to waterway	not near	E1		F1
	near	E2		F2
	immediate vicinity	E3		F4
Ash content	<10%	E1		F1
	>10%	E3		F4
Sulphur content	<0,50%	E1		F1
	0,50–1%	E2		F2
	>1 %	E3		F4
Acid sulphate soil	no	E1		F1
	potential	E2		F2
	yes	E3		F4
Black schists	not near	E1		F1
	near	E2		F2
	immediate vicinity	E3		F4

Table 4. Allocation of E- and F-axis codes for peat carbon storage in Finland.

Active production area	carbon storage diminishes	E3.1		F4
Accuracy of the study	good	E1		F1
	scattered	E2		F1
Natural state of the	class of natural state 3–5	E1		F1
peatland	class of natural state 2	E2		F2
	class of natural state 0–1	E3		F3
Groundwater area	immediate vicinity	E1		F1
	near	E1		F1
	not near	E2		F1
Carbon accumulation	raised bogs	E1		F1
	aapa mires	E2		F2
Acid sulphate soil	no	E2		F1
	potential	E1		F1
	yes	E1		F1
Black schists	not near	E2		F1
	near	E1		F1
	immediate vicinity	E1		F1

Methodology of calculating volumes

Total volumes were calculated for each EFG zone by multiplying thickness by surface area. An additional correction factor of 0.3–0.5 m peat from the bottom was reduced from peat production volumes as an estimated unusable bottom layer due to unevenness of the bottom (because of, e.g., boulders) and high ash or sulphur content of the peat. In the case of carbon storage such reduction has not needed.

Results

In table 5, there are all peat resources suitable for horticultural and energy production and in table 6 their carbon storage value in the municipality of Kruunupyy calculated and classified to UNFC-categories. Part of the peatlands are suitable for peat production or as peat in carbon storage. Quite a lot of peatlands are however not suitable for peat production mostly because of their small size or thin peat layer, neither they are not generally good as carbon storage. Some peatlands are in peat production and some are protected. Some peatlands are only potentially viable for peat production.

Table 5. Volume of peat resources suitable for horticultural and energy production (million m^3 peat).

EFG	HORTICULTURE PEAT	ENERGY PEAT (MILLION M^3)
111	8,74	12,88
112	3,72	6,91
113	2,11*	5,01*
211	8,07	3,13
221	0,14	0,21
222	0,23	0,23
223	0,15	0,06
311	5,28	3,65
312		1,77*
321	0,20	0,04
333		0,36
342	0,41	
343	0,69	1,68
Total	**29,74***	**35,93***

Table 6. Volume of peat resources as carbon storage (million t peat).

EFG	CARBON STORAGE OF PEAT (MILLION TONNES)
111	2,06
112	4,65
113	0,91*
222	0,29
342	0,03
Total	**7, 94***

* Numbers need to be reduced a little bit by already produced volumes.

Challenges

Training should have been organised in all countries, also in the native language, for all users to gain a full understanding of the UNFC code.

Quite a lot of factors contribute to the UNFC classification of peatlands. It is not easy to define the right UNFC-category for each peatland. In addition, an active production area is normally rapidly changing during some decades. It is also not easy to evaluate the effect of peatland type and nutrient content on peat as carbon storage.

Additional Questions:

What have you learned from this work? Quite a many UNFC- class combinations are realistic, so it is not quite easy to define the right UNFC-category especially for peat resources because of fact that the system is originally designed for the mineral resources.

What kind of challenges have you experienced during this work? Insufficient workforce resources. Categorising into UNFC is often not straight forward and needs much of calculating and evaluation.

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UNFC Case study – Hungary

Dr. Zoltán Horváth and Árpád Máthé (MBFSZ)

Introduction

In the framework of the MINTELL4EU project the methodology of data harmonization by UNFC with case studies is shared according to the Bridging Document by the Mining and Geological Survey of Hungary (MBFSZ) which is under development.

This document provides an overview about the Hungarian mineral resource and reserve classification system (hereinafter: Hungarian classification) that is similar to the Russian mineral resource and reserve classification system (hereinafter Russian classification) and provides information on international reporting systems and the United Nations Framework Classification for Resources (UNFC 2020).

International reporting systems here are referred as the family of the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) with the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves ('the JORC Code') and with the Pan-European Reserves and Resources Reporting Committee ('the PERC Code').

The study compares the terminology of the Hungarian classification with categories and classes of the UNFC-2020 and also refers for interoperability to internationally recognized reporting systems (CRIRSCO, JORC, PERC).

This case study presents results anhydrite classification. Gypsum and anhydrite are used as a raw material for gypsum stucco (decoration), gypsum board (installed partitions, fire protection coverings, elements of certain suspended ceilings, dry floors).

The aim of this document is to present a methodology for the harmonization and to demonstrate the applicability of the harmonization between different classification and reporting systems. This document can also be useful on international level regarding the development of the joint language for mineral commodities and can contribute to the improvement of the UNFC (2020) as a sustainable resource management system.

Description of mineral deposit

Characterization of Gypsum-Anhidrite:

Hungary's industrially significant geological reources of gypsum and anhydrite are located in three counties: Baranya (SW-Hungary); Heves and Borsod-Abaúj-Zemplén (NE-Hungary).

<u>Baranya:</u>

In the western part of Mecsek-Mts. and in the NW-foreland of Villány-Mts. there was a suitable period for evaporites to form on the border of lower-, and middle-Triassic. The formation is defined as Hetvehely Dolomite Formation has a member called Magyarürög Anhydrite M. which is a sabkha facies and consists of dense alternation layers of marl, dolomite and gypsum-anhydrite. These dark gray coloured evaporite layers are coarse-grained, 0.5-30cm thick and usually highly disturbed. (MÁFI, 1961.) In the '60-s there was an intensive exploration project in the Hetvehely-Abaliget-

Petőczpuszta area, but mining activity has not started since then (MÁFI, 2000.). In the studied area there's an operating open pit limestone mine near Bükkösd which contains significant anhydrite resources, but it is in exploration phase yet (MBFSZ, 2020.). In the NW-foreland of Villány-Mts. there is a site called Túrony which also has an area in exploratory research phase with minor anhydrite geological resource in place (MBFSZ, 2020.).

Heves:

There are significant gypsum-anhydrite reserves in the Garadnavölgy Member of the Upper-Permian Szentlélek Formation in the NW part of Bükk-mts. The sabkha facies section is composed of a dense alternation of claystone, dolomite, and gypsum-anhydrite layers (Pelikán, 2001.). Preliminary phase research was carried out near Nagyvisnyó, where a 120-140 m thick settlement complex was excavated under an Upper-Permian limestone cover. The gypsum anhydrite resource has an average thickness of 80 m. Due to its varying thickness and quality, the product can be used primarily as an additive and soil improver in the cement industry.

Borsod-Abaúj-Zemplén:

The Upper Permian Perkupai Evaporit Formation, which is a shallow lagoon and tidal sabkha facies forms the basis of the Aggtelek-mountain range, is built of alternating black, green, purple claystone, sandstone, dolomite and gypsum-anhydrite, the thickness of the formation is unknown, probably several hundred meters. In this region was Hungary's biggest and best known gypsum-anhydrite mine near Perkupa. After its closure a few km-s away a new open pit evaporite mine was opened in Alsótelekes (Fig. 1.). The exploitable layers lie under Pannonian cover which means more than a 200 Ma year gap in sedimentation. The layers are 32 m thick on average, but in some places it's more than 100 m. The product can be used as cement additive and soil improvement. The Alsótelekes II. is the only operating gypsum-anhydrite mine in Hungary recently that can be classified as UNFC E1F1G1.

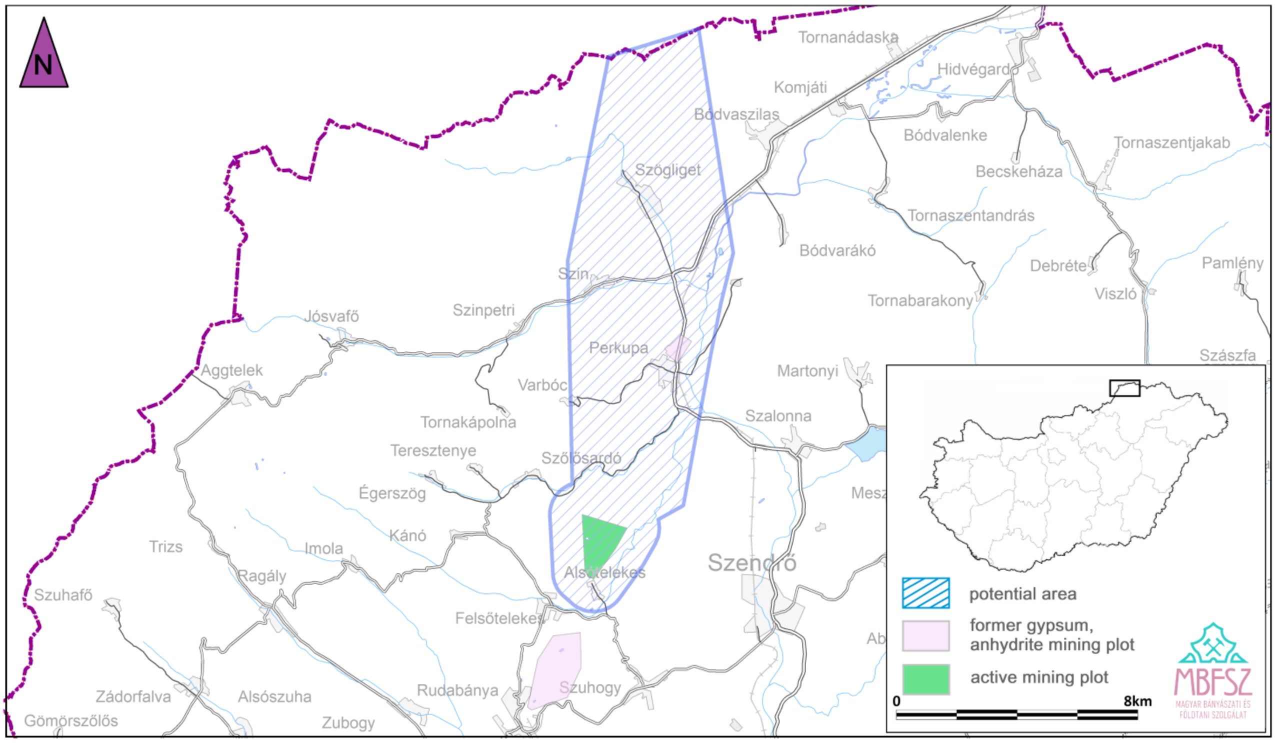

Fig. 1. Location of gypsum-anhydrite mining plots in Borsod-Abaúj-Zemplén County

Geological background:

The observed area located in the Darno Zone (NE-Hungary), which consists of several individual fault blocks (Fig. 2.). The Telekes Valley itself indicates a fault parallel with the main strike of the zone. On the SE-side of this fault at Alsótelekes Gutenstein Dolomite crops out, the NW-side is covered by neogene sediments. Surface geoelectronical (resistivity and IP) measurements proved the presence of the evaporite complex under 20-50m cover next to the NW-side of the Alsótelekes dolomite quarry (Vero & Milankovich 1983). The gypsum open pit in the Nagy Valley lies some hundred meters away from that fault. Stratigraphically the evaporitic formation can be considered the lowermost known unit of the Silicikum, named Perkupa Anhydrite Formation of Upper Permian age (Fülöp 1994). It is a typical lagoon facies sediment with sabkha-like conditions on the higher and reductive conditions on the deeper parts. There are three textural types of gypsum layers: brecciated, selenitic (coarse-grained) and laminitic. Anhydrite occurs either with shale inclusions or with dolomite interlayering (Fig. 3.). The frequent alternation of the different rock types shows the undulation of the water level during the sedimentation. The microlayering of the dolomitic anhydrite indicates (probably seasonal) changes in temperature. The uppermost beds are Pannonian fine-grained lacustric and limnic sediments with several lignite beds. The bedding is subhorizontal but seems to be inclined over the highest parts of the gypsum body. The present open pit explores the western side of a NE-SW elongated dome structure. In the upper 30-35 m of the evaporitic complex in the pit mainly gypsum with laminated black mudstone and anhydrite stripes can be found while under it there is a laminated dolomite-striped anhydrite. Several diapirs or mushroom-shaped intrusions of 10-20 m diameter with steep or vertical lamination are explored. The laminated gypsum (which is the most prevalent type) shows at every part of the pit well-developed signs of ductile flow. Anhydrite is also laminated but small-scale thirdorder folding is rare and of different style: the lamination bends with a gentle curvature, there are no sharp hinges (Zelenka, 2005.).

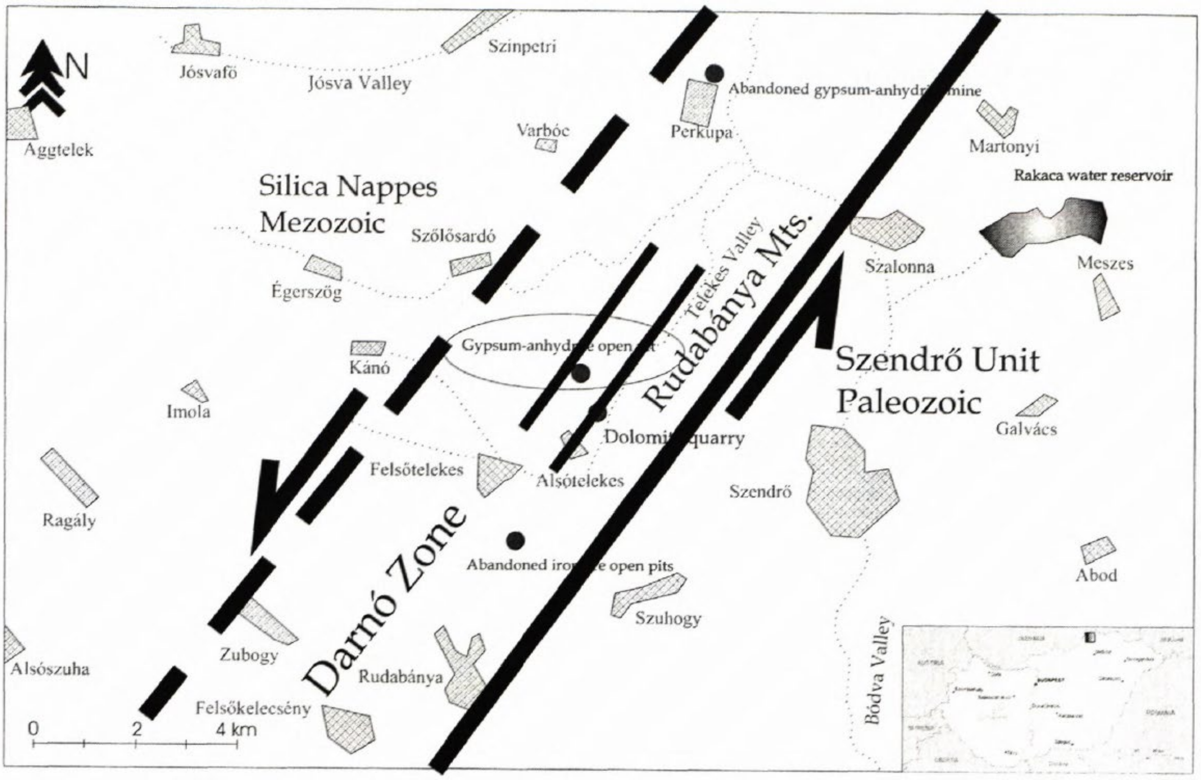

Fig. 2. Sketch map of the Rudabánya Mountains with the major tectonic elements (Zelenka, 2005.).

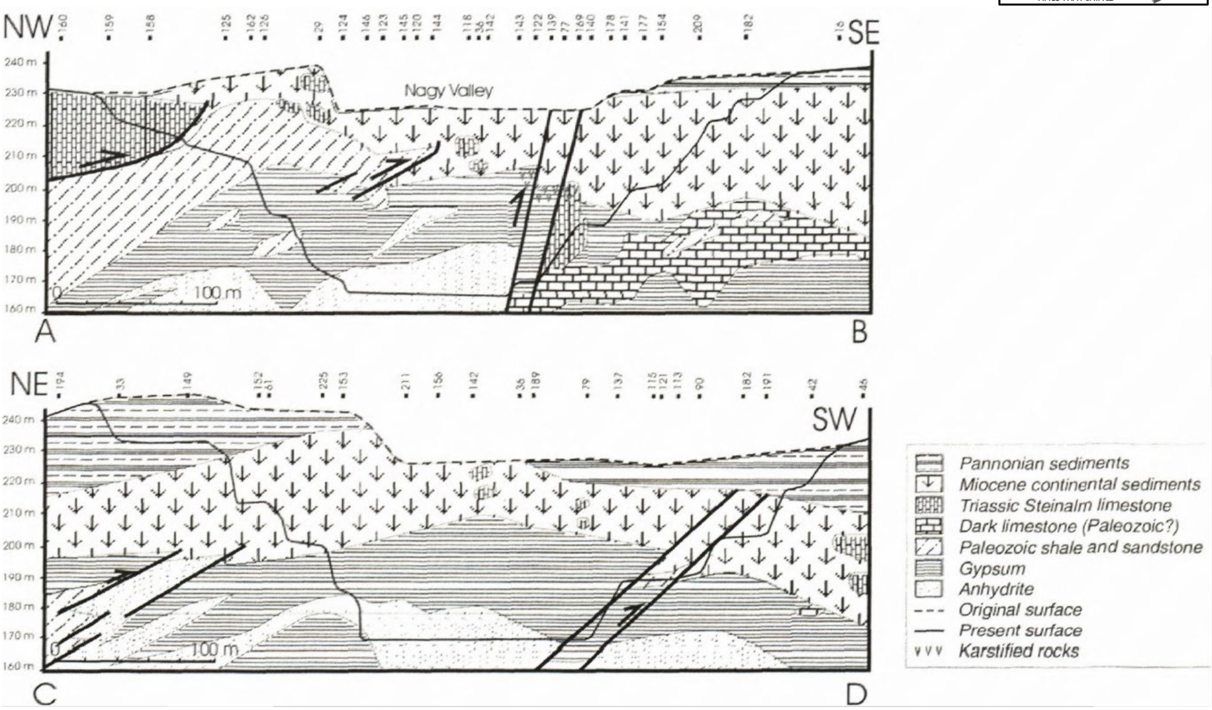

Fig. 3. Profiles across the Alsótelekes gypsum-anhydrite open pit (Zelenka, 2005.).

Research history:

In 1951–1952, the Rudabánya Iron Ore Mining Company deepened 5 iron ore exploration wells near Alsótelekes. Two of these wells crossed evaporites in tectonic position. In 1962, more in-depth research began in the area for structural research purposes. Three of these boreholes support large-thickness evaporite formations. The wells couldn't cross the whole formation, so the total thickness was unknown. A targeted exploration plan was completed in 1981, the drilling of three 300m boreholes began in 1982. all of the boreholes crossed the evaporite formations but failed to drill through them. From that research, it could be concluded that the upper part of the productive layers consists of gypsum, while the lower part consists of anhydrite. Based on the results of these researches and the emerging needs (agriculture, cement industry), the possibility of opening an open pit mine was identified. For this purpose, another 50 smaller wells (100-200 m) were drilled. This drilling research program was succesful, beucase the spread of the gypsum-anhydrite layers became well-known. Evaluating the datas, it was already possible to select the most suitable area for mining (Hernyák, 1981.).

Methodology

Data source is:

1) *General overview and history:*
    a. *scientific publication*
    b. *published book*
    c. *exploration report (MBFSZ Data Repository)*
2) *Mineral resource data:*
    a. *publically available book*
    b. *mineral resource inventory*

c. *exploration report (MBFSZ Data Repository) and National Inventory for Mineral Resources and Geothermal Energy (hereinafter: Resource Inventory). Official data are in the Resource Inventory, exploration reports can be used for checking basic data derived from exploration report. Resource data of exploration report during the permitting procedure is integrated into the Resource Inventory after approval of permission for establishment of mining plot and Technical Operation Plan for exploitation and in the year following the start of mining activity (exploitation).*

3) *State of mine*
   a. *Inventory of mining areas*
   b. *Resource Inventory*
   c. *exploration reports include details but main results can be found in inventories*
4) *Harmonization key:*
   a. *FGU GKZ (Russian Federal Government Agency State Commission on Mineral Reserves), CRIRSCO (Committee for Mineral Reserves International Reporting Standards) 2010: Guidelines on Alignment of Russian minerals reporting standards and the CRIRSCO Template. Moscow, 112 p.*
   b. *Bridging Document between the Hungarian classification and the United Nations Framework Classification for Resources (UNFC 2020) and the family of the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) including the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves ('the JORC Code') Pan-European Reserves and Resources Reporting Committee ('the PERC Code') – internal national project result (Bridging Document is a project result of the MBFSZ, publication is in progress).*
5) *Additional considerations: presence of valid environmental and other permissions, news on government intention, infrastructure, social acceptance, metallurgy, etc.*

How have data been gathered?

1) *General overview and history:*
   a. *scientific publication: collection of publically available data by using internet*
   b. *published book: selection of proper publication*
   c. *overview of exploration report*
2) *Mineral resource data:*
   a. *publically available book: selection of proper information*
   b. *mineral resource inventory: internal use of public datasets of the Resource Inventory*
   c. *mineral resource data can also be found in exploration reports that might help but results are summarized in inventories including inhomogeneity as well.*
3) *State of mine*
   a. *Inventory of mining areas (BATER): internal use of this inventory*
   b. *Resource Inventory: internal use*
4) *Harmonization key:*
   a. *FGU GKZ (2010): translation and comparison between two systems with development of the methodology*
   b. *Bridging Document*: internal use of this document based on previous tests and discussions on national and international forums, sharing experience.
   c. *Bridging between UNFC and CRIRSCO*

The Mining and Geological Survey of Hungary collects and maintains datasets for minerals reported by mine operators according to the traditional Russian classification system of resources. According to the Mining Law (Act No. XLVIII. 1993 on Mining), operators are obliged to report exploration and exploitation data to the Mining Authority:

- data on quality, quantity and location of minerals when the exploration is completed;
- changes of the quantity of mineral resources during the exploitation annually;
- data on the remaining mineral resources after stopping the mine/quarry.

Reported data are included in the Resource Inventory. The type of reporting standard is not prescribed by law, however, traditionally the “Russian” system is used in the practice by experts of companies in Hungary. In this system mineral resource is divided into 4 categories: A, B, C1 and C2. In the case of non-metallic minerals A and B are merged (A+B). There are further 3 prognostic categories: D1, D2 and D3 which are not included in the Resource Inventory. Each category means a level of uncertainty; A, B, C1 and C2 categories involve ±10%, ±20%, ±35% and ±60% uncertainty respectively in general, however the specification of each categories harmonized with international reporting standards and the UNFC framework is in progress. The alignment between the national classification in the practice and the international reporting standards and with UNFC in the frame of the 5th Enclosure of the Implementation Government Decree (203/1998. (XII. 19.) for XLVIII of 1993 on mining law (Implementation) was submitted at the responsible Ministry of Innovation and Technology at the end of 2020 (see below details). The specification will much more reflect the style of the international reporting codes and will not contain exact quantitative data for certainties or uncertainties. This is the responsibility of a proper expert who identifies and calculate the mineral resource or reserve.

Until 2007 economic parameters such as real cost were included in the inventory but are not recorded any more.

What kind of data have been used?

1) *General overview and history:*
    a. *scientific publication: background with history, maps, sections, research and exploration data, genesis-potential.*
    b. *published book: background with history, maps, sections, research and exploration data, genesis-potential and resource/reserve data.*
2) *Mineral resource data:*
    a. *publically available book: resource/reserve, exploitation data*
    b. *mineral resource inventory: geological resource in place characterized by A, B, C1 and C2. “Exploitable Resource” that might be harmonized with “Reserve” according to the CRIRSCO template is not necessarily used in the harmonization because without considering Modifying Factors registered Resources remain in resource state and according to the GKZ Bridging between the Russian classification system and the CRIRSCO (2010) there are obvious links from national resource information to Indicated and Measured Resources (Inferred Resources can also be linked with mineral deposits having lower geological confidence and mineral potential.*
3) *State of mine*
    a. *Inventory of mining areas:*
        i. *0: exploration area (accepted exploration report, free for mining plot/lease*
        ii. *1: operating mine*
        iii. *2: pending mine*

iv. *3: closed mine*

b. *National Registry on Mineral Raw Materials and Geothermal Resources:*

i. *National mineral resource classification categories: A, B, C1 and C2.*

ii. *inhomogeneity – complexity:*

Complexity: A determining indicator of the inhomogeneity of sites. The variability of the site, which is the number of productive blocks per 1 km2, can be considered homogeneous in itself, but can be characterized by the number of basic mineral resource calculation units (blocks) that are different in terms of quality or occurrence, or tectonically separated due to geological features - should be counted as separate mining units, fields. Based on this, the site can be:

- *undisturbed, homogeneous: <30 pcs / km2*
- *gently disturbed, slightly inhomogeneous: 30–69 pcs / km2*
- *disturbed, inhomogeneous: 70–159 pcs / km2*
- *very disturbed, especially inhomogeneous: ≥160 pcs / km2.*

4) *Harmonization key:*

a. *FGU GKZ (2010): translation and comparison between two systems with development of the methodology (Fig. 3.).*

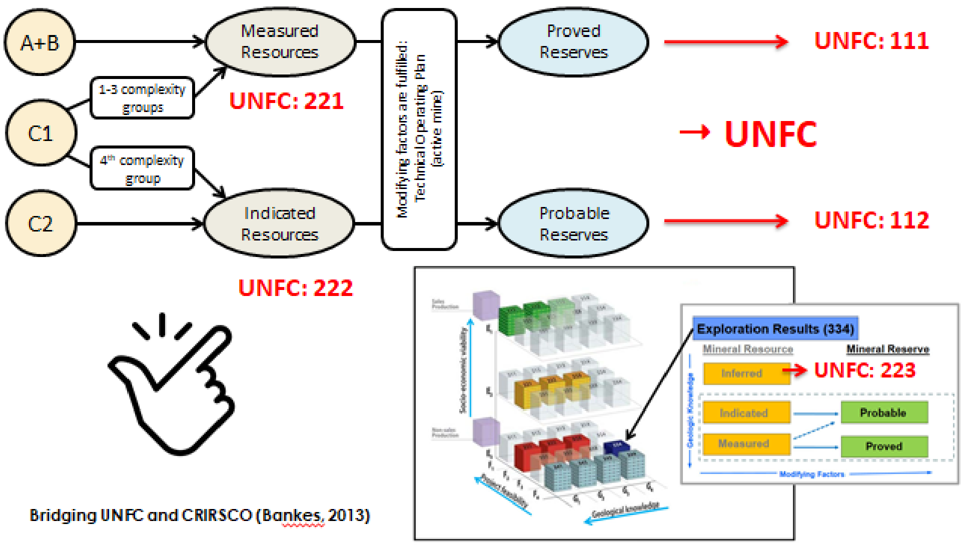

Fig. 4. Harmonization key between Hungarian national classification and CRIRSCO type reporting codes and UNFC (Hungarian project result based on FGU GKZ (2010) and Bankes (2013).

UNFC classes can be determined based on UNFC–CRIRSCO bridging document (UNECE 2013).

Active mines can be considered as Proved Mineral Reserves (CRIRSCO) and 111 (UNFC).

Suspended mines can be considered several ways according to the reason of the break of the mining activity. In case of temporary suspension of permission (e.g. environmental, because of nature conservation) the mining plot with the related mineral deposit may be identified as Measured or Indicated Resources depending on the complexity of the deposit but according to the UNFC it can be only Potentially Commercial Project (221 or 222) until the project gets the permission to continue the mining operation. Closed mines are considered also as Mineral Resources because further feasibility studies are needed to decide on the potential economic and social viability of the project that means (221 or 222 in the UNFC. Geological knowledge can be different: originally prior opening the mine G1 was necessary or specific risk is undertaken in case of G2 or G3. However during the lifetime of the mine specific areas can be reached where further geological or geophysical survey is needed (e.g. deep levels).

Bridging between UNFC, CRIRSCO and the Russian/Hungarian system based on UNECE 2013 and FGU GKZ – CRIRSCO 2010 can be seen on Table I.

Table I. Bridging between UNFC, CRIRSCO and the Russian/Hungarian system based on UNECE 2013 and FGU GKZ – CRIRSCO 2010.

UNFC		CRIRSCO	Russian (Hungarian)
111	Commercial projects	Proved Mineral Reserves	Exploitation Reserves in fully explored deposits
112		Probable Mineral Reserves	Exploitation Reserves in estimated deposits
221	Potentially commercial projects	Measured Mineral Resources	Resources of category C_2 in deposits of all complexity groups and category C_1 in deposits of the 4th complexity group
222		Indicated Mineral Resources	Resources of category C_1 in deposits of 1st, 2nd, and 3rd complexity groups with Resources of categories A and B in areas of detailed study
223		Inferred Mineral Resources	P_1 (D_1)
334	Exploration projects	Exploration results	-

For explored areas there are exploration reports and based on the complexity of the deposit(s) involved in the exploration area (Indicated M.R.: C2 and C1 complexity 4; Measured M.R.: C1 complexity 1-3). In case of different types of mineral deposits in a certain area different surveys and reporting is required (e.g. construction gravel, feldspar sand). Complexity can also be characterised by the inhomogenity that describes the uniform setup of blocks that are considered in the mineral resource management. This is a key-factor between the Russian type national and CRIRSCO-type international systems. This shows the number of blocks that are separated tectonically or may differ by their quality. Resources can be calculated for these blocks and separation may also be interpreted by the need of different mining operation. Dimension: pieces of blocks per km^2. Deposits may be classified into 3 or 4 or 5 classes depending on national/regional practices. Generally below 50 blocks/km^2 can be considered as a deposit of low complexity (relatively homogeneous), while over 100 blocks/km^2 a deposit can be considered as a complex one (heterogeneous). Taking into account the status of the mine for a certain mineral deposit, its complexity group, the original classification, theoretically the correlation with the CRIRSCO type reporting terms can be done and due to the Bridging Document between the CRIRSCO and the UNECE classification system, the UNFC codes can also be indicated.

Bridging document

Terms and links between the Hungarian national classification and international reporting codes were harmonized as follows:

Hungarian Mineral Resource Classification System (according to the submitted modification on the 203/1998. (XII. 19.) Government Decree implementation of the XLVIII of 1993 on mining act (enclosure 5).

The Hungarian mineral resource classification is dealing with at least four main categories that have brief descriptions (below) and detailed specifications of the UNFC 2019.

Category "A":

The geometry (location, shape, size, geological setting), internal variability, barren settlements, fracture displacement geometry of the mineral bodies are known in detail and contoured. The natural and technological types and quality varieties, useful and harmful components of the mineral raw material are known in detail - in sufficient detail to design the complex processing log - and characterized according to the cut-off conditions. Hydrogeological, engineering geological (geotechnical), mining geological and other natural conditions are known in such detail as to allow the basic data necessary for its exploitation planning. The contouring of the mineral resource or the exploitable mineral resource (reserve) was carried out by drilling and mining (mining preparation) facilities according to cut-off condition requirements - without extrapolation.

Category "B":

The position and geometry of the mineral bodies and significant fracture displacements are known and contoured, the internal variability, the nature of the barren settlements and the tectonic settings are known. The natural types of the mineral raw material are known and contoured, the spatial distribution regularities and quantitative ratio of the technological types and quality varieties are known, mineral binding of useful and harmful components is known. Hydrogeological, engineering (geotechnical), mining geological and other natural conditions are known in such detail that they allow the quantitative and qualitative characterization of their parameters and the assessment of their impact on the exploration and extraction of the site. The contouring of the mineral resource or the exploitable mineral resource (reserve) by boreholes and mining facilities was basically based on the cut-off condition requirements, in case of raw material having consistent thickness and quality according to geological criteria, completed with a limited extrapolation zone based on geophysical and geochemical data.

Category "C1":

The dimensions and characteristic shapes of the mineral raw material bodies, their settlement conditions and the basic characteristics of their internal structure are known. The variability of raw material bodies and in the case of stratified mineral deposits possible disruption of continuities and the occurrence of construction and dimension stones low-amplitude intensively tectonized areas were assessed. The natural and technological types of mineral raw materials have been determined, the general settings of their spatial distribution are known. The general settings for spatial distribution and for quantities of technological types and quality varieties are known. The mineral binding of useful and harmful components – to the interpretation of the value of mineral resources and exploitable resource (reserves) - is known as they were characterized according to the cut-off conditions. The level of detail of the study of hydrogeological, engineering geological (geotechnical), mining geology and other natural conditions allows the preliminary characterization of their basic parameters. The contouring of the mineral resource or the exploitable mineral resource (reserve) by boreholes and mining facilities was basically based on the cut-off condition requirements, taking into account the data of geophysical research and geologically based extrapolation.

Category "C2":

The size, shape, internal structure and geological setting of the raw material bodies have been assessed on the basis of geological and geophysical data, which are confirmed by the crossing of the raw material with drilling or mining facilities. The quality and technological properties of the raw material were determined on the basis of data from limited number of laboratory tests or were assessed by analogy with parts of the same or similar site known in detail. The hydrogeological, engineering geological (geotechnical), mining geological and other natural conditions were assessed on the basis of the data available in the research facilities, together with the data available in other parts of the given site, and by analogy with known sites in the given area. The contouring of the geological and industrial assets (stocks) of the mineral raw material was performed on the basis of individual drilling, mining areas, natural excavations or a combination of these methods, taking into account geophysical and geochemical surveys and geological interpretations, as well as geologically supported parameter-extrapolation that was used during the calculation of resources having higher geological knowledge and reserves.

UNFC categories

UNFC 221: E2: Development and operation are expected to become environmentally-socially-economically viable in the foreseeable future; F2: Technical feasibility of a development project is subject to further evaluation; G1: Product quantity associated with a project that can be estimated with a high level of confidence.

UNFC 222: Development and operation are expected to become environmentally-socially-economically viable in the foreseeable future; F2: Technical feasibility of a development project is subject to further evaluation; G2: Product quantity associated with a project that can be estimated with a moderate level of confidence.

UNFC 112: E1: Development and operation are confirmed to be environmentally-socially-economically viable; F1: Technical feasibility of a development project has been confirmed; G2: Product quantity associated with a project that can be estimated with a moderate level of confidence.

UNFC 111: E1: Development and operation are confirmed to be environmentally-socially-economically viable; F1: Technical feasibility of a development project has been confirmed; G1: Product quantity associated with a project that can be estimated with a high level of confidence.

A Mineral Resource is a concentration or occurrence of solid material of economic interest in or on the Earth's crust in such form, grade or quality and quantity that there are reasonable prospects for eventual economic extraction. The location, quantity, grade or quality, continuity and other geological characteristics of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge, including sampling. Mineral Resources are subdivided, in order of increasing geological confidence into Inferred, Indicated and Measured categories.

With increasing certainty, solid geological mineral resources can be classified into inferred, explored, and explored categories. Solid geological mineral resources are harmonized with the definition of geological mineral resources in Section 49 (30) of the Mining Act in relation to solid mineral resources.

Modifying Factors are considerations used to convert Mineral Resources to Mineral Reserves (aligned with Industrial Resource pursuant to Section 49, Paragraph 14 of the Mining Act). These include, but are not restricted to mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors.

All Modifying Factors and assumptions made regarding mining methods, minimum mining dimensions (or pit shell) and internal and, if applicable, external planned and unplanned mining dilution and mining losses used for the techno-economic study and signed off, such as mining method, mine design criteria, infrastructure, capacities, production schedule, mining efficiencies, grade control, geotechnical and hydrological considerations, closure plans, and personnel requirements.

A Measured Mineral Resource is that part of a Mineral Resource for which quantity, grade or quality, densities, shape, and physical characteristics are estimated with confidence sufficient to allow the application of Modifying Factors to support detailed mine planning and final evaluation of the economic viability of the deposit. Geological evidence is derived from detailed and reliable exploration, sampling and testing and is sufficient to confirm geological and grade or quality continuity between points of observation. A Measured Mineral Resource has a higher level of confidence than that applying to either an Indicated Mineral Resource or an Inferred Mineral Resource. It may be converted to a Proved Mineral Reserve or to a Probable Mineral Reserve.

An Indicated Mineral Resource is that part of a Mineral Resource for which quantity, grade or quality, densities, shape and physical characteristics are estimated with sufficient confidence to allow the application of Modifying Factors in sufficient detail to support mine planning and evaluation of the economic viability of the deposit. Geological evidence is derived from adequately detailed and reliable exploration, sampling and testing and is sufficient to assume geological and grade or quality continuity between points of observation. An Indicated Mineral Resource has a lower level of confidence than that applying to a Measured Mineral Resource and may only be converted to a Probable Mineral Reserve.

An Inferred Mineral Resource is that part of a Mineral Resource for which quantity and grade or quality are estimated on the basis of limited geological evidence and sampling. Geological evidence is sufficient to imply but not verify geological and grade or quality continuity. An Inferred Resource has a lower level of confidence than that applying to an Indicated Mineral Resource and must not be converted to a Mineral Reserve. It is reasonably expected that the majority of Inferred Mineral Resources could be upgraded to Indicated Mineral Resources with continued exploration.

Category "A" and "B" and the lower (1-3) complexity "C1" geological knowledge categories can be harmonized with Measured Mineral Resources according to the CRIRSCO international reporting template. Taking into account Modifying Factors and economic considerations economic assessment can be made on the basis of this category type (Proved Reserve and probable industrial resource that is also Reserve).

The measured geological mineral resources (Measured Resources) correspond to UNFC 221 category. Proven "industrial resource" (Proved Reserve) corresponds to UNFC 111 and "probable industrial resource" (Probable Reserve) to UNFC 112.

The higher complexity (4) "C1" and "C2" geological knowledge categories can be harmonized with Indicated Mineral Resource according to the international reporting template (CRIRSCO). According to the International Reporting Standard, an economic valuation can be made on the basis of these categories and taking into account the Modifying Factors, but only "probable industrial resource", i.e. Probable Reserve can be determined. The Probable Reserve corresponds to UNFC category 112.

Bridging between CRIRSCO and UNFC (UNFC 2020) is seen on the Fig. 5.

Total Products	Produced				
	Sold or used production				
	Production which is unused or consumed in operations[a]				
		Class	Minimum Categories		
			E	F	G[b]
	The project's environmental-socio-economic viability and technical feasibility has been confirmed	Viable Projects[c]	1	1	1, 2, 3
	The project's environmental-socio-economic viability and/or technical feasibility has yet to be confirmed	Potentially Viable Projects[d]	2[e]	2	1, 2, 3
		Non-Viable Projects[f]	3	2	1, 2, 3
	Remaining products not developed from identified projects[g]		3	4	1, 2, 3
	There is insufficient information on the source to assess the project's environmental-socio-economic viability and technical feasibility	Prospective Projects	3	3	4
	Remaining products not developed from prospective projects[g]		3	4	4

Fig. 5. Bridging between CRIRSCO and UNFC (UNFC 2020)

UNFC Classes Defined by Categories and Sub-categories						
Total Products	Produced	Sold or used production				
		Production which is unused or consumed in operations				
	Class		Sub-class	Categories		
				E	F	G
	Known Sources	Viable Projects	On Production	1	1.1	1, 2, 3
			Approved for Development	1	1.2	1, 2, 3
			Justified for Development	1	1.3	1, 2, 3
		Potentially Viable Projects	Development Pending	2[b]	2.1	1, 2, 3
			Development On Hold	2	2.2	1, 2, 3
		Non-Viable Projects	Development Unclarified	3.2	2.2	1, 2, 3
			Development Not Viable	3.3	2.3	1, 2, 3
		Remaining products not developed from identified projects		3.3	4	1, 2, 3
	Potential Sources	Prospective Projects	[No sub-classes defined]	3.2	3	4
		Remaining products not developed from prospective projects		3.3	4	4

a. Refer also to the notes for Figure 2.
b. Development Pending Projects may satisfy the requirements for E1.

Fig. 6. UNFC Classes and Sub-classes defined by Sub-categoriesa (UNFC 2020)

UNFC

UNFC categories were identified according to the UNFC 2019 (2000) and basic data on mineral resources in the Resource Inventory and in the Inventory of Mining Areas and additional considerations. Tables for bridging between national data sets and UNFC and also for CRIRSCO type reporting codes see above. Resource data related to localities (mineral deposit) are presented in the percentage of the total volume on country level taking into account different levels of geological knowledge respectively.

Table II. Selected anhydrite sites in Western Hungary

Mining Plot	**administrative place**	**name of raw material**	**state of site**	**category**	**geological resource in place** (% of total resource for different geological knowledge)
Anhydrite mine	Perkupa	anhydrite	3	A+B	5 %
				C1	22 %
Bódva-creek, W side	Perkupa	anhydrite	0	C2	80 %

Table III. Harmonization between national (Russian type) and UNFC classification (Table III) via CRIRSCO):

Name of mineral on site	**Classification category Traditional (similat to the Russian one)**	**Resource in place based on exploration reports and exploitation** (% of A+B and C1 together and C2 respectivley)	**state of mine or exploration area**	**UNFC**	**Comment**
Anhydrite mine	(A+B) + C1	21%	3 (closed)	E: 3.3 F: 2.3 G: 1 *(E3.3, F4, G1)*	*(Regarding CRIRSCO in case of exploration project it would be Measured Resource)*
Bódva-creek, W side	C2	80 %	0 (exploration area)	E: 2 F: 2 G: 2 *(E3.3, F4, G2)*	*(Regarding CRIRSCO Indicated Resource might be considered in case of an active project)*

Summary

One of the anhydrite mine that is called “Anhdrite mine” together with A+B and C1 categories having higher level geological knowledge and the fact that it has closed and there is no more information on further developments regarding socio-economic (“E”) and technical “F”) issues was identified as non-commercial project where recently development is not seen. Result: E3.3, F2.3, G: 1. This mineral deposit represents 27% of the total anhydrite mineral resource volume for A+B and C1. In case of lack of information for further development UNFC sub-class can also be “Additional Quantities in Place (E3.3, F4, G1).

The Bódva-creek W side exploration area has only C2 category at the recent state of the exploration phase, so 80 % of the total country level anhydrite mineral resource having medium level geological knowledge might b identified as E2, F2, G2 in case of an active exploration project. Taking into account that this site was explored and a report was submitted in 1999 the development of this previously active project can not be recently identified. In this case – similarly to the previous case – where there is no more information on further developments regarding socio-economic (“E”) and technical “F”) issues, the identification of the project as non-commercial project seems to be logical. Result: E3.3, F2.3, G: 2. This mineral deposit represents 80% of the total anhydrite mineral resource volume for C2.

Challenges

The main challenge of practical implement of the UNFC in the daily work is to provide updated data and information and taking into account available data for permitting stages that is related to economic, social and environmental considerations. Basically all mineral deposits would require detailed analysis but inventories of mineral resources and inventory of mining and exploration areas provide sufficient information.

Common bridging between CRIRSCO type reporting and UNFC classification can be applied well mainly for exploration projects but in case of changes in state of mining areas after temporary or final termination of a mining activity the direct reclassification of UNFC 111 project to 221 is not obvious. Depending on the reason of pending or termination of a mining project 331 can also be considered in case of rejection of environmental permission or loosing economic viability, or technical feasibility needs to be justified. The later on one is addressed in the Technical Operation Plan. The use of common classes of the UNFC and bridging between CRIRSCO may induce the classification of a terminated project without justification of E and F categories to Inferred Resource that is not reflecting the moderate or high level geological knowledge on a mineral deposit. It might cause that not common EFG categories will be used but UNFC is also open for using all types of EFG categories depending on different E, F and G circumstances based on national / regional legislation (stages of permitting procedure) and different technological consideration and level of geological knowledge (degree of confidence).

Additional Questions:

What have you learned from this work?

Direct (national classification to UNFC) and indirect (national to CRIRSCO to UNFC) might cause different results depending used details of a project. Specification based on permitting stages can be useful to identify EFG categories more precisely.

What kind of challenges have you experienced during this work? See above.

How can your work and experience be used into a UNFC guideline?

This practice will be useful in the daily work that will be supplemented with legislative support with the use of UNFC. This case study with all the others previously done will be useful to develop the inventory for mineral resources that will be supplemented with UNFC categories.

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UNFC Case study – Hungary

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Introduction/Background

In the framework of the MINTELL4EU project the methodology of data harmonization by UNFC with case studies is shared according to the Bridging Document by the Mining and Geological Survey of Hungary (MBFSZ) which is under development.

This document provides an overview about the Hungarian mineral resource and reserve classification system (hereinafter: Hungarian classification) that is similar to the Russian mineral resource and reserve classification system (hereinafter Russian classification) and provides information on international reporting systems and the United Nations Framework Classification for Resources (UNFC 2020).

International reporting systems here are referred as the family of the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) with the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves ('the JORC Code') and with the Pan-European Reserves and Resources Reporting Committee (’the PERC Code’).

The study compares the terminology of the Hungarian classification with categories and classes of the UNFC-2020 and also refers for interoperability to internationally recognized reporting systems (CRIRSCO, JORC, PERC).

A Hungarian project (2012-2020) is also referred to show that the most important stakeholder consultations that were implemented in order to establish the agreement on the concept and on the terminology. Case studies are presented for manganese ore. Recommendations are collected in order to facilitate the harmonization on national level with the integration of this concept and terms into the national legislation.

The aim of this document is to present a methodology for the harmonization and to demonstrate the applicability of the harmonization between different classification and reporting systems. This document can also be useful on international level regarding the development of the joint language for mineral commodities and can contribute to the improvement of the UNFC (2020) as a sustainable resource management system.

Define the resource

General-genesis

This case study provides information in UNFC for carboniferous manganese ore of Hungary in the Transdanubian Range (Fig. 1.).

The Transdanubian Range (Hungary, ALCAPA Unit) preserves a series of black shale-hosted Mn-carbonate deposits and cherty, Fe-rich Mn-oxide mineralized rocks associated with varicolored metalliferous claystones. The Mn-carbonates and Mn-oxides are of Jurassic (Lias-Toarcian) age (Polgári et al., 2000 and 2012). This important deposit is among the 10 largest Mn deposits (of this genetic type) in the World with pre-mining resources of Mn-carbonate ore (24 wt.% average Mn and 10 wt.% Fe).

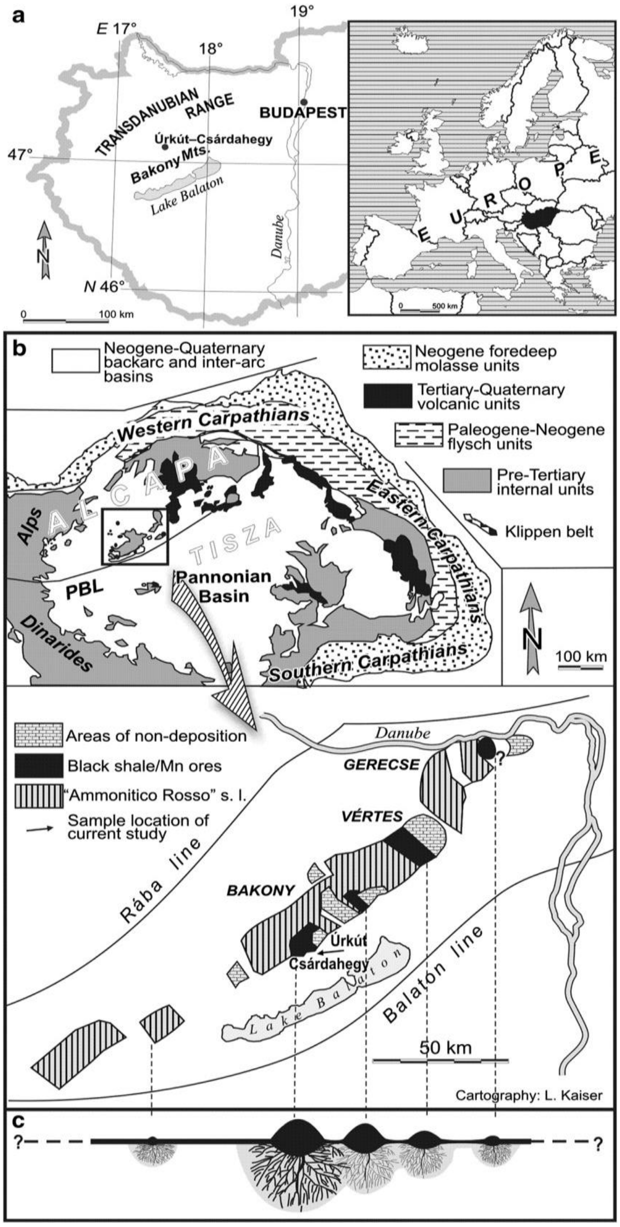

Fig. 1.: Distribution of Jurassic manganese deposits and occurrences in the TR, Central Europe. (a) Location of the Jurassic Mn deposits in Hungary; (b) Early Toarcian palaeogeographical sketch map modified from Vörös and Galácz (1998); PBL — Periadriatic-Balaton Line and DKH — Transdanubian Central Range; and (c) sedimentary dyke system under the Mn deposits.

The original features of this deposit were overprinted by diagenesis. Genesis: the carbonate manganese ore deposit in Úrkút is a marine sedimentary, black shale environment, biogenic-bacterial manganese ore of local hydrothermal origin formed with tuff contribution (aerobic microbial pulsation ore type). Based on SEM-EDS, and TEM studies and identification of local selective enrichment of bioessential elements (Mn, Fe, S, As, P, Mg, Ba, Sr, Co, Ce) together with low δ13C values of the Mn carbonates also supports microbial mediated reactions (Polgár et al. 2012).

Main minerals of the manganese-carbonate deposit: rodocrozite, kutnohorite with seladonite, goethite.

Geological profile

The geological setting is seen on the Fig. 2.

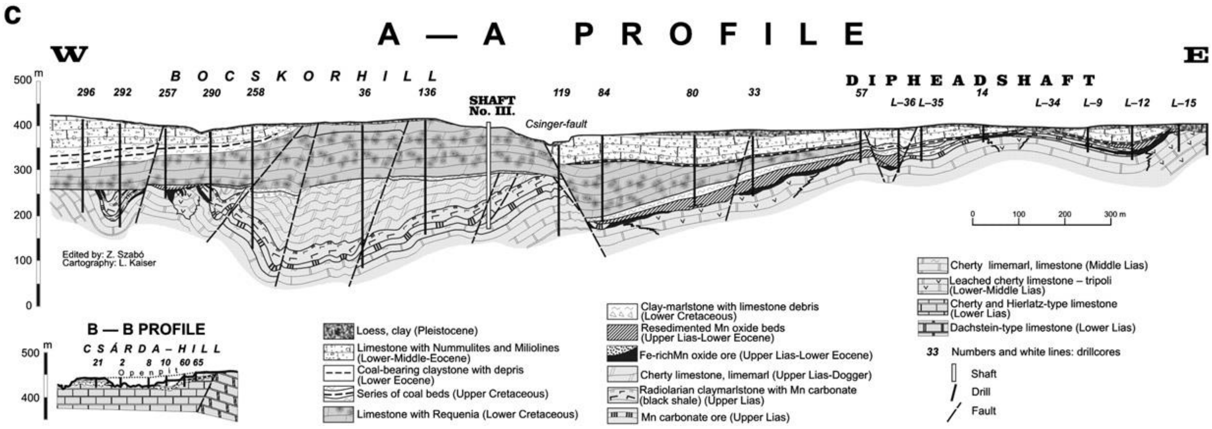

Fig. 2. Geological profile of the manganese ore bearing sedimentary complex (Polgár et al. 2012).

History

Exploration phase: 1917 (Úrkút), 1928 (Eppléný)

Beginning of mining: 1925 (Úrkút), 1932 (Eppléný), first oxidic Mn-ore was mined.

1950: Mining and Geological Survey of Úrkút with detailed exploration activity.

1950-1990: intensive drilling survey, detailed scientific research of the genesis of the ore deposit.

1177 deep drilling, 105 000 m drills in the mine, 13 000 samples were analysed.

Hungary was the second manganese-producing state in Europe in the 1970s. A total of 10 million tons of mineral raw materials were mined from this site during 99 years for operation.

2016: The underground mine has been closed.

Methodology

Data source is:

1) *General overview and history:*
    a. *scientific publication*
    b. *published book*
2) *Mineral resource data:*
    a. *publically available book*
    b. *mineral resource inventory*
3) *State of mine*
    a. *Inventory of mining areas*
    b. *National Inventory for Mineral Resources and Geothermal Energy (hereinafter: Resource Inventory)*
    c. *exploration reports includes details but main results can be found in inventories*
4) *Harmonization key:*
    a. *FGU GKZ (Russian Federal Government Agency State Commission on Mineral Reserves), CRIRSCO (Committee for Mineral Reserves International Reporting*

Standards) 2010: Guidelines on Alignment of Russian minerals reporting standards and the CRIRSCO Template. Moscow, 112 p.

b. *Bridging Document between the Hungarian classification and the United Nations Framework Classification for Resources (UNFC 2020) and the family of the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) including the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves ('the JORC Code') Pan-European Reserves and Resources Reporting Committee ('the PERC Code') – internal national project result (Bridging Document is a project result of the MBFSZ, publication is in progress).*

5) *Additional considerations: presence of valid environmental and other permissions, news on government intention, infrastructure, social acceptance, metallurgy, etc.*

How have data been gathered?

1) *General overview and history:*
   a. *scientific publication: collection of publically available data by using internet*
   b. *published book: selection of proper publication*
2) *Mineral resource data:*
   a. *publically available book: selection of proper information*
   b. *mineral resource inventory: internal use of public datasets of the Resource Inventory*
   c. *there is opportunity to overview and analyse details from exploration reports that might help but results are summarized in inventories including inhomogeneity as well.*
3) *State of mine*
   a. *Inventory of mining areas (BATER): internal use of this inventory*
   b. *Resource Inventory: internal use*
4) *Harmonization key:*
   a. *FGU GKZ (2010): translation and comparison between two systems with development of the methodology*
   b. *Bridging Document*: internal use of this document based on previous tests and discussions on national and international forums, sharing experience.
   c. *Bridging between UNFC and CRIRSCO*

The Mining and Geological Survey of Hungary collects and maintains datasets for minerals reported by mine operators according to the traditional Russian classification system of resources. According to the Mining Law (Act No. XLVIII. 1993 on Mining), operators are obliged to report exploration and exploitation data to the Mining Authority:

- data on quality, quantity and location of minerals when the exploration is completed;
- changes of the quantity of mineral resources during the exploitation annually;
- data on the remaining mineral resources after stopping the mine/quarry.

Reported data are included in the Resource Inventory. The type of reporting standard is not prescribed by law, however, traditionally the "Russian" system is used in the practice by experts of companies in Hungary. In this system mineral resource is divided into 4 categories: A, B, C1 and C2. In the case of non-metallic minerals A and B are merged (A+B). There are further 3 prognostic categories: D1, D2 and D3 which are not included in the Resource Inventory. Each category means a level of uncertainty; A, B, C1 and C2 categories involve ±10%, ±20%, ±35% and ±60% uncertainty respectively in general, however the specification of each categories harmonized with international reporting standards and the UNFC framework is in progress. The alignment between the national classification in the practice and the international reporting standards and with UNFC in the frame of the 5th Enclosure of the Implementation Government Decree (203/1998. (XII. 19.) for XLVIII of 1993 on mining law (Implementation) was submitted at the responsible Ministry of Innovation and Technology at the end of 2020 (see below details). The specification will much more reflect the style of the international reporting codes and will not contain exact quantitative data for certainties or uncertainties. This is the responsibility of a proper expert who identifies and calculate the mineral resource or reserve.

Until 2007 economic parameters such as real cost were included in the inventory but are not recorded any more.

What kind of data have been used?

1) *General overview and history:*
    a. *scientific publication: background with history, maps, sections, research and exploration data, genesis-potential.*
    b. *published book: background with history, maps, sections, research and exploration data, genesis-potential and resource/reserve data.*
2) *Mineral resource data:*
    a. *publically available book: resource/reserve, exploitation data*
    b. *mineral resource inventory: geological resource in place characterized by A, B, C1 and C2. "Exploitable Resource" that might be harmonized with "Reserve" according to the CRIRSCO template is not necessarily used in the harmonization because without considering Modifying Factors registered Resources remain in resource state and according to the GKZ Bridging between the Russian classification system and the CRIRSCO (2010) there are obvious links from national resource information to Indicated and Measured Resources (Inferred Resources can also be linked with mineral deposits having lower geological confidence and mineral potential.*
3) *State of mine*
    a. *Inventory of mining areas:*
        i. *0: exploration area (accepted exploration report, free for mining plot/lease*
        ii. *1: operating mine*
        iii. *2: pending mine*
        iv. *3: closed mine*
    b. *National Registry on Mineral Raw Materials and Geothermal Resources:*
        i. *National mineral resource classification categories: A, B, C1 and C2.*
        ii. *inhomogeneity – complexity:*

Complexity: A determining indicator of the inhomogeneity of sites. The variability of the site, which is the number of productive blocks per 1 km2, can be considered homogeneous in itself, but can be characterized by the number of basic mineral resource calculation units (blocks) that are different in terms of quality or occurrence, or tectonically separated due to geological features - should be counted as separate mining units, fields. Based on this, the site can be:

- *undisturbed, homogeneous: <30 pcs / km2*
- *gently disturbed, slightly inhomogeneous: 30–69 pcs / km2*
- *disturbed, inhomogeneous: 70–159 pcs / km2*
- *very disturbed, especially inhomogeneous: ≥160 pcs / km2.*

4) *Harmonization key:*

   a. *FGU GKZ (2010): translation and comparison between two systems with development of the methodology (Fig. 3.).*

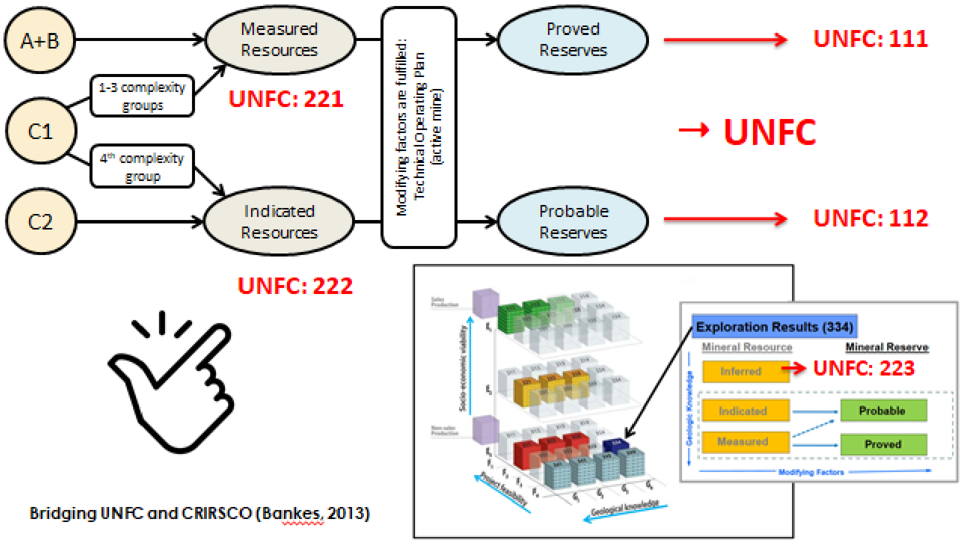

Fig. 3. Harmonization key between Hungarian national classification and CRIRSCO type reporting codes and UNFC (Hungarian project result based on FGU GKZ (2010) and Bankes (2013).

UNFC classes can be determined based on UNFC–CRIRSCO bridging document (UNECE 2013).

Active mines can be considered as Proved Mineral Reserves (CRIRSCO) and 111 (UNFC).

Suspended mines can be considered several ways according to the reason of the break of the mining activity. In case of temporary suspension of permission (e.g. environmental, because of nature conservation) the mining plot with the related mineral deposit may be identified as Measured or Indicated Resources depending on the complexity of the deposit but according to the UNFC it can be only Potentially Commercial Project (221 or 222) until the project gets the permission to continue the mining operation. Closed mines are considered also as Mineral Reosurces because further feasibility studies are needed to decide on the potential economic and social viability of the project that means (221 or 222 in the UNFC. Geological knowledge can be different: originally prior opening the mine G1 was necessary or specific risk is undertaken in case of G2 or G3. However during the lifetime of the mine specific areas can be reached where further geological or geophysical survey is needed (e.g. deep levels).

Bridging between UNFC, CRIRSCO and the Russian/Hungarian system based on UNECE 2013 and FGU GKZ – CRIRSCO 2010 can be seen on Table I.

1. Table: Bridging between UNFC, CRIRSCO and the Russian/Hungarian system based on UNECE 2013 and FGU GKZ – CRIRSCO 2010.

UNFC		CRIRSCO	Russian (Hungarian)
111	Commercial projects	Proved Mineral Reserves	Exploitation Reserves in fully explored deposits
112		Probable Mineral	Exploitation Reserves in estimated

		Reserves	deposits
221	Potentially commercial projects	Measured Mineral Resources	Resources of category C_2 in deposits of all complexity groups and category C_1 in deposits of the 4th complexity group
222		Indicated Mineral Resources	Resources of category C_1 in deposits of 1st, 2nd, and 3rd complexity groups with Resources of categories A and B in areas of detailed study
223		Inferred Mineral Resources	P_1 (D_1)
334	Exploration projects	Exploration results	-

For explored areas there are exploration reports and based on the complexity of the deposit(s) involved in the exploration area (Indicated M.R.: C2 and C1 complexity 4; Measured M.R.: C1 complexity 1-3). In case of different types of mineral deposits in a certain area different surveys and reporting is required (e.g. construction gravel, feldspar sand). Complexity can also be characterised by the inhomogenity that describes the uniform setup of blocks that are considered in the mineral resource management. This is a key-factor between the Russian type national and CRIRSCO-type international systems. This shows the number of blocks that are separated tectonically or may differ by their quality. Resources can be calculated for these blocks and separation may also be interpreted by the need of different mining operation. Dimension: pieces of blocks per km^2. Deposits may be classified into 3 or 4 or 5 classes depending on national/regional practices. Generally below 50 blocks/km^2 can be considered as a deposit of low complexity (relatively homogeneous), while over 100 blocks/km^2 a deposit can be considered as a complex one (heterogeneous). Taking into account the status of the mine for a certain mineral deposit, its complexity group, the original classification, theoretically the correlation with the CRIRSCO type reporting terms can be done and due to the Bridging Document between the CRIRSCO and the UNECE classification system, the UNFC codes can also be indicated.

b. *Bridging Document* :

Terms and links between the Hungarian national classification and international reporting codes were harmonized as follows:

Hungarian Mineral Resource Classification System (according to the submitted modification on the 203/1998. (XII. 19.) Government Decree implementation of the XLVIII of 1993 on mining act (enclosure 5).

The Hungarian mineral resource classification is dealing with at least four main categories that have brief descriptions (below) and detailed specifications of the UNFC 2019.

Category "A":

The geometry (location, shape, size, geological setting), internal variability, barren settlements, fracture displacement geometry of the mineral bodies are known in detail and contoured. The natural and technological types and quality varieties, useful and harmful components of the mineral raw material are known in detail - in sufficient detail to design the complex processing log - and characterized according to the cut-off conditions. Hydrogeological, engineering geological (geotechnical), mining geological and other natural conditions are known in such detail as to allow the basic data necessary for its exploitation planning. The contouring of the mineral resource or the exploitable mineral resource (reserve) was carried out by drilling and mining (mining preparation) facilities according to cut-off condition requirements - without extrapolation.

Category "B":

The position and geometry of the mineral bodies and significant fracture displacements are known and contoured, the internal variability, the nature of the barren settlements and the tectonic settings are known. The natural types of the mineral raw material are known and contoured, the spatial distribution regularities and quantitative ratio of the technological types and quality varieties are known, mineral binding of useful and harmful components is known. Hydrogeological, engineering (geotechnical), mining geological and other natural conditions are known in such detail that they allow the quantitative and qualitative characterization of their parameters and the assessment of their impact on the exploration and extraction of the site. The contouring of the mineral resource or the exploitable mineral resource (reserve) by boreholes and mining facilities was basically based on the cut-off condition requirements, in case of raw material having consistent thickness and quality according to geological criteria, completed with a limited extrapolation zone based on geophysical and geochemical data.

Category "C1":

The dimensions and characteristic shapes of the mineral raw material bodies, their settlement conditions and the basic characteristics of their internal structure are known. The variability of raw material bodies and in the case of stratified mineral deposits possible disruption of continuities and the occurrence of construction and dimension stones low-amplitude intensively tectonized areas were assessed. The natural and technological types of mineral raw materials have been determined, the general settings of their spatial distribution are known. The general settings for spatial distribution and for quantities of technological types and quality varieties are known. The mineral binding of useful and harmful components – to the interpretation of the value of mineral resources and exploitable resource (reserves) - is known as they were characterized according to the cut-off conditions. The level of detail of the study of hydrogeological, engineering geological (geotechnical), mining geology and other natural conditions allows the preliminary characterization of their basic parameters. The contouring of the mineral resource or the exploitable mineral resource (reserve) by boreholes and mining facilities was basically based on the cut-off condition requirements, taking into account the data of geophysical research and geologically based extrapolation.

Category "C2":

The size, shape, internal structure and geological setting of the raw material bodies have been assessed on the basis of geological and geophysical data, which are confirmed by the crossing of the raw material with drilling or mining facilities. The quality and technological properties of the raw material were determined on the basis of data from limited number of laboratory tests or were assessed by analogy with parts of the same or similar site known in detail. The hydrogeological, engineering geological (geotechnical), mining geological and other natural conditions were assessed on the basis of the data available in the research facilities, together with the data available in other parts of the given site, and by analogy with known sites in the given area. The contouring of the geological and industrial assets (stocks) of the mineral raw material was performed on the basis of individual drilling, mining areas, natural excavations or a combination of these methods, taking into account geophysical and geochemical surveys and geological interpretations, as well as geologically supported parameter-extrapolation that was used during the calculation of resources having higher geological knowledge and reserves.

UNFC categories

UNFC 221: E2: Development and operation are expected to become environmentally-socially-economically viable in the foreseeable future; F2: Technical feasibility of a development project is subject to further evaluation; G1: Product quantity associated with a project that can be estimated with a high level of confidence.

UNFC 222: Development and operation are expected to become environmentally-socially-economically viable in the foreseeable future; F2: Technical feasibility of a development project is subject to further evaluation; G2: Product quantity associated with a project that can be estimated with a moderate level of confidence.

UNFC 112: E1: Development and operation are confirmed to be environmentally-socially-economically viable; F1: Technical feasibility of a development project has been confirmed; G2: Product quantity associated with a project that can be estimated with a moderate level of confidence.

UNFC 111: E1: Development and operation are confirmed to be environmentally-socially-economically viable; F1: Technical feasibility of a development project has been confirmed; G1: Product quantity associated with a project that can be estimated with a high level of confidence.

A Mineral Resource is a concentration or occurrence of solid material of economic interest in or on the Earth's crust in such form, grade or quality and quantity that there are reasonable prospects for eventual economic extraction. The location, quantity, grade or quality, continuity and other geological characteristics of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge, including sampling. Mineral Resources are subdivided, in order of increasing geological confidence into Inferred, Indicated and Measured categories.

With increasing certainty, solid geological mineral resources can be classified into inferred, explored, and explored categories. Solid geological mineral resources are harmonized with the definition of geological mineral resources in Section 49 (30) of the Mining Act in relation to solid mineral resources.

Modifying Factors are considerations used to convert Mineral Resources to Mineral Reserves (aligned with Industrial Resource pursuant to Section 49, Paragraph 14 of the Mining Act). These include, but are not restricted to mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors.

All Modifying Factors and assumptions made regarding mining methods, minimum mining dimensions (or pit shell) and internal and, if applicable, external planned and unplanned mining dilution and mining losses used for the techno-economic study and signed off, such as mining method, mine design criteria, infrastructure, capacities, production schedule, mining efficiencies, grade control, geotechnical and hydrological considerations, closure plans, and personnel requirements.

A Measured Mineral Resource is that part of a Mineral Resource for which quantity, grade or quality, densities, shape, and physical characteristics are estimated with confidence sufficient to allow the application of Modifying Factors to support detailed mine planning and final evaluation of the economic viability of the deposit. Geological evidence is derived from detailed and reliable exploration, sampling and testing and is sufficient to confirm geological and grade or quality continuity between points of observation. A Measured Mineral Resource has a higher level of confidence than that applying to either an Indicated Mineral Resource or an Inferred Mineral Resource. It may be converted to a Proved Mineral Reserve or to a Probable Mineral Reserve.

An Indicated Mineral Resource is that part of a Mineral Resource for which quantity, grade or quality, densities, shape and physical characteristics are estimated with sufficient confidence to allow the application of Modifying Factors in sufficient detail to support mine planning and evaluation of the economic viability of the deposit. Geological evidence is derived from adequately detailed and reliable exploration, sampling and testing and is sufficient to assume geological and grade or quality continuity between points of observation. An Indicated Mineral Resource has a lower level of confidence than that applying to a Measured Mineral Resource and may only be converted to a Probable Mineral Reserve.

An Inferred Mineral Resource is that part of a Mineral Resource for which quantity and grade or quality are estimated on the basis of limited geological evidence and sampling. Geological evidence is sufficient to imply but not verify geological and grade or quality continuity. An Inferred Resource has a lower level of confidence than that applying to an Indicated Mineral Resource and must not be converted to a Mineral Reserve. It is reasonably expected that the majority of Inferred Mineral Resources could be upgraded to Indicated Mineral Resources with continued exploration.

Category "A" and "B" and the lower (1-3) complexity "C1" geological knowledge categories can be harmonized with Measured Mineral Resources according to the CRIRSCO international reporting template. Taking into account Modifying Factors and economic considerations economic assessment can be made on the basis of this category type (Proved Reserve and probable industrial resource that is also Reserve).

The measured geological mineral resources (Measured Resources) correspond to UNFC 221 category. Proven "industrial resource" (Proved Reserve) corresponds to UNFC 111 and "probable industrial resource" (Probable Reserve) to UNFC 112.

The higher complexity (4) "C1" and "C2" geological knowledge categories can be harmonized with Indicated Mineral Resource according to the international reporting template (CRIRSCO). According to the International Reporting Standard, an economic valuation can be made on the basis of these categories and taking into account the Modifying Factors, but only "probable industrial resource", i.e. Probable Reserve can be determined. The Probable Reserve corresponds to UNFC category 112.

Bridging between CRIRSCO and UNFC (UNFC 2019) is seen on the Fig. 4.

CRIRSCO Template		UNFC-2009 "minimum" Categories			UNFC-2009 Class
Mineral Reserve	Proved	E1	F1	G1	Commercial Projects
	Probable			G2	
Mineral Resource	Measured	E2	F2	G1	Potentially Commercial Projects
	Indicated			G2	
	Inferred			G3	
Exploration Results		E3	F3	G4	Exploration Projects

Fig. 4. Bridging between CRIRSCO and UNFC (UNFC 2019).

Availability of data sources

UNFC

UNFC categories were identified according to the UNFC 2019 (2000) and basic data on mineral resources in the Resource Inventory and in the Inventory of Mining Areas and additional considerations. Tables for bridging between national data sets and UNFC and also for CRIRSCO type reporting codes see above.

Evaluation of data and areas, calculation of volumes.

We have started from official mineral resource inventory where the type and volume and the state of the mine/exploration are defined according to legal background and obligations (see above).

The volume and quality (type that is an official category with specific quality specifications) of this mineral resource was identified by the responsible company and expert who provided report in the past and served data each year to the responsible authority (name and structure were changed many times in the past tens of years (recently MBFSZ).

Defining the E, F and G-axis

Here we provide information for the Úrkút manganese ore deposit following the development of the most important stages of exploration, exploitation and finally the closure of the mine (Table II.).

History	Definition	Additional comment	UNFC category
Prior exploration planning phase of Úrkút mining	Development and operation are not expected to become environmentally-socially-economically viable in the foreseeable future or evaluation is at too early a stage to determine environmental-socioeconomic viability. **E3** Technical feasibility of a development project cannot be evaluated due to limited data. F**3** Product quantity associated with a Prospective Project, estimated primarily on indirect evidence.**G4**	Estimates	334
During exploration prior exploitation	Development and operation are expected to become environmentally-socially and economically viable in the foreseeable future. **E2** Technical feasibility of a development project cannot be evaluated due to limited data. **F2** Product quantity associated with a project that can be estimated with a lower/medium/high level of confidence. **G1-G2-G3** depending on Reference Point too.	Exploration Result, Indicated and Measured Resources	221-222-223
Mining phase in general	Development and operation are confirmed to be environmentally-socially-conomically viable. **E1** Technical feasibility of a development project has been confirmed. **F1** Product quantity associated with a project that can be estimated with a lower/medium/high level of confidence. **G1-G2-G3** depending on Reference Point too.	Proved and Probable Reserves (Resources too) different developing areas , different codes (reference p.)	111 (112, 113)

After closure of mine	Solution one: Development and operation are expected to become environmentally-socially-economically viable in the foreseeable future. **E2** Technical feasibility of a development project is subject to further evaluation. **F2** Product quantity associated with a project that can be estimated with a low/medium/high level of confidence. **G1-G2-G3** .	No recent developments are known but Resources are in place.	**222** according to recorded inhomogenity (4)
	Solution 2/A: This version takes into account that a previously economically viable project with active mine was closed due to economic decision. Recently there is a Mn ore deposit with medium/high degree of confidence, with previously accepted social-environmental circumstances but further development of the project recently is not known (additionally the establishment of a historical industry park on this site is in progress). This way: Development and operation are not expected to become environmentally-socially-economically viable in the foreseeable future. **E3** Technical feasibility of a development project is subject to further evaluation. **F2** (probably the common methodology for exploitation and processing would be viable max. with minor maintenance by updates for methodology – innovation, etc.) Product quantity associated with a project that can be estimated with a moderate level of confidence. **G2** (this identification considers the fact that the degree of confidence was proper for mining operation during the active phase of the mine but after the closure new approach, a new project may require further analysis and data).	Resurce left without recent economic viability but feasibility can not be series challenge See the text left	**322**
	Solution 2/B: Remaining products not developed from prospective projects. No development project has been identified.	resource left without recent economic perspectivity and without further developments.	**341/342 /343**

Resource data related to localities (mineral deposit) are presented in the percentage of the total volume on country level taking into account different levels of geological knowledge respectively.

Recently following data and UNFC categorization can be done (Table III):

Name of mineral	Classification category	Resource in place based on exploration reports and exploitation (%)	CRIRSCO Resource (% of the total registered mineral resource)	UNFC
Carboniferous manganese ore	A	0,3%	Indicaed Resource 7% *Due to inhomogenity: 4*	222
	B	7%		
	C1	43%	Indicated Resource 81% *Due to inhomogenity: 4*	222
	C2	38%		

We can return to the original consideration of categorization that is based on proper identification of volume and quantity (geological knowledge – degree of confidence), proper technology that was used during the operation of the mine (F) and also previously accepted mining activity from environmental and social points of view (E). It means that the mineral deposit that was left behind under the ground is not the same that was planned to be pillar or loss. In this case the (temporally?) closed mine covers sufficient and well known manganese ore and the technology is viable. The decision on closure was based on economic reason, so reclassifying from Reserve state should stop at **Indicated Resource (222)**. This way the UNFC-CRIRSCO Bridging seems to be proper.

Challenges

The challenge is to implement practically in the daily work and use officially the UNFC.

MBFSZ has established the methodology of use of the UNFC based on bridging between national classification of mineral resources, CRIRSCO type reporting and UNFC up to 2020. The national legislation (Implementation Gov. Decree of the Mining Law) was supplemented with basic categories of UNFC in 2020 but the assessment of projects and identification of projects according to UNFC needs to be done by experts of the MBFSZ. Data production for exploitation and for identified mineral resources according to modernized Russian type reporting to Mining Authorities (annual data to MBFSZ, identified resources in exploration reports to Mining Departments of Regional Government Offices) is still obligation for mining entrepreneurs.

More case studies may be needed to refine the methodology and use UNFC with sub-categories is also challenging.

Trainings and education are needed in the MBFSZ, in other Mining Departments to use the joint language including UNFC for mineral resources and to support sustainable resource management concept that includes consideration of both primary and secondary raw materials.

Additional Questions:

What have you learned from this work?

For ores more detailed assessment is needed to classify and maintain the history of a deposit according to UNFC.

Next to more sensitive inhomogenity circumstances of ores (related to genesis, tectonic setting, even technology too) **specific considertions may appear.** Here the closure of the mine based on economic reason is such a consideration, but existence of proper Resources that are in favourable conditions with developments might be Reserves calls the attention fo flexibility and dynamics of using UNFC.

Benefit: The UNFC is a tool to maintain the state of a project including resources or reserves in a logical, dinamic system and can support decision on local/regional/national levels developments with considerations of environmental and social issues, so it supports the sustainable resourtces management with SDGs.

Based on gathering experience with cases proper Guidance will be useful.

What kind of challenges have you experienced during this work? See above.

How can your work and experience be used into a UNFC guideline?

This practice will be useful in the daily work that will be supplemented with legislative support with the use of UNFC. This case study with all the others previously done will be useful to develop the inventory for mineral resources that will be supplemented with UNFC categories.

How can this case and your experience be used into the next deliverables and Milestones in Mintell4EU WP4:

D4.1 Case study review with practical guidelines/work flows and examples for applying UNFC to European mineral resources

D4.2 Report on harmonization issues, data gaps and challenges, reviewing also the quality of Pan-European aggregated inventories for selected commodities.

Descriptions, tables and interpretations will contribute to the joint methodology of using UNFC and development of decision flowchart for EU-level application of the UNFC supported professionally by EGS.

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UNFC Case study – Hungary

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Introduction/Background

In the framework of the MINTELL4EU project the methodology of data harmonization by UNFC with case studies is shared according to the Bridging Document by the Mining and Geological Survey of Hungary (MBFSZ) which is under development (submitted in report in 2020, unpublished).

This document provides an overview about the Hungarian mineral resource and reserve classification system (hereinafter: Hungarian classification) that is similar to the Russian mineral resource and reserve classification system (hereinafter Russian classification) and provides information on international reporting systems and the United Nations Framework Classification for Resources (UNFC 2020).

International reporting systems here are referred as the family of the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) with the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves ('the JORC Code') and with the Pan-European Reserves and Resources Reporting Committee (’the PERC Code’).

The study compares the terminology of the Hungarian classification with categories and classes of the UNFC-2020 and also refers for interoperability to internationally recognized reporting systems (CRIRSCO, JORC, PERC).

A Hungarian project (2012-2020) is also referred to show that the most important stakeholder consultations that were implemented in order to establish the agreement on the concept and on the terminology. A new case study is presented for perlite that is an important mineral raw material in Hungary with export to other European countries. Recommendations are collected in order to facilitate the harmonization on national level with the integration of this concept and terms into the national legislation.

The aim of this document is to present a methodology for the harmonization and to demonstrate the applicability of the harmonization between different classification and reporting systems. This document can also be useful on international level regarding the development of the joint language for mineral commodities and can contribute to the improvement of the UNFC (2020) as a sustainable resource management system.

Define the resource

Characterization of Perlite

Perlite is a high SiO_2 bearing amorphous volcanic glass-type. The name „Perlite” came from the Romans, who were the first to extract it almost 2000 years ago and because of the rock’s structure reminded them to precious pearls so they just combined the word ’perla’ (pearl) and ’lit’(stone). It is usually formed during rhyolitic-volcanism. Perlite is mostly a light-grey, slightly translucent rock-type which looks like an easily disintegrating yet compact set of tiny pearls. The structure of perlite formed in underwater circumstances, the erupting lava cools down so rapidly the minerals don't have enough time to crystallize, so the rock falls into tiny spheres. The core of these 1-2 mm pearls are often obsidian (volcanic glass) grains. Perlit has an unusual and important property: when heated sufficiently it's volume can expand 7-16 x bigger. Mainly because of this property perlite is an important non-metallic mineral raw material. The world's reserves are estimated at 700 million tonnes. Hungary has two natural occurrences: one minor in the foreground of Mátra and one major in the Tokaj Mountains (figure1.). With these two occurrences Hungary is in the Top10 perlite producers in the world.

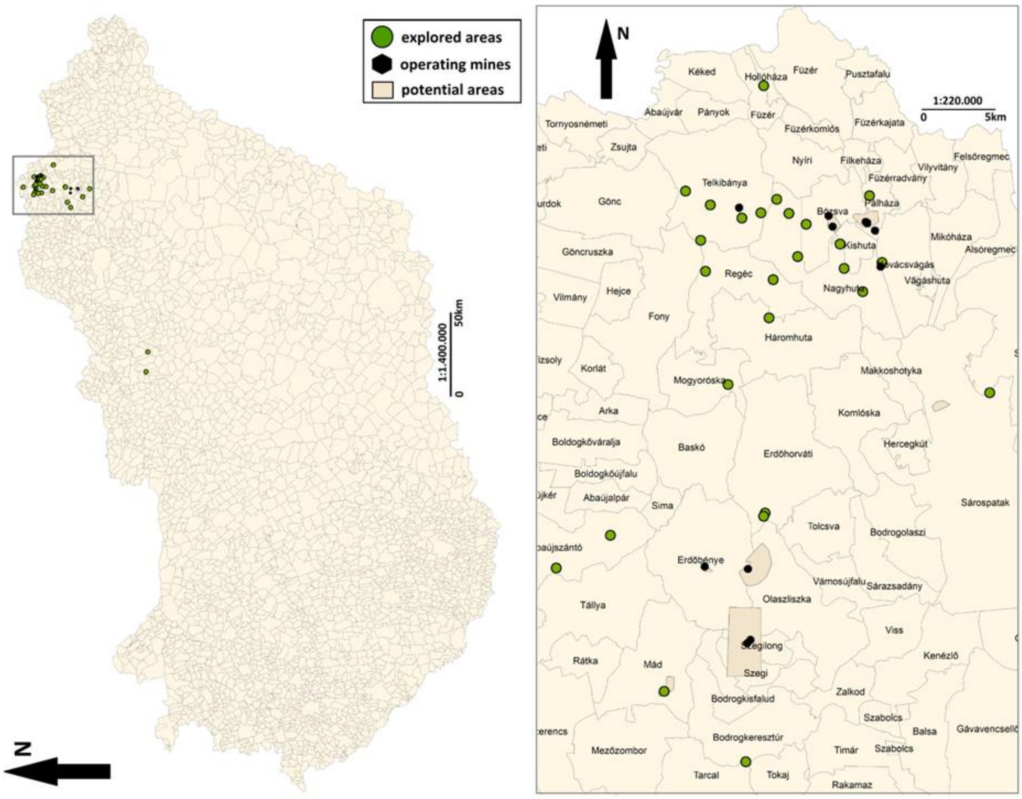

Fig. 1.: Location of perlites in Hungary

Fig 2: perlitic texture in Rhyolite (Tokaji-Mts).

Geological background

The nearly N-S striking Tokaj Mountains are situated in the northeastern part of the Miocene ALCAPA microplate, between the Pannonian Basin and the inner side of the Carpathian Arc. The mountains were formed in the middle and late Miocene during subduction, with the calc-alkaline bimodal, intermediate and felsic volcanism of the ancient inner island arc. The mountains bordered by tectonic zones in a triangle shape. The basement and the Miocene volcanics become thicker to the west, indicating back-arc basin character. In the western part of the Tokaj Mts. three volcanic cycles produced nearly 2500m thick successions int he descending lagoon:

1. Upper Badenian (14-15 Ma) rhyolite-dacite pyroclastic flows, the subaqueous peperitic, hyaloclastitic, stratovolcanic andesite with lava beds and rhyodacite subvolcanoes.
2. Lower Sarmatian (12-13 Ma) large volumes of phreatomagmatic ignimbrite flows from rhyolite calderae, fallen pyroclastics and single rhyolite domes. In the central zone of the mountains there are several large andesite stratovolcanoes and subvolcanoes, with attached hydrothermal epithermal precious metal mineralization and less well-known Pb-Zn enrichment.
3. At the Sarmatian-Pannonian boundary (10-11 Ma): phreatomagmatic rhyolite ignimbrites, rhyolite domes and andesitic-dacitic stratovolcanoes; finally (9-10 Ma) olivine andesite domes, dykes and calc-alkaline olivine basalt shield volcanoes as final products.

   Since then, on average 200-300 m of material was eroded from the uplifted area.

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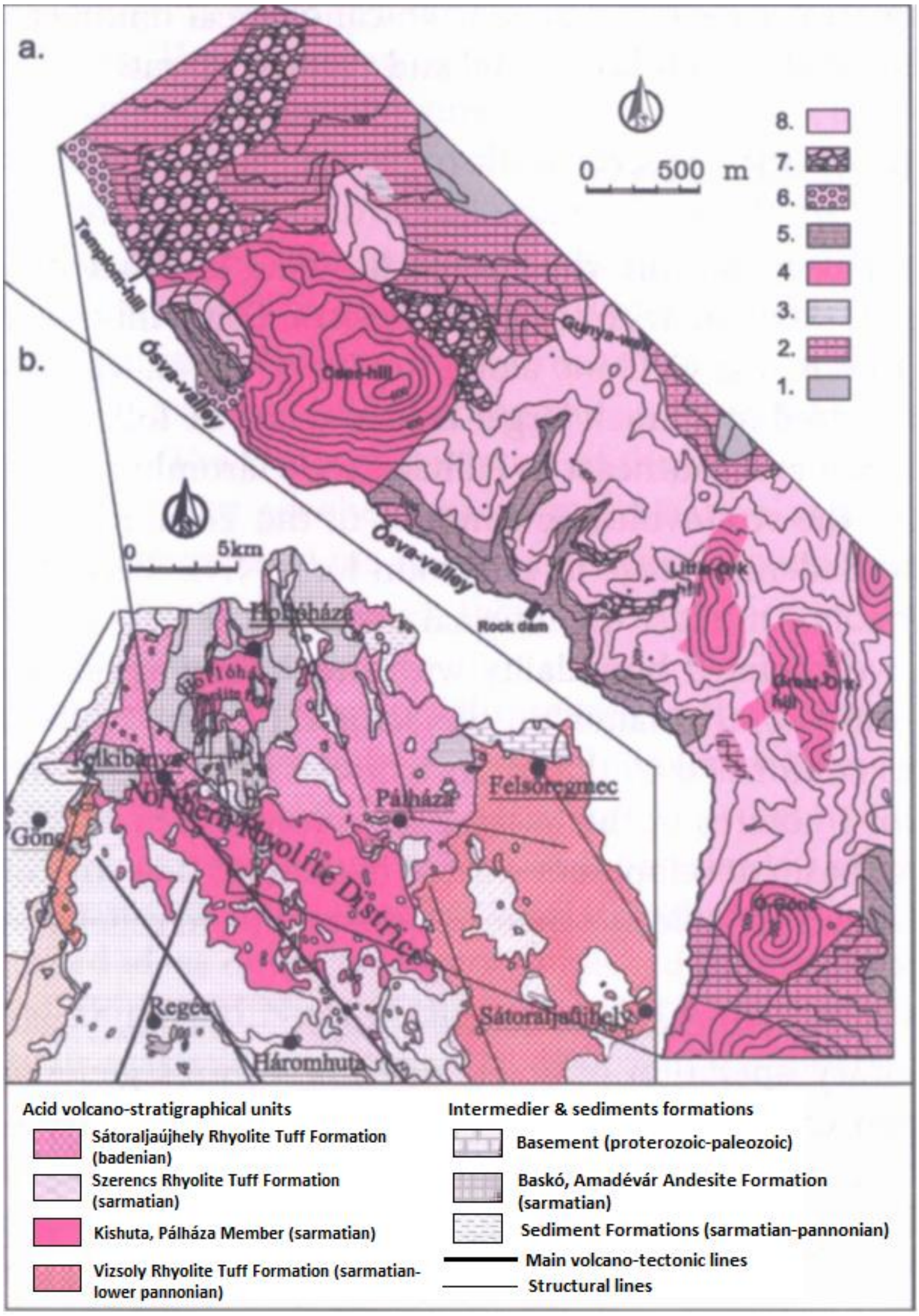

Fig. 3: Geological map of the study area (Based on the 1:25000 scaled geological maps *(Based on the 1:25000 scaled geological maps of Gönc and Nyíri and those of Telkibánya-Kőgát scaled 1:1000, and 1:5000 (I. Perlaki, 1967,1972b, 1978) and that of the Tokaj Mts. (Gyarmati, 1981) perlite predictions. Legend: Bedrocks (Sarmatian): 1. Andesite (Baskó Andesite Formation) 2 Acidpyroclasts (reworked, ash fall tuffs and ignimbrites, 3 Clay (Szerencs Rhyolite Tuff Formation, Kéked, Füzérkomlós Members), Acid lavas (Sarmatian Pannonian, Szerencs Rhyolite Tuff Formation, Kishuta Rhyolite and Pálháza Perlite Members): 4 Rhyolite (grey fluidal and red) 5 Perlite (obsidianlike, grey perlite). 6 Spherulitic perlite 7 Perlite breccia 8 Pumiceous perlite Fig. lb Simplified geological map of the Northern Tokaj Mountains (modified from the structural-volcanotectonic sketch of the Tokaj Mts, Gyarmati, 1972), colouring based on 1:100 000 geological maps of the Tokaj Mountains (Pentelényi, 2005a, b).*

Research history

The acid lavas of the Eperjes-Tokaj (Slanské-Zemplínske) Mountains are emplaced in unique diversity amongst the members of the Inner Carpathian volcanic chain. The ore bearing neutral and acid volcanism of Telkibánya is especially has been a classic area in the Carpathian Basin for more than two centuries to attract Hungarian and foreign researchers (Fichtel 1791, Townson 1797, Esmark 1798, Zipser 1817). The mountain ranges framed by the Ósva Valley and its tributary valleys gave a unique study area for petrographers who revealed the igneous bodies eroded at variable scales with a diversity of horizontal and vertical lava facies.

The formation of perlite with the contemporary "neptunist" approach was explained by lava flowing into water. József Szabó, a mining geologist was the first Hungarian researcher of rhyolites. He also carried out observations in relation to obsidians in Telkibánya and separated perlite from obsidian in its origin (Szabó 1867). The first monographic description of the area was made by Liffa (1951):

a) who summarized results of more than 20 years of research.

b) He correctly recognized that "the perlite rushed to the surface as a facies of rhyolite lava" but this very important finding has not been taken into account in subsequent researches. The last representative of the cycle, Hermann M. (1952) addressed petrographic and geochemical characterization of the rhyolites. The rhyolite subtypes of her meticulous microscopic thin-section studies, reflected the diversity of devitrification.

Geological mapping and raw material research in the Tokaj Mountains was started in the 1960s, its results required the development of a new volcanological model. The system dissected and clearly separated the major categories of lava - foam lava - pyroclast flow (Pantó 1964 and I. Perlaki 1972a) on the basis of volatile contents,

In the surroundings of Telkibánya (especially in the vicinity of Kőgát) large amount of perlite was identified and a two-cycle raw material research was performed to estimate the mineral resource (I. Perlaki 1972b, Gyarmati 1981). Although the principles of perlite raw material distribution were interpreted on the basis of Russian model tests (Volarovich 1944).

According to the maps of resource calculation blocks and the related describtion of the complexity of perlite deposit, the complexity can be identified max. 3. According to the FGU-GKZ (2010) this level of complexity means that in case of harmoniztaion of the Russian type resource classification with CRIRSCO type resource categorization C1 can be aligned with Measured Resource and C2 category can be aligned with Indictaed Resource. Due to the Bridging between CRIRSCO type reporting and UNFC categories Measured Resources can be identified as 221 and Indictaed Resources can be identified as 222.

Summary

The perlite deposits in the Tokaj Mountains in Hungary are very important on a global scale, because they can provide very significant reserves of raw materials (Table 1) from the Pálháza, Nagybózsva and Telkibánya-Kőgát areas beyond the current production level. This means for many decades it is possible to produce raw materials in excess of current production levels. In addition to perlites, swellable pumice tuffs can also provide an additional raw material base for the production of low-strength expanded products in the Tokaj Mountains. The problem of the utilization of domestic perlites and pumice tuffs is the spatial collapse of rhyolite-perlite deposits and protected landscape areas. It will depend on the coordination of the industrial policy and environmental protection concept of the current government on how the utilization of the unique domestic raw material base in Central Europe as a natural resource will develop in the future.

Methodology

Data source is

1) *General overview and history:*
    a. *scientific publication*
    b. *published book*
    c. *exploration report (MBFSZ Data Repository)*
2) *Mineral resource data:*
    a. *publically available book*
    b. *mineral resource inventory*
    c. *exploration report (MBFSZ Data Repository) and National Inventory for Mineral Resources and Geothermal Energy (hereinafter: Resource Inventory). Official data are in the Resource Inventory, exploration reports can be used for checking basic data derived from exploration report. Resource data of exploration report during the permitting procedure is integrated into the Resource Inventory after approval of permission for establishment of mining plot and Technical Operation Plan for exploitation and in the year following the start of mining activity (exploitation).*
3) *State of mine*
    a. *Inventory of mining areas*
    b. *Resource Inventory*
    c. *exploration reports include details but main results can be found in inventories*
4) *Harmonization key:*
    a. *FGU GKZ (Russian Federal Government Agency State Commission on Mineral Reserves), CRIRSCO (Committee for Mineral Reserves International Reporting Standards) 2010: Guidelines on Alignment of Russian minerals reporting standards and the CRIRSCO Template. Moscow, 112 p.*
    b. *Bridging Document between the Hungarian classification and the United Nations Framework Classification for Resources (UNFC 2020) and the family of the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) including the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves ('the JORC Code') Pan-European Reserves and Resources Reporting Committee ('the PERC Code') – internal national project result (Bridging Document is a project result of the MBFSZ, publication is in progress).*
5) *Additional considerations: presence of valid environmental and other permissions, news on government intention, infrastructure, social acceptance, metallurgy, etc.*

How have data been gathered?

1) *General overview and history:*
    a. *scientific publication: collection of publically available data by using internet*
    b. *published book: selection of proper publication*

c. *overview of exploration report*

2) *Mineral resource data:*
   a. *publically available book: selection of proper information*
   b. *mineral resource inventory: internal use of public datasets of the Resource Inventory*
   c. *mineral resource data can also be found in exploration reports that might help but results are summarized in inventories including inhomogeneity as well.*
3) *State of mine:*
   a. *Inventory of mining areas (BATER): internal use of this inventory*
   b. *Resource Inventory: internal use*
4) *Harmonization key:*
   a. *FGU GKZ (2010): translation and comparison between two systems with development of the methodology*
   b. *Bridging Document*: internal use of this document based on previous tests and discussions on national and international forums, sharing experience.
   c. *Bridging between UNFC and CRIRSCO*

The Mining and Geological Survey of Hungary collects and maintains datasets for minerals reported by mine operators according to the traditional Russian classification system of resources. According to the Mining Law (Act No. XLVIII. 1993 on Mining), operators are obliged to report exploration and exploitation data to the Mining Authority:

- data on quality, quantity and location of minerals when the exploration is completed;
- changes of the quantity of mineral resources during the exploitation annually;
- data on the remaining mineral resources after stopping the mine/quarry.

Reported data are included in the Resource Inventory. The type of reporting standard was not prescribed by law until 2020, however, traditionally the "Russian" system was used in the practice by experts of companies in Hungary. In this system mineral resource is divided into 4 categories: A, B, C1 and C2. In the case of non-metallic minerals A and B are merged (A+B). There are further 3 prognostic categories: D1, D2 and D3 which are not included in the Resource Inventory. Each category means a level of uncertainty; A, B, C1 and C2 categories involve ±10%, ±20%, ±35% and ±60% uncertainty respectively in general, however the specification of each categories harmonized with international reporting standards and the UNFC framework is in progress. The alignment between the national classification in the practice and the international reporting standards and with UNFC in the frame of the 5th Enclosure of the Implementation Government Decree (203/1998. (XII. 19.) for XLVIII of 1993 on mining law (Implementation) was submitted at the responsible Ministry of Innovation and Technology at the end of 2020 (see below details). This amandement was published in December in 2020. The specification reflects the most important criteria for mineral resource classification that are aligned with international reporting codes (CRIRSCO type reporting, e.g. JORC) and does not contain exact quantitative data for certainties or uncertainties. This is the responsibility of a proper expert who identifies and calculate the mineral resource or reserve.

Until 2007 economic parameters such as real cost were included in the inventory but are not recorded any more.

What kind of data have been used?

1) *General overview and history:*
   a. *scientific publication: background with history, maps, sections, research and exploration data, genesis-potential.*

b. *published book: background with history, maps, sections, research and exploration data, genesis-potential and resource/reserve data.*

2) *Mineral resource data:*
   a. *publically available book: resource/reserve, exploitation data*
   b. *mineral resource inventory: geological resource in place characterized by A, B, C1 and C2. "Exploitable Resource" that might be harmonized with "Reserve" according to the CRIRSCO template is not necessarily used in the harmonization because without considering Modifying Factors registered Resources remain in resource state and according to the GKZ Bridging between the Russian classification system and the CRIRSCO (2010) there are obvious links from national resource information to Indicated and Measured Resources (Inferred Resources can also be linked with mineral deposits having lower geological confidence and mineral potential.*
3) *State of mine*
   a. *Inventory of mining areas:*
      i. *0: exploration area (accepted exploration report, free for mining plot/lease*
      ii. *1: operating mine*
      iii. *2: pending mine*
      iv. *3: closed mine*
   b. *National Registry on Mineral Raw Materials and Geothermal Resources:*
      i. *National mineral resource classification categories: A, B, C1 and C2.*
      ii. *inhomogeneity – complexity:*

Complexity: A determining indicator of the inhomogeneity of sites. The variability of the site, which is the number of productive blocks per 1 km2, can be considered homogeneous in itself, but can be characterized by the number of basic mineral resource calculation units (blocks) that are different in terms of quality or occurrence, or tectonically separated due to geological features - should be counted as separate mining units, fields. Based on this, the site can be:

- *undisturbed, homogeneous: <30 pcs / km2*
- *gently disturbed, slightly inhomogeneous: 30–69 pcs / km2*
- *disturbed, inhomogeneous: 70–159 pcs / km2*
- *very disturbed, especially inhomogeneous: ≥160 pcs / km2.*

4) *Harmonization key:*
   a. *FGU GKZ (2010): translation and comparison between two systems with development of the methodology (Fig. 5.).*

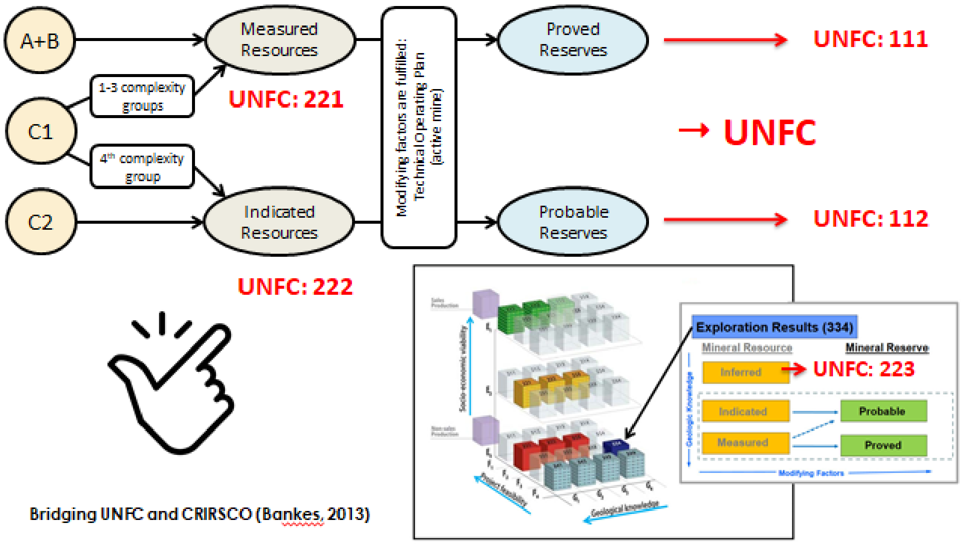

Fig. 5. Harmonization key between Hungarian national classification and CRIRSCO type reporting codes and UNFC (Hungarian project result based on FGU GKZ (2010) and Bankes (2013).

UNFC classes can be determined based on UNFC–CRIRSCO bridging document (UNECE 2013).

Active mines can be considered as Proved Mineral Reserves (CRIRSCO) and 111 (UNFC).

Suspended mines can be considered several ways according to the reason of the break of the mining activity. In case of temporary suspension of permission (e.g. environmental, because of nature conservation) the mining plot with the related mineral deposit may be identified as Measured or Indicated Resources depending on the complexity of the deposit but according to the UNFC it can be only Potentially Commercial Project (221 or 222) until the project gets the permission to continue the mining operation. Closed mines are considered also as Mineral Resources because further feasibility studies are needed to decide on the potential economic and social viability of the project that means (221 or 222 in the UNFC. Geological knowledge can be different: originally prior opening the mine G1 was necessary or specific risk is undertaken in case of G2 or G3. However during the lifetime of the mine specific areas can be reached where further geological or geophysical survey is needed (e.g. deep levels).

Bridging between UNFC, CRIRSCO and the Russian/Hungarian system based on UNECE 2013 and FGU GKZ – CRIRSCO 2010 can be seen on Table I.

For explored areas there are exploration reports and based on the complexity of the deposit(s) involved in the exploration area (Indicated M.R.: C2 and C1 complexity 4; Measured M.R.: C1 complexity 1-3). In case of different types of mineral deposits in a certain area different surveys and reporting is required (e.g. construction gravel, feldspar sand). Complexity can also be characterised by the inhomogenity that describes the uniform setup of blocks that are considered in the mineral resource management. This is a key-factor between the Russian type national and CRIRSCO-type international systems. This shows the number of blocks that are separated tectonically or may differ by their quality. Resources can be calculated for these blocks and separation may also be interpreted by the need of different mining operation. Dimension: pieces of blocks per km^2. Deposits may be classified into 3 or 4 or 5 classes depending on national/regional practices.

Generally below 50 blocks/km^2 can be considered as a deposit of low complexity (relatively homogeneous), while over 100 blocks/km^2 a deposit can be considered as a complex one (heterogeneous). Taking into account the status of the mine for a certain mineral deposit, its complexity group, the original classification, theoretically the correlation with the CRIRSCO type reporting terms can be done and due to the Bridging Document between the CRIRSCO and the UNECE classification system, the UNFC codes can also be indicated.

Table 1: Bridging between UNFC, CRIRSCO and the Russian/Hungarian system based on UNECE 2013 and FGU GKZ – CRIRSCO 2010.

UNFC		CRIRSCO	Russian (Hungarian)
111	Commercial projects	Proved Mineral Reserves	Exploitation Reserves in fully explored deposits
112		Probable Mineral Reserves	Exploitation Reserves in estimated deposits
221	Potentially commercial projects	Measured Mineral Resources	Resources of category C_2 in deposits of all complexity groups and category C_1 in deposits of the 4^{th} complexity group
222		Indicated Mineral Resources	Resources of category C_1 in deposits of 1^{st}, 2^{nd}, and 3^{rd} complexity groups with Resources of categories A and B in areas of detailed study
223		Inferred Mineral Resources	P_1 (D_1)
334	Exploration projects	Exploration results	-

b. *Bridging Document* :

Terms and links between the Hungarian national classification and international reporting codes were harmonized as follows:

Hungarian Mineral Resource Classification System (according to the submitted modification on the 203/1998. (XII. 19.) Government Decree implementation of the XLVIII of 1993 on mining act (enclosure 5).

The Hungarian mineral resource classification is dealing with at least four main categories that have brief descriptions (below) and detailed specifications of the UNFC 2019.

Category "A":

The geometry (location, shape, size, geological setting), internal variability, barren settlements, fracture displacement geometry of the mineral bodies are known in detail and contoured. The natural and technological types and quality varieties, useful and harmful components of the mineral raw material are known in detail - in sufficient detail to design the complex processing log - and characterized according to the cut-off conditions. Hydrogeological, engineering geological (geotechnical), mining geological and other natural conditions are known in such detail as to allow the basic data necessary for its exploitation planning. The contouring of the mineral resource or the exploitable mineral resource (reserve) was carried out by drilling and mining (mining preparation) facilities according to cut-off condition requirements - without extrapolation.

Category "B":

The position and geometry of the mineral bodies and significant fracture displacements are known and contoured, the internal variability, the nature of the barren settlements and the tectonic settings are known. The natural types of the mineral raw material are known and contoured, the spatial distribution regularities and quantitative ratio of the technological types and quality varieties are known, mineral bonding of useful and harmful components is known. Hydrogeological, engineering (geotechnical), mining geological and other natural conditions are known in such detail that they allow the quantitative and qualitative characterization of their parameters and the assessment of their impact on the exploration and extraction of the site. The contouring of the mineral resource or the exploitable mineral resource (reserve) by boreholes and mining facilities was basically based on the cut-off condition requirements, in case of raw material having consistent thickness and quality according to geological criteria, completed with a limited extrapolation zone based on geophysical and geochemical data.

Category "C1":

The dimensions and characteristic shapes of the mineral raw material bodies, their settlement conditions and the basic characteristics of their internal structure are known. The variability of raw material bodies and in the case of stratified mineral deposits possible disruption of continuities and the occurrence of construction and dimension stones low-amplitude intensively tectonised areas were assessed. The natural and technological types of mineral raw materials have been determined, the general settings of their spatial distribution are known. The general settings for spatial distribution and for quantities of technological types and quality varieties are known. The mineral bonding of useful and harmful components – to the interpretation of the value of mineral resources and exploitable resource (reserves) - is known as they were characterised according to the cut-off conditions. The level of detail of the study of hydrogeological, engineering geological (geotechnical), mining geology and other natural conditions allows the preliminary characterization of their basic parameters. The contouring of the mineral resource or the exploitable mineral resource (reserve) by boreholes and mining facilities was basically based on the cut-off condition requirements, taking into account the data of geophysical research and geologically based extrapolation.

Category "C2":

The size, shape, internal structure and geological setting of the raw material bodies have been assessed on the basis of geological and geophysical data, which are confirmed by the crossing of the raw material with drilling or mining facilities. The quality and technological properties of the raw material were determined on the basis of data from limited number of laboratory tests or were assessed by analogy with parts of the same or similar site known in detail. The hydrogeological, engineering geological (geotechnical), mining geological and other natural conditions were assessed on the basis of the data available in the research facilities, together with the data available in other parts of the given site, and by analogy with known sites in the given area. The contouring of the geological and industrial assets (stocks) of the mineral raw material was performed on the basis of individual drilling, mining areas, natural excavations or a combination of these methods, taking into account geophysical and geochemical surveys and geological interpretations, as well as geologically supported parameter-extrapolation that was used during the calculation of resources having higher geological knowledge and reserves.

UNFC categories

UNFC 221: E2: Development and operation are expected to become environmentally-socially-economically viable in the foreseeable future; F2: Technical feasibility of a development project is subject to further evaluation; G1: Product quantity associated with a project that can be estimated with a high level of confidence.

UNFC 222: Development and operation are expected to become environmentally-socially-economically viable in the foreseeable future; F2: Technical feasibility of a development project is subject to further evaluation; G2: Product quantity associated with a project that can be estimated with a moderate level of confidence.

UNFC 112: E1: Development and operation are confirmed to be environmentally-socially-economically viable; F1: Technical feasibility of a development project has been confirmed; G2: Product quantity associated with a project that can be estimated with a moderate level of confidence.

UNFC 111: E1: Development and operation are confirmed to be environmentally-socially-economically viable; F1: Technical feasibility of a development project has been confirmed; G1: Product quantity associated with a project that can be estimated with a high level of confidence.

A Mineral Resource is a concentration or occurrence of solid material of economic interest in or on the Earth's crust in such form, grade or quality and quantity that there are reasonable prospects for eventual economic extraction. The location, quantity, grade or quality, continuity and other geological characteristics of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge, including sampling. Mineral Resources are subdivided, in order of increasing geological confidence into Inferred, Indicated and Measured categories. With increasing certainty, solid geological mineral resources can be classified into inferred, explored, and explored categories. Solid geological mineral resources are harmonized with the definition of geological mineral resources in Section 49 (30) of the Mining Act in relation to solid mineral resources.

Modifying Factors are considerations used to convert Mineral Resources to Mineral Reserves (aligned with Industrial Resource pursuant to Section 49, Paragraph 14 of the Mining Act). These include, but are not restricted to mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors. All Modifying Factors and assumptions made regarding mining methods, minimum mining dimensions (or pit shell) and internal and, if applicable, external planned and unplanned mining dilution and mining losses used for the techno-economic study and signed off, such as mining method, mine design criteria, infrastructure, capacities, production schedule, mining efficiencies, grade control, geotechnical and hydrological considerations, closure plans, and personnel requirements.

A Measured Mineral Resource is that part of a Mineral Resource for which quantity, grade or quality, densities, shape, and physical characteristics are estimated with confidence sufficient to allow the application of Modifying Factors to support detailed mine planning and final evaluation of the economic viability of the deposit. Geological evidence is derived from detailed and reliable exploration, sampling and testing and is sufficient to confirm geological and grade or quality continuity between points of observation. A Measured Mineral Resource has a higher level of confidence than that applying to either an Indicated Mineral Resource or an Inferred Mineral Resource. It may be converted to a Proved Mineral Reserve or to a Probable Mineral Reserve.

An Indicated Mineral Resource is that part of a Mineral Resource for which quantity, grade or quality, densities, shape and physical characteristics are estimated with sufficient confidence to allow the application of Modifying Factors in sufficient detail to support mine planning and evaluation of the economic viability of the deposit. Geological evidence is derived from adequately detailed and reliable exploration, sampling and testing and is sufficient to assume geological and grade or quality continuity between points of observation. An Indicated Mineral Resource has a lower level of confidence than that applying to a Measured Mineral Resource and may only be converted to a Probable Mineral Reserve.

An Inferred Mineral Resource is that part of a Mineral Resource for which quantity and grade or quality are estimated on the basis of limited geological evidence and sampling. Geological evidence is sufficient to imply but not verify geological and grade or quality continuity. An Inferred Resource has a lower level of confidence than that applying to an Indicated Mineral Resource and must not be converted to a Mineral Reserve. It is reasonably expected that the majority of Inferred Mineral Resources could be upgraded to Indicated Mineral Resources with continued exploration.

Category "A" and "B" and the lower (1-3) complexity "C1" geological knowledge categories can be harmonized with Measured Mineral Resources according to the CRIRSCO international reporting template. Taking into account Modifying Factors and economic considerations economic assessment can be made on the basis of this category type (Proved Reserve and probable industrial resource that is also Reserve).

The measured geological mineral resources (Measured Resources) correspond to UNFC 221 category. Proven "industrial resource" (Proved Reserve) corresponds to UNFC 111 and "probable industrial resource" (Probable Reserve) to UNFC 112.

The higher complexity (4) "C1" and "C2" geological knowledge categories can be harmonized with Indicated Mineral Resource according to the international reporting template (CRIRSCO). According to the International Reporting Standard, an economic valuation can be made on the basis of these categories and taking into account the Modifying Factors, but only "probable industrial resource", i.e. Probable Reserve can be determined. The Probable Reserve corresponds to UNFC category 112. Bridging between CRIRSCO and UNFC (UNFC 2019) is seen on the Fig. 4.

CRIRSCO Template		UNFC-2009 "minimum" Categories			UNFC-2009 Class
Mineral Reserve	Proved	E1	F1	G1	Commercial Projects
	Probable			G2	
Mineral Resource	Measured	E2	F2	G1	Potentially Commercial Projects
	Indicated			G2	
	Inferred			G3	
Exploration Results		E3	F3	G4	Exploration Projects

Fig. 6. Bridging between CRIRSCO and UNFC (UNFC 2019).

Availability of data sources

UNFC

UNFC categories were identified according to the UNFC 2019 (2000) and basic data on mineral resources in the Resource Inventory and in the Inventory of Mining Areas and additional considerations. Tables for bridging between national data sets and UNFC and also for CRIRSCO type reporting codes see above.

Evaluation of data and areas, calculation of volumes.

We have started from official mineral resource inventory where the type and volume and the state of the mine/exploration are defined according to legal background and obligations (see above).

The volume and quality (type that is an official category with specific quality specifications) of this mineral resource was identified by the responsible company and expert who provided report in the past and served data each year to the responsible authority (name and structure were changed many times in the past tens of years (recently MBFSZ).

Resource data related to localities (mineral deposit) are presented in the percentage of the total volume on country level taking into account different levels of geological knowledge respectively.

Defining the E, F and G-axis

Table II.: explored and operating perlite mines in Tokaj-Mts. (2016 dataset)

mining Plot	administrative place	other name	name of raw material	state of site	category	geological resource in place (%)
Pálháza I. – perlite, rhyolite tuff	Pálháza	Gyöngykő-hegy (Pálháza I.-perlite, rhyolite tuff)	Perlite	1	A+B	2%
					C1	5%
					C2	1%
	Pálháza	Gyöngykő-hegy, reserve area (Pálháza I.-perlite, rhyolite tuff)	Perlite	2	C1	2%
	Nagyhuta	Somhegy south, Kovácsvágás	Perlite	0	C1	11%

Code of the state of the mine and the mineral deposit: 1: active mine, 2: pending, 3. closed, 0: identified mineral deposit based on exploration.

Harmonization between national (Russian type) and UNFC classification (Table III) via CRIRSCO:

Name of mineral on site	Classification category Russian/National	Resource in place based on exploration reports and exploitation (%)	state of mine or exploration area	CRIRSCO	UNFC
Pálháza – Gyöngykő-hegy	A+B	2%	1	Proven Reserve	E 1.1., F1.1 G1
	C1	5%	1	Proven Reserve/Measured Resource (221) under mining operation	E1.1. F1.1 G1
	C2	1%	1	Probable Reserve (mining operation on Indicated Resource)	E1.1 F1.1 G2
Pálháza – Gyöngykő-hegy, reserve area	C1	2%	2	Measured resource *inhomogenity:max: 3.*	E2/E1.2 F2.2 [x] G1
Nagyhuta	C2	11%	0	Indicated Resource	222

[x]: according to the detailed UNFC mapping of the Hungarian Mineral Resource Inventory and Invnetory of Mining Areas that is under development in 2021, mining areas having Technical Operation Plan for pending the mining activity can be harmonized with UNFC E2/E1.2; F category 2.2.

Challenges

Handling together data from Inventory of Mining Areas and data from Mineral Resource Inventory. In case of project (here explored are or mining plot) if the direction of the development is towards to extraction of raw material, bridging between national data sets and international systems can be done on higher level (main categories: C2, Indicated Resource, UNFC 222). In case of changes in the mining activity (pending, closure) E, F categories depending on different reasons might be changed that needs to be taken into account in the mirror of national inventory of different legislative potion of a mining plot.

The challenge is to implement practically in the daily work and use officially the UNFC. Quick response on changing categories: an Indicated Resource can be move to Probable Reserve in a short time in case of mining operation starts (F1) and the project is viable (E1). As the UNFC is a dynamic system, at each permitting stage and changes in mining activity UNFC categories need to be updated.

MBFSZ has established the methodology of use of the UNFC based on bridging between national classification of mineral resources, CRIRSCO type reporting and UNFC up to 2020. The national legislation (Implementation Gov. Decree of the Mining Law) was published with basic categories of UNFC in 2020 but the assessment of projects and identification of projects according to UNFC needs to be done by experts of the MBFSZ. Data production for exploitation and for identified mineral resources according to modernized Russian type reporting to Mining Authorities (annual data to MBFSZ, identified resources in exploration reports to Mining Departments of Regional Government Offices) is still obligation for mining entrepreneurs.

More case studies may be needed to refine the methodology and use UNFC with sub-categories is also challenging.

Trainings and education are needed in the MBFSZ, in other Mining Departments to use the joint language including UNFC for mineral resources and to support sustainable resource management concept that includes consideration of both primary and secondary raw materials.

Additional Questions:

What have you learned from this work?

For perlite that is an important volcanic mineral raw material different state of different occurences require speacial attention taking into account national datasets for mining areas that might have several legislative positions and taking also account datasets for mineral resources.

Benefit: The UNFC is a tool to maintain the state of a project including resources or reserves in a logical, dinamic system and can support decision on local/regional/national levels developments with considerations of environmental and social issues, so it supports the sustainable resourtces management with SDGs.

What kind of challenges have you experienced during this work? See above.

How can your work and experience be used into a UNFC guideline?

This practice will be useful in the daily work with UNFC that is supported with legislative background. This case study with all the others were previously done will be useful to develop the inventory for mineral resources that will be aligned with UNFC.

How can this case and your experience be used into the next deliverables and Milestones in Mintell4EU WP4:

D4.1 Case study review with practical guidelines/work flows and examples for applying UNFC to European mineral resources

D4.2 Report on harmonization issues, data gaps and challenges, reviewing also the quality of Pan-European aggregated inventories for selected commodities.

Descriptions, tables and interpretations will contribute to the joint methodology of using UNFC and development of decision flowchart for EU-level application of the UNFC supported professionally by EGS.

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UNFC Pilot Case Study – Norwegian Crushed Hard Rock Aggregates

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Introduction/Background

Geological Survey Organisations (GSOs) collect mineral resource information in form of geological, geophysical and geochemical data, and compile geological maps that support spatial planning, business development, and government policy making. Robust data on in-ground mineral resource potentials are of particular relevance for economic development because they help secure the raw material supply for industrial supply chains and underpin infrastructure establishment. Moreover, reliable quantitative estimates are needed to develop national policies that create favourable operating conditions for the mining and processing industry and that promote sustainable mineral resource management (United Nations Environment Assembly 2019). The extractive industries typically use resource classification standards at a local per-project scale to assess, quantify and report (potentially) extractible quantities for public disclosure and stock market financing purposes. The quantities reported for projects are then often aggregated by different stakeholders across several projects at a regional or national level to compile mineral studies, manage national resource endowments, and develop government policies. The United Nations Framework Classification for Resources UNFC (UNECE 2020) aims to support such regional and national data aggregation and harmonisation by providing a generic unified and principles-based framework with more detailed UNFC Specifications for reporting resource potentials for different resource types including fossil fuels, geothermal energy, minerals, anthropogenic resources, and injection projects.

The scope of this UNFC pilot study conducted by the Geological Survey of Norway (NGU) is not to produce a realistic and bankable resource classification such as those used by the industry to report quantities for specific, well-constrained industry projects. We acknowledge that other case studies already compellingly demonstrate that the UNFC can be used to bridge from national and international classifications, or to describe how to categorise quantities for well-defined projects entirely with the UNFC. The UNFC Specifications section II on National Resource Reporting state that 'where government organizations have a responsibility for developing estimates at a regional or national level, the estimates may be different from corporate estimates on an individual project basis, regardless of the classification system being used. In such cases, regional or national estimates using UNFC shall be derived using an appropriate methodology based on the nature and extent of available data.' Accordingly, this case study aims to test two hypotheses regarding such pre-commercial regional estimates: (1) that the UNFC can be applied to categorise and report the entire 3D geological volume delineated by the regional-scale case study perimeter, and (2) that only minor, if any, changes to the existing UNFC framework would be required to accommodate such a full-coverage categorisation.

This UNFC pilot case study thus tests the general feasibility of a GIS workflow that applies the UNFC to the entire geological volume (i.e. full-spatial and 3D coverage) of a regional-scale pilot area in order to identify, assess, categorise, and report the region's 'unused' mineral potential according to the UNFC. While it investigates hard rock construction aggregates, the principles should be applicable also for other commodities.

Define the resource

Non-metallic materials — mainly sand, gravel and crushed rock, together referred to as construction aggregates — are the most used raw materials globally (IRP 2019) and their annual demand is projected to rapidly increase from 44 Gt in 2017 to 86 Gt in 2060 (OECD 2019). In Norway, construction minerals production dominates the extractive industry activity by value and tonnage, both in terms of domestic mineral consumption and export statistics. In 2019 a total of 130 Mt of geomaterial were excavated by licensed mining operations for aggregates production, 114 Mt of which were crushed hard rock aggregates won by quarrying activities (DMF 2020). Total sales in 2019 amounted to 110 Mt, of which 34 Mt (ca. 30% of total sales) were exported, generating an export value of 3.763 billion NOK and a total annual turnover of 4.956 billion NOK (DMF 2020). This made Norway the world's second biggest exporter of construction aggregates in 2019, following the United Arab Emirates with 43.667 Mt (UN Comtrade 2021). Crushed rock aggregates production for export has continuously increased in Norway since 1975 (Neeb 2019), and suitable material is sourced mainly from quarries along the south-western coast that are closest to big international markets such as Germany, The Netherlands, Denmark and the UK (Figure 1). The global construction aggregates demand is projected to double between 2011 and 2060 (OECD 2018) and to safeguarding the long-term sustainable supply to domestic and international markets, it imperative that potentially suitable geological prospects are identified, protected from competing land-use claims, and developed for future production.

Given the increase in demand for Norwegian construction aggregates and the favourable setting of the coastal regions of southern Norway, this case study tests a workflow to quantify and classify potential hard rock aggregate resources at a 'regional scale' in a roughly 10x10 km pilot case study area located along the south-west coast of Norway in the Suldal municipality in Rogaland county (Figure 1).

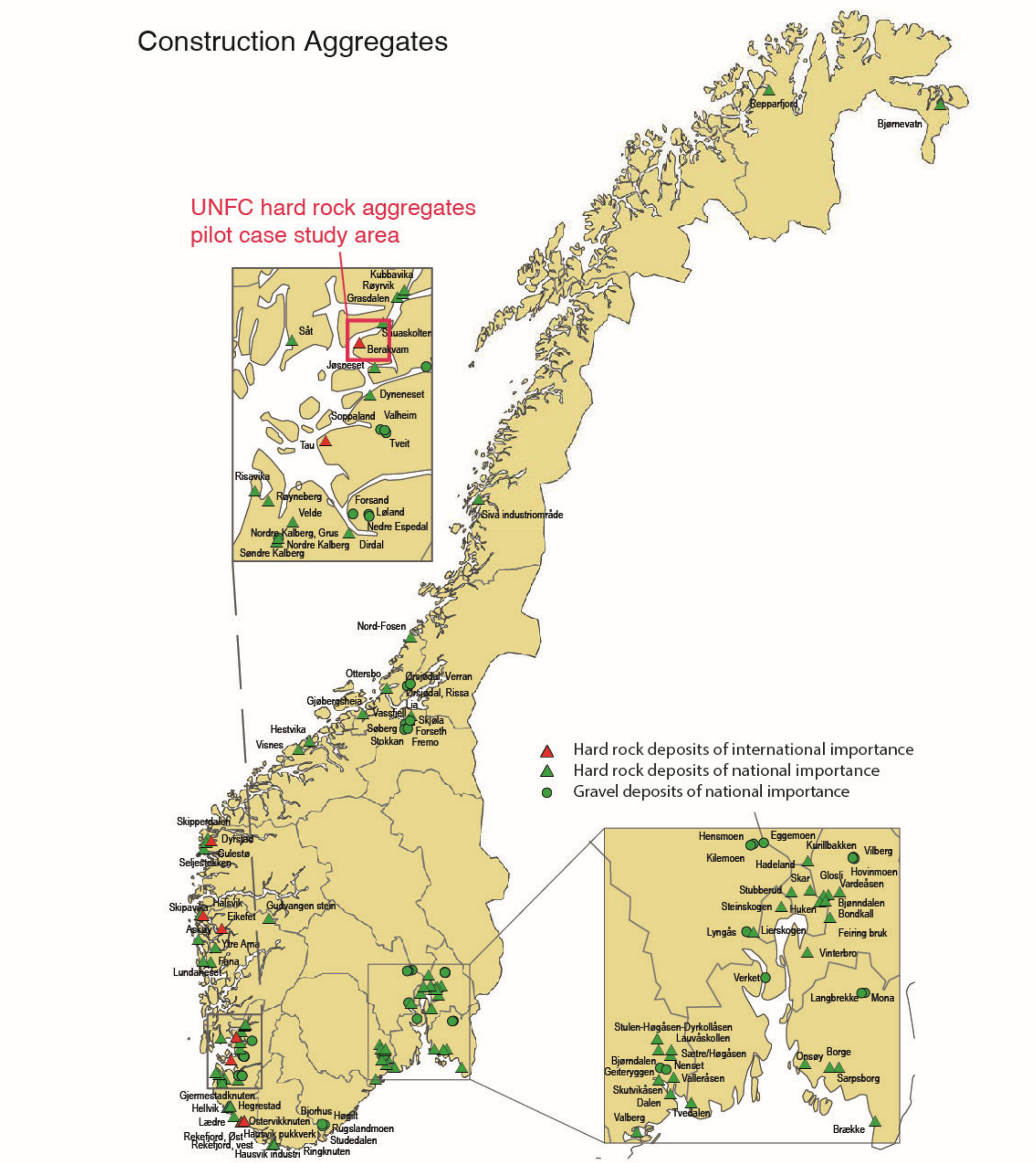

Figure 1: Geological map of Norway with important coastal aggregates producers, modified from NGU (2017) to highlight the UNFC pilot case study area in red.

The pilot area also covers the licensing area of Europe's largest hard rock aggregates operation, the Berakvam (Jelsa) quarry operated through Norsk Stein AS by the German Mibau Holding Gmbh. The mined granodiorite deposit has been designated by NGU as of international importance due to its suitable geology and its intrinsic material properties that make it suitable for high quality aggregates production, as well as a favourable topography, location, and infrastructure with a deep-water quay for bulk marine shipping.

Methodology

National mineral resource classification efforts in Norway include criteria to report the importance of mineral deposits in order to support minerals development efforts (Dahl *et al.* 2014; NGU 2017). Various harmonisation and data standardisation efforts by EU-co-financed international research projects such as Minerals4EU (Lopes *et al.* 2018) and ORAMA (Bide *et al.* 2018) have contributed to implementing INSPIRE (European Commission 2007) conventions for mineral resources into NGUs databases. However, there is no nationally mandated use of mineral resource classification and reporting standards in Norway, and the existing mineral resource and reserve data in national databases are not systematically standardised to any international reporting standard such as the CRISCO-aligned reporting codes (Committee for Mineral Reserves International Reporting Standards (CRIRSCO) 2013) or the UNFC (UNECE 2020). Moreover, relevant information that are required to classify resources according to UNFC are fragmented across norwegian government institutions that may — or may not — make the required data accessible in a format that can be used for UNFC classification. This impedes national data integration and consistent and systematic minerals accounting. Industry project data, for example, are reported to the Norwegian Directorate of Mining with the Commissioner of Mines at Svalbard (DMF) but not publicly disclosed. NGU in turn is tasked with compiling national pre-competitive geological datasets that inevitably include the same geological volumes that the industry is reporting on, but the data are not integrated across the two organisations.

Because the required project-specific resources, reserves, and production information of existing operations are not publicly available, this case study does not aim to (re-)classify projects. Neither does it involve bridging of existing project-specific data from other resource classification standards, mainly because there is no mandated Norwegian standard for resource classification to bridge from. Rather, this pilot case study is a GIS desktop study that investigates the possible use of UNFC for regional-scale resource prospectivity assessments that incorporate only publicly available pre-competitive 'base' datasets that are not restricted by commercial interests and confidentiality constraints. This distinguishes it from traditional resource classification approaches of industry-projects that are commonly used for financing and stock market reporting, and that typically require data from business operations and assumptions about technical design and financial planning that are outside of the public domain and GSO mandate.

The developed workflow tests a concept for how different public datasets can be combined using an ArcGIS Modelbuilder routine to auto-calculate the volumes needed for regional scale UNFC categorisation of potential hard rock aggregate resources. It combines geological data with georeferenced data on technical material properties (sampling and mechanical testing), and spatial datasets on socio-economic factors to calculate the

(1) area and total material volume of the delineated case study area using the topographic model (DTM) as upper and the sea level as lower bounding surfaces

(2) areas and individual volumes of the different geological units within the perimeter based on the 1:50'000 geological map and vertical projection

(3) areas and volumes known or expected to be inaccessible (i.e. 'sterilised') due to potential conflicts with competing uses such as existing settlements, public road infrastructures or nature conservation

(4) areas and volumes of the remaining, potentially accessible 'prospective' areas, as well as those of the geologically well-constrained and explicitly defined 'mapped deposit' and 'prospect areas', and

(5) UNFC categorisation of the volumes calculated in 3&4 based on geological data, sampled mechanical properties, and different constraints that may limit or potentially allow for extraction.

Geological data

The geology of the pilot study area (Figure 2) has been mapped at different levels of detail by the Geological Survey of Norway (NGU) and is generally well-documented. Data for the geological descriptions in this report are based on the following sources:

- regional scale 1:250'000 geological bedrock map
- detail scale 1:50'000 Vindafjord map: geological setting
- local scale 1:5'000 Berakvam map and report by Marker (2003): additional detailed data
- NGU's national aggregates database: rock quality data, occurrence polygons

National coverage geological datasets maintained by NGU

The Geological Survey of Norway (NGU) provides national full-coverage harmonised 1:250'000 geological bedrocks maps, and for selected regions also 1:50'000 geological bedrock maps that can be downloaded, and explored on NGU's website. Further maps and associated reports (in PDF format) can be downloaded from NGU's publications webpage, granted that the desired documents are not confidential. Generally, confidential reports are also released on the NGU website after two years.

NGU oversees several geological databases, among which the construction aggregates database used in this UNFC case study. NGU's aggregates data are publicly accessible through NGU's website, where selected datasets can be downloaded, or explored on an interactive web map.

NGU's construction aggregates inventory consists of georeferenced points for all mapped occurrences of interest (first hierarchy level). To visualise occurrence areas, polygons are drawn manually around the registration points, but these areas are often neither consistent with spatial planning, nor do they necessarily correspond to mapped 2D/3D geological map boundaries, which limits their utility for deposit volume calculations. Mapped mineral occurrence areas can contain sample localities, registered as georeferenced point features (second level). Samples can be associated with different laboratory test results (third level), that characterise the material composition and the mechanical properties used to assess the material quality and potential suitability for different purposes. Note that at every level of the database, point and polygons features are linked to data tables, where text descriptions, pictures, and laboratory test results are registered.

Regional geological data

The north-eastern part of the study area is dominated by late Mesoproterozoic basement rocks dated at 1050-1020 Ma. Those rocks are granitic to granodioritic, showing a reddish grey colour, a porphyritic texture and a weak to moderate foliation. In the 'mapped prospect' area a NW-SE lithological contact separates the Mesoproterozoic granitoides from early Mesoproterozoic volcanic rock (dated at ca. 1500 Ma) that are dark grey, fine-grained, and foliated metadacite to meta-andesite.

The southern and central parts of the study area are dominated by Cambro-silurian meta-sediments (so-called Ryfylke Schists) which are part of the Lower Allochton and were overthrusted during the Caledonian orogeny. Those metasediments include phyllite, mica schist and quartz-mica schist, in place garnet-bearing. In the Harastigfjellet area, the Storheia Nappe which belongs to the Middle Allochton is locally observed as an overthrusted, tonalitic to quartz dioritic gneiss unit lying onto the Ryfylke schists. The gneisses are pale grey, fine-to medium grained and strongly banded and lineated. The Storheia Nappe is part of the Hardangervidda-Ryfylke Nappe Complex which is assumed of Mesoproterozoic to Ordovician age.

Local geological data

The Berakvam quarry and surrounding reserve area have been mapped at a detailed 1:5’000 scale by NGU in 2003 (Marker 2003). The report provides geological maps, drill core logs, geological cross sections, petrographic analyses, and mechanical test results. The 1:5’000 geological provides additional detail on smaller occurrences of pegmatites, fine grained gneisses and granitic rocks embedded in the massive granodiorite that dominates the area on the 1:50’000 map. Three cross sections and four drill core logs confirm the dominance of the rather uniform porphyritic granodiorite down to a depth of at least fifty meters.

Geological map and geological data quality for the pilot case study area

Overall, the geology of the pilot case study area is well-known for the purpose of a regional-scale UNFC hard rock aggregates study, and the four main rock units are well-constrained, even at depth in some areas. This report refers to them with simplified names as shown in Table 1 and Figure 2:

Table 1 Rock units mentioned in this case study.

Map reference	Simplified name
Basement rocks, granitic to granodioritic	Granodiorite
Meta sediments, phyllite, mica schists etc.	Schist
Volcanic rocks, metadacite to meta-andesite	Metadacite
Tonalitic to quartz dioritic fine-grained gneiss	Fine-grained gneiss

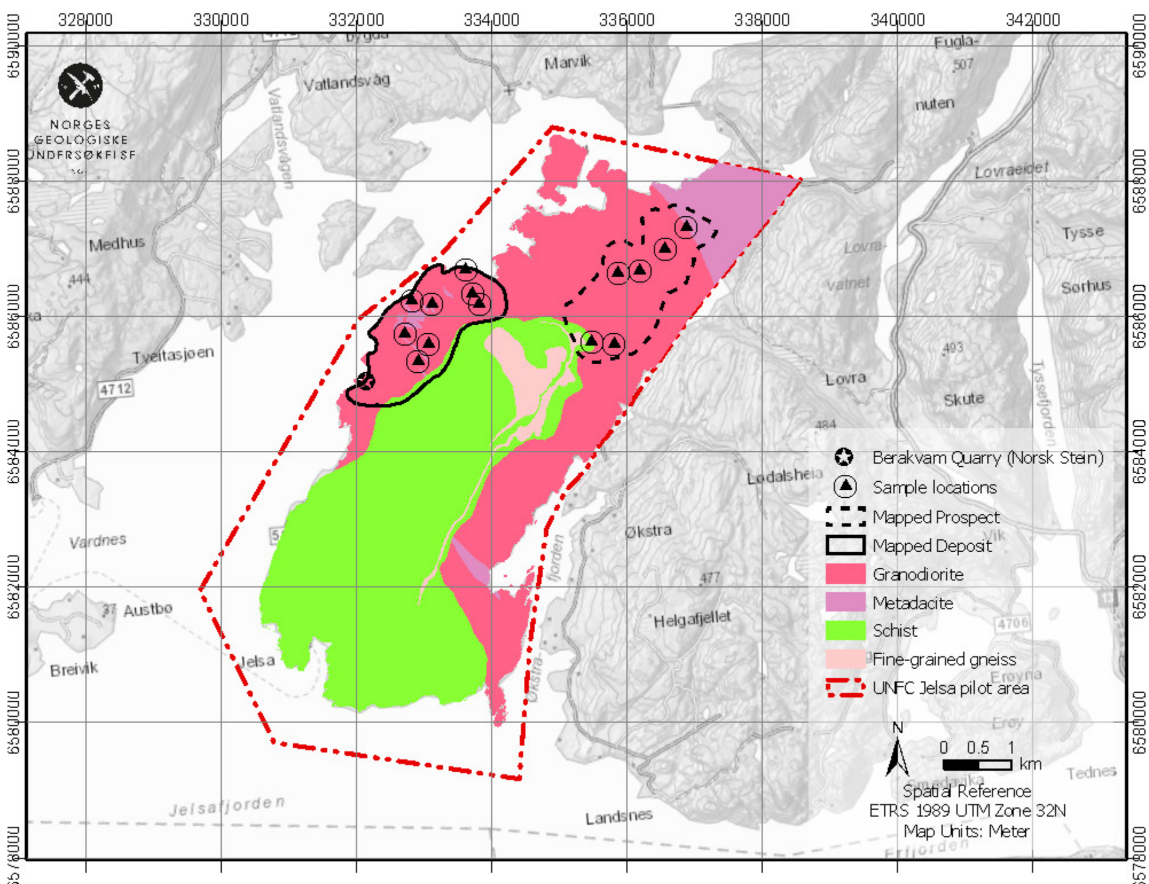

Figure 2: Geological map of the pilot case study area, clipped to the case study perimeter and showing NGU’s mineral occurrence outlines and sampling locations in the existing Berakvam quarry (mapped deposit) and a nearby prospect area (mapped prospect). The geology is dominated by four rock types, of which the metadacite and granodiorite are considered most prospective for aggregates production.

Data on material quality

Description of product quality requirements and test results (LA, KM, (MDE))

Aggregate materials are used for many industrial applications, including for concrete production, road construction, railway ballast, and for various geotechnical and landscaping applications. In this UNFC case study, only hard rock material product quality requirements for road construction are used to illustrate the general feasibility of material quality evaluation based on NGU's mechanical test results and laboratory analysis.

The Norwegian Roads Administration (Statens Vegvesen) defines the minimum quality requirements for aggregates for road construction in terms of resistance to fragmentation and abrasion, which can be tested with the Los Angeles (LA) and the Nordic Abrasion (NA) tests (Statens vegvesen 2015). NGU has developed a rock quality index based on these tests and the Norwegian Road Administration's guideline for road construction (Statens vegvesen 2018), which is used to categorise the pilot case study rock samples into different quality classes.

Quality index values and matching quality requirements are summarized in Table 2.

Table 2: Mechanical quality requirements for rock aggregates to be used in the construction of a road surface-layers and resulting rock quality index used in this UNFC case study.

Rock quality	Very Good	Good	Medium	Poor / Rejected
Los Angeles value (LA)	≤ 25	≤ 30	≤ 40	> 40
Nordic Abrasion value (NA)	≤ 10	≤ 14	≤ 19	> 19

In the 'mapped deposit' (Berakvam) area, eight samples of the granodiorite were taken, six of which have been tested with the Los Angeles and Nordic Abrasion methods (Marker 2003). The results are surprisingly consistent, and all samples have returned Los Angeles values under 25 and Nordic Abrasion values under 14, resulting in a "good quality" index. Four of the six samples have a Nordic Abrasion value under 10, which qualifies as "very good" for aggregates production.

For the 'mapped prospect' area north-east of Berakvam, six additional samples were tested, five of which have from the granodiorite. Again, mechanical test results have returned consistent Los Angeles and Nordic Abrasion values which gave an overall "good quality" index to the granodiorite. The last sample is from the rather homogeneous metadacite in the north-eastern part of the case study area. It has mechanical test results qualifying as "very good" (LA = 11.2 and NA = 8.4).

Based on the geological observations and mechanical tests only two of the four rock units in the study area, the granodiorite and the metadacite, are considered to be potential aggregate resources (Table 3). Mapping and drill cores suggest that the two units remain uniform at depth, and they have a "good" and "very good" quality index, respectively. The schist unit has not been tested and was not considered as a potential resource because phyllites and mica-schists typically have poor mechanical properties. While the fine-grained gneiss of the Storheia Nappe is likely of medium to good quality, it was equally dismissed because its limited extent and its location are unfavourable for aggregates production.

Table 3: Rock quality index for the UNFC Jelsa case study area based on geological observations and mechanical testing.

Rock Unit	Average Rock Quality Index	Samples analysed
Metadacite	Very Good	1
Granodiorite	Good	11
Schist	Poor/Rejected	
Fine-grained gneiss	Poor/Rejected	

Description of socio-economic data

Application of UNFC at a regional scale needs to consider available information such as municipal zoning plans, mining concession areas, and environmental protection areas. Some of these datasets may explicitly allow for mining, while others may have different degrees of non-repudiability. Essentially, all socio-economic and technical constraints that may limit mining today are to some degree negotiable, and many are likely to change in the future. Nevertheless, they can be listed, appraised, and ranked according to different criteria to illustrate their current status, as outlined by Pfleiderer (2020) for Austrian gravel resources. Following datasets were of particular interest for this case study:

Zoning data:
Existing buildings and road infrastructure available as vector datasets were used in the GIS analysis for workflow testing and illustration purposes only. While additional zoning data in different formats exist and could be — and should be — integrated into an automatic GIS workflow, they were not considered for the scope of this pilot study.

Mining data:
Accessible GIS information from the Norwegian Directorate of Mining with the Commissioner of Mines at Svalbard (DMF) only contain point information with very limited attribute data (Appendix Figure 3 & 4). Vector data for the licensing areas are not available from the DMF, and the annually reported industry reserves, resources and production that could be used to categorise the different UNFC volumes of operating quarries are not disclosed. In consequence, the data that is made publicly available by DMF did not provide any additional information of value for this UNFC pilot case study.

Spatial planning:
Municipal plans and regulations (Appendix Figure 1, bottom left inset map) are very important for UNFC analyses but were not available in a readily useable GIS format. Some municipal plans with maps can be downloaded in PDF format, but would have to be digitised and correctly georeferenced, or solicited as GIS files through local authorities to be of use for an automated analysis such as the one presented here.

Environmental protection:
National datasets on topics such as nature protection, water protection, and cultural heritage are hosted by different government and non-government organisations. To some degree they may constitute legally binding and thus essentially 'non-repudiable' restrictions (e.g. nature reserves, groundwater protection), but generally all have varying degrees of negotiability because they are subject to stakeholder decisions, legislation, and government policies. It was outside of the scope of this case study to consider all known and potential restrictions, and to rank how binding they are, which would have required a dialogue and consensus with different institutions.

ArcGIS modelling

A two-stage ArcGIS Pro Modelbuilder workflow (cf. Figure 3) was fed with the study area perimeter polygon, 1:50’000 geological map polygons, raster terrain model of 2017, point features for mechanical sample locations and associated lab analysis results, occurrence polygons from the NGU aggregates database, and line and polygon datasets for roads and buildings as input parameters. Buffers around roads (50m) and buildings (250m) are automatically generated by the model, and input data as well as analysis results are shown in several pre-defined map layouts (Appendix Figure 1). Appendix Figure 2 shows areas for volume calculations and UNFC reporting.

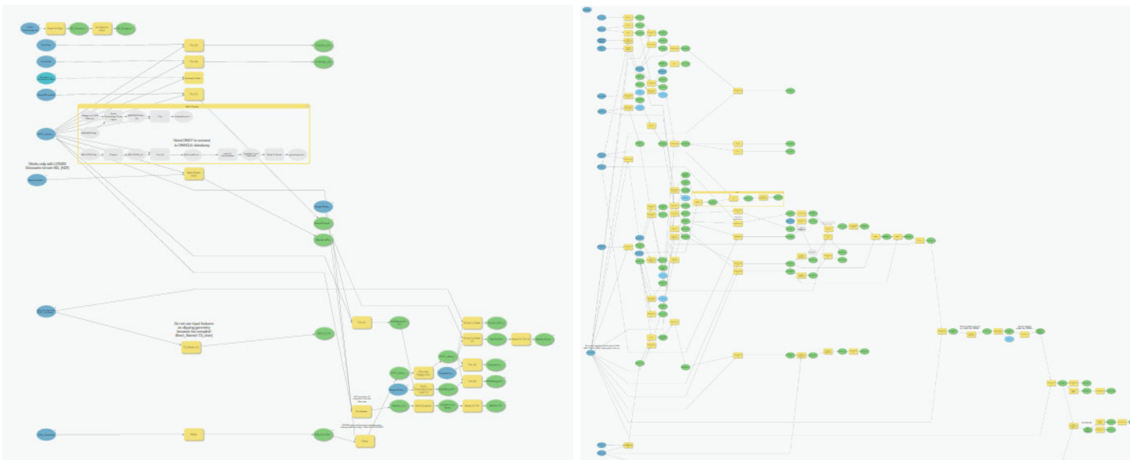

Figure 3: ArcGIS Pro Modelbuilder tool for (a) base data preparation (21 processes), and (b) automatic calculation of the geological volumes (70 processes) by stepwise exclusion of potential conflict areas (i.e. those ‘sterilised’ by existing settlements and infrastructure). Results map the volumes of presumably conflict-free ‘prospective area’ and ‘prospective volume’.

Results of volume calculation

Attribute tables with area and volume information for the different GIS layers were exported as Excel files and linked to produce the overview Table 4, with surface footprint areas in square kilometres (km^2) and volumes in million cubic metres (Mm^3). For illustration purposes, the volume calculation assumes that the geological resources can be exploited down to sea level; at industry project scale practical constraints such as public planning and regulations, as well as technical constraints of mine design and property rights, determine the exploitable volumes.

Table 4: Volume calculation and UNFC classification of rock units within the pilot case study perimeter. The ‘Prospect volume’ is part of the ‘Prospective volume’, while the ‘Permitted volume’ is not quantified because data from DMF are inaccessible.

Rock unit	**Perim. area [km2]**	**Perim. volume [Mm3]**	**Prospective area [km2]**	**Prospective volume [Mm3]**	**Prospect area [km2]**	**Prospect volume [Mm3]**	**Permitted area & volume**
Granodiorite	15	1'406	6	870	2.7	489	Concession polygons & resource data not available from DMF
Schist	15	3'108	9	2'567	0.1	18	
Metadacite	2	290	1	126	0.2	39	
Fine-grained gneiss	1	361	1	332	0.0	7	
Total	**33**	**5'164**	**18**	**3'895**	**3.0**	**553**	

UNFC

The objective applying the generic framework classification UNECE (2020) to hard rock construction aggregates at a regional scale was to evaluate whether the UNFC can be applied as-is, i.e. with as few changes as possible, in order to maintain compatibility with the traditional project-specific (often site-scale) classification approach. For this regional scale approach, the generic UNFC template was interpreted as shown in Table 5. Since the UNFC was primarily designed to categorise project, it needs to be considered whether a regional-scale application needs additional clarifications or further specifications for certain sub-categories. Table 5 includes some comments in brackets to indicate where classification along the E-F-G axes was seen as uncertain or subject to interpretation, and where a need for further definition or refinement of the generic sub-categories may exist.

Table 5: UNFC definition of classes, adapted from Figure 3 in UNECE (2020) with modifications in brown font.

UNFC Classes and Sub-classes defined by Sub-categories[a]

UNFC Classes Defined by Categories and Sub-categories							
Total Products	Produced	Sold or used production					
		Production which is unused or consumed in operations					
		Class	Sub-class	Hard Rock Aggregates (NO)	Categories E	Categories F	Categories G
	Known Sources	Viable Projects	On Production	Permitted Active Quarry Operation	1	1.1	1, 2, 3
			Approved for Development	Permitted for Development	1	1.2	1, 2, 3
			Justified for Development	Investigation Area under Development	1	1.3	1, 2, 3
		Potentially Viable Projects	Development Pending	Designated Mining Area	2[b]	2.1	1, 2, 3
			Development On Hold	Investigation Area On Hold	2	2.2	1, 2, 3
		Non-Viable Projects	Development Unclarified	Unused Proven Resource, Mineral Awareness Zones	3.2	2.2	1, 2, 3
			Development Not Viable	Proven Resource 'Sterilised' by Competing Use Claims	3.3	2.3[c]	1, 2, 3
		Remaining products not developed from identified projects		Proven Resources Currently Not Developed	3.3	4	1, 2, 3
	Potential Sources	Prospective Projects	Prospect	Indicated Resource	3.2	3.1-3.3	2, 3, 4
			Early Exploration	Inferred Resource	3.2	3.2-3.3	3, 4
			Exploration Not Viable[d]	Prospective Resources 'Sterilised' by Competing Use Claims	3.3	3.1-3.3	3, 4
		Remaining products not developed from prospective projects		Remaining Quantities with No Development Project	3.3	4, 4.3[e]	3,4

a. Refer also to the notes for Figure 2 in UNECE (2020).

b. Development Pending Projects may satisfy the requirements for E1.

c. Development Not Viable Projects may satisfy this broader F2.3 definition: There are no plans to develop or to acquire additional data at the current time ~~due to limited potential~~. Cf. Abbreviated UNFC Figure 2, footnote f: 'Non-Viable Projects include those that are at an early stage of evaluation in addition to those that are considered unlikely to become viable developments within the foreseeable future.'

d. Exploration Not Viable Quantities include those that may be technically feasible but are considered unlikely to become viable developments within the foreseeable future due to known or inferred environmental-socio-economic constraints.

e. Potential Sources may also satisfy this broader F4.3 definition: The F4.3 Subcategory is specified as follows: The technology is not currently under research or development *and/or at the earliest stage of studies, where it may be inferred from regional studies that there are no favourable conditions for potential development in an area (modifications in italic).*

Following UNFC sections (UNECE 2020) are particularly relevant for this pilot case study:

Part II, IV generic specifications:

H. Distinction between E1, E2 and E3

"[…] The Environmental-socio-economic axis Categories encompass the non-technical issues that directly impact the viability of a project, including product prices, costs, legal/fiscal framework, environmental regulations and known environmental or social impediments, barriers or benefits."

"[…] Where development or operation activities are suspended, but there are "reasonable prospects for environmentally, socially and economically viable production in the foreseeable future", the project shall be reclassified from E1 to E2. Where "reasonable prospects for environmentally, socially and economically viable production in the foreseeable future" cannot be demonstrated, the project shall be reclassified from E1 to E3."

guidelines from Annex III:

(b) Potentially Viable Projects

Development Pending *is limited to those projects that are actively subject to project-specific technical activities, such as acquisition of additional data (e.g. appraisal drilling) or the completion of project feasibility studies and associated socio, environmental and economic analyses designed to confirm project viability and/or to determine the optimum development scenario. In addition, it may include projects that have non- technical contingencies, provided these contingencies are currently being actively pursued by the developers and are expected to be resolved positively within a reasonable time frame. Such projects would be expected to have a high probability of achieving viability.*

Development On Hold *is used where a project is considered to have at least a reasonable chance of achieving viability (i.e. there are reasonable prospects for eventual economic production), but where there are currently major non-technical contingencies (e.g. environmental or social issues) that need to be resolved before the project can move towards development. The primary difference between Development Pending and Development On Hold is that in the former case the only significant contingencies are ones that can be, and are being, directly influenced by the developers (e.g. through negotiations), whereas in the latter case the primary contingencies are subject to the decisions of others over which the developers have little or no direct influence and both the outcome and the timing of those decisions is subject to significant uncertainty.*

(c) Non-Viable Projects

Development Unclarified *is appropriate for projects that are still in the early stages of technical and environmental-socio-economic evaluation (e.g. a recent new discovery), and/or where significant further data acquisition will be required, in order to make a meaningful assessment of the potential for a viable development, i.e. there is currently insufficient basis for concluding that there are reasonable prospects for eventual viable production.*

Development not Viable *is used where a technically feasible project can be identified, but it has been assessed as being of insufficient potential to warrant any further data acquisition activities or any direct efforts to remove contingencies. In such cases, it can be helpful to identify and record these quantities so that the potential for a viable development opportunity will be recognized in the event of a major change in technology or environmental-socio-economic conditions.*

Result of UNFC application

The 3D physical system boundaries for the UNFC case study are defined by the georeferenced 'UNFC Jelsa pilot area' perimeter (Figure 2), as well as by the topography (DEM) and sea level as upper and lower bounding surfaces. The reporting date is 16.03.2021. The UNFC classification results shown in Table 6 follow the UNFC definitions of Table 5 and use the volumes of the different geological units as shown in Table 4. The total volume of the prospective area (3895 Mm^3) includes the volume of the prospect area (553 Mm^3), but not that of the concession area (excluded because annually reported data are not disclosed) and conflict areas (1178 Mm^3, excluded because that volume is not considered to be prospective). The rock quality index was used as an indicator for the technical feasibility of producing aggregates with satisfactory product quality (physical constraints of in-situ geology).

Both the metadacite and granodiorite fulfil the described technical product quality requirements (very good and good rock quality index), and technical feasibility has been demonstrated by the ongoing extraction of the granodiorite in the Berakvam concession area, which is categorised as "On production" (1.1,1,1). Note that detailed data were not available for verification and quantification and that any remote-sensing-based calculation of remaining material volumes would need to consider the surveying date of the digital elevation model (here 2017), the volume reduction by extraction during the timespan from surveying to UNFC reporting (here 16.03.2021), and also public zoning plans.

The metadacite and granodiorite portions in the conflict-free 'prospect area' are categorised as "Development on hold" (2,2.2,3) since technical feasibility is assumed but there may be significant non-technical contingencies. Poor quality material in the prospect area has a lower probability of being developed and is categorised as "Development unclarified" (3.2,2.2,3) because evaluation is at a too early stage to determine environmental-socioeconomic viability. Note that this does preclude that potential development of the 'poor quality' material in this area cannot be viable, for example for applications that have lower quality requirements than asphalt road surfacing.

Categorisation of the volumes in the 'prospective area' builds on similar justifications. Higher quality material in the prospective (i.e. potentially accessible and presumably conflict-free) area is categorised as UNFC (3.2,3.3,4.3). E3.2 is used because "environmental-socio-economic viability cannot yet be determined due to insufficient information" (cf. Annex I, E Axis explanations for E3) and F3.3 because "favourable conditions for the potential development in an area may be inferred from regional studies." Given the clustering of mapping and sampling around the existing concession and possible prospect areas, there is lower confidence for the material properties and geological homogeneity of inferred for the significantly more expansive entire prospective area (G4), and the volume estimate here comprises the total volume down to sea level as described before (G4.3). For the poorer quality material "Remaining products not developed from prospective projects" (3.3,4.3,4) is used, assuming a "lack of reasonable prospects for environmental-socio-economic viability in the foreseeable future" E3.3 , a modified F4.3 "The technology is not currently under research or development *and/or at the earliest stage of studies, where it may be inferred from regional studies that there are no favourable conditions for potential development in an area.*" to capture the inferred limited potential, and G4.3.

For the conflict area's "Exploration not viable" (3.3,3.3,4.3) categorisation, it is "currently considered that there are no reasonable prospects for environmental-socio-economic viability in the foreseeable future" E3.3. It can be inferred from the regional study that production of high-quality aggregates from the 'very good' and 'good' material may be feasible, thus F3.3, and similar to before G4.3. The poor quality material in the conflict area is categorised as E3.3., modified F4.3 to capture the inferred limited potential, and G4.3.

Note that for any industry project seeking development in the UNFC pilot case study area investigated here, the appropriate site investigations and permitting procedures would still be needed.

Table 6: UNFC classification according to geological certainty, material quality and assumed conflict level, for the given UNFC case study perimeter area and reporting date 16.03.2021. The prospective area volumes include the prospect area volumes, but not the conflict and concession area volumes. All numbers in Mio. m^3 (Mm3).

UNFC Pilot Case Study Area	UNFC Sub-class	E	F	G	Rock Quality Index			Total
					Very good	Good	Poor	
Concession area	On production	1.1 [a]	1.1 [a]	1 [a]	Relevant data reported to DMF annually, but not published.			**N/A**
Prospect area	Development on hold	2	2.2	3	39	489		**553**
	Development Unclarified	3.2	2.2	3			24	
Prospective area	Early Exploration	3.2	3.3	4.3	126	870		**3895**
	Remaining Quantities with No Development Project	3.3	4.3 [b]	4.3			2'899	
Conflict area	Exploration Not Viable	3.3	3.3	4.3	148	525		**1'178**
	Remaining Quantities with No Development Project	3.3	4.3 [b]	4.3			505	

[a] Data are assumed to be sufficient for documenting the EFG categories of industry operations with 'production currently taking place', but were not available for verification.

[b] The F4.3 Subcategory is specified as follows: The technology is not currently under research or development *and/or at the earliest stage of studies, where it may be inferred from regional studies that there are no favourable conditions for potential development in an area (modifications in italic).*

Discussion of results and challenges

This pilot case study demonstrates that the UNFC can be applied and is well suited for assessing and reporting resources of hard rock construction aggregates at a regional scale (hypothesis 1 confirmed). The GIS workflow for such a regional assessment can be largely automated, provided the spatial datasets are available in suitable format, and that they are ranked according to their importance/non-repudiability. Only minor clarifications or rewording of some Sub-Category Definitions may be needed (hypothesis 2 confirmed), particularly to facilitate the consistent reporting of quantities that have *known, inferred, or unknown* F-axis conditions (cf. F2.3, F3.3. and F4.3).

Generally, the regional application of UNFC for hard rock construction aggregates remains challenging for three reasons: First, targeted data collection and mechanical testing for rock quality assessments are both labour and capital intensive, as they involve time-consuming field mapping and sampling, and expensive laboratory equipment and routines for mechanical testing and petrographic analysis. Second, additional datasets from different stakeholders and institutions are needed for assessing the technical feasibility and environmental-socio-economic viability, and such datasets must be obtained through collaboration or specifically prepared and if they are not available in a useful format. Third, the application of UNFC requires significant expert know-how, an adequate degree of geological knowledge of the area in question, professional expertise with the type of resource under investigation, a fair level of GIS/data modelling/3D-software skills for data processing and volume calculation, and experience with the UNFC classification system. Detailed discussions follow below:

Allocation of capital and labour. Field mapping, sampling and mechanical testing for hard rock aggregates require comprehensive logistics. At NGU, each rock sample for mechanical analysis consists of 60 kg of fragmented fresh rock material that is typically excavated by blasting and needs to be collected and transported to NGU's mechanical testing laboratory in Trondheim. During field visits, teams of two NGU geologists survey the sampling site and collect samples, mostly from existing quarries, road cuts, or groundwork excavations that provide easy road or water access. Sampling in more remote areas requires special transport such as ATVs or helicopters and is usually only warranted in combination with co-funding by industry projects. Mechanical testing and petrographic analysis in NGU's testing facilities are equally expensive and time consuming, and running a single mechanical sample through NGU's testing protocol often takes more than a full day of laboratory work. Without additional financing through industry development projects, GSOs have limited funding for collecting new data and must rely mainly on pre-existing data with coarse resolution. Any regional analyses will therefore have a high uncertainty and be indicative at best.

Data availability and collaboration. Different datasets are needed to evaluate the three fundamental UNFC criteria at a regional scale. GSOs typically have the national mandate to collect, maintain and publish the required regional scale pre-commercial geological maps and data. NGU also has laboratory facilities that can be used for certifying rock quality parameters at the resolution required for commercial site-scale industry resource assessments, but latter are typically not part of the NGU's mandate if they can be prepared by private actors. Data from local or regional spatial planning authorities, as well as national-scale datasets on environmental protection, infrastructure-, transportation- and utility networks are particularly relevant for regional application of UNFC. To what degree these data correspond to *de facto* mining bans, and whether they should be considered for regional UNFC analyses, needs to be established though a dialogue with the issuing organisations. For this case study, for instance, municipal zoning plans were only available as PDF reports and not as GIS datasets, which made it impossible to accurately delineate the spatial boundary and calculate the exact volume of the regulated Berakvam extraction area. Generally, confidentiality issues may impede full-coverage regional UNFC application. The Norwegian Minerals Act (The Norwegian Government 2009; Norwegian Ministry of Trade 2011) requires annual industry reporting to The Norwegian Directorate of Mining with the Commissioner of Mines at Svalbard (DMF). DMF thus collects annual production as well as resource and reserve quantities but data are not published on a per-site level. Without these numbers, it is not possible to prepare consistent full-spatial-coverage UNFC studies at regional scale.

Knowledge and skills requirements. The level of geological knowledge required for construction aggregates quality assessments varies with the scale of investigation. Assessments at a regional (1:50'000) scale may associate two or three mechanical test samples to one very large area, and mechanical test results should, at best, be interpreted as 'potential quality' indicators. Site-scale project assessments require additional data such as detailed geological maps, higher density field sampling, and additional drill cores that confirm the geological geometries and rock quality at depth. Local geological parameters need to be considered already when planning rock quality assessment, as some rock types such as slate, mica-schist, or phyllites are unlikely to be suitable for hard rock aggregates production and would typically not be tested to save costs. Other rock types such as gneisses may be suitable but can be inhomogeneous, requiring denser mechanical sampling to confirm that quality requirements are met. In addition to geological expertise, a certifiable standardised testing routine, GIS & 3D modelling skills, and UNFC competence are required. GSOs are likely best suited to conduct regional UNFC assessments such as the one tested in this pilot case study because they have the required geological data, knowledge and skills at their disposal, and they can use synergies with other government institutions that need to provide the missing information on the UNFC E and F axes.

General comments on the regional scale application of UNFC

A key aim of national mineral accounting is to provide a consistent inventory of the national mineral endowment. For this, in-ground geological resources (i.e. material stocks) and mine production (i.e. material flows) need to be linked such that geological stock changes can be mass-balanced over time. Accordingly, the 'Total Products' of UNFC inventories (UNECE 2020) comprise both the categorised in-ground quantities and the 'Produced' quantities that can be further subdivided into 'Sold or used production' and 'Production which is unused or consumed in operations'. How 'Produced' quantities may be linked with in-ground stocks in an UNFC inventory is explained by Lax *et al.* (2017) and further illustrated by Blystad *et al.* (2020). However, this procedure explicitly assumes that both in-ground and production quantities are reported for at the site-scale well-defined industry projects. In contrast, regional approaches cover larger areas that may include several industry projects, or none at all. To integrate the two approaches, project-specific numbers need to be treated as seamless part of regional scale geological models/GIS data inventories (i.e. geological 'stock' inventories).

In Norway, regional integration poses different challenges: (1) some data are only partially reported (e.g. reporting of excavation by the construction industry, such as from tunnelling activity is not mandatory), (2) the data needed for evaluating the three UNFC axes are distributed across different government organisations (e.g. NGU for geological data, and DMF for licensing and production data, local authorities for spatial plans), and (3) some data are inaccessible (e.g. industry production data are reported to DMF but not published). This demonstrates that the data and responsibilities for UNFC classification and national resource accounting in Norway are distributed across stakeholders.

Overall, a regional-scale UNFC approach appears to be both feasible and useful to identify, indicate, and quantify mineral occurrences that may be of interest for further investigation, and also to indicate which portions of the total 3D volume are thought to have limited potential for further development. Under the current circumstances it appears unlikely that any one organisation in Norway can tackle the challenge of integrated national UNFC accounting all by itself. Collaboration between different government bodies seems to be a prerequisite for national-scale UNFC application, and public-private partnerships and more open data exchange between industry and government are a must. The United Nations Environment Assembly (2019) explicitly highlights the need for more accountability, transparency and knowledge sharing in its joint Resolution on Mineral Resource Governance, and we expect it to be of mutual benefit for both industry and government to implement better data sharing workflows and establish a dialogue that helps safeguard prospective mining areas for future extraction.

Based on the lessons learnt from this pilot case study it can be recommended that a permanent task force or network of experts is created that have the national mandate to (1) develop guidelines for how to compile regional scale geological volume calculations and how to categorise and report associated UNFC quantities; (2) establish contact with the organisations and government authorities responsible for the different environmental-socio-economic datasets in order to make them accessible in GIS format, and discuss how to list, rank and prioritise potential mining restrictions according to their non-repudiability; (3) create, test, and publish GIS & 3D assessment workflows that can be adapted and automated, and lastly (4) to investigate how to implement the UNFC as a national tool to support public-private partnerships, knowledge sharing and sustainable mineral resource governance.

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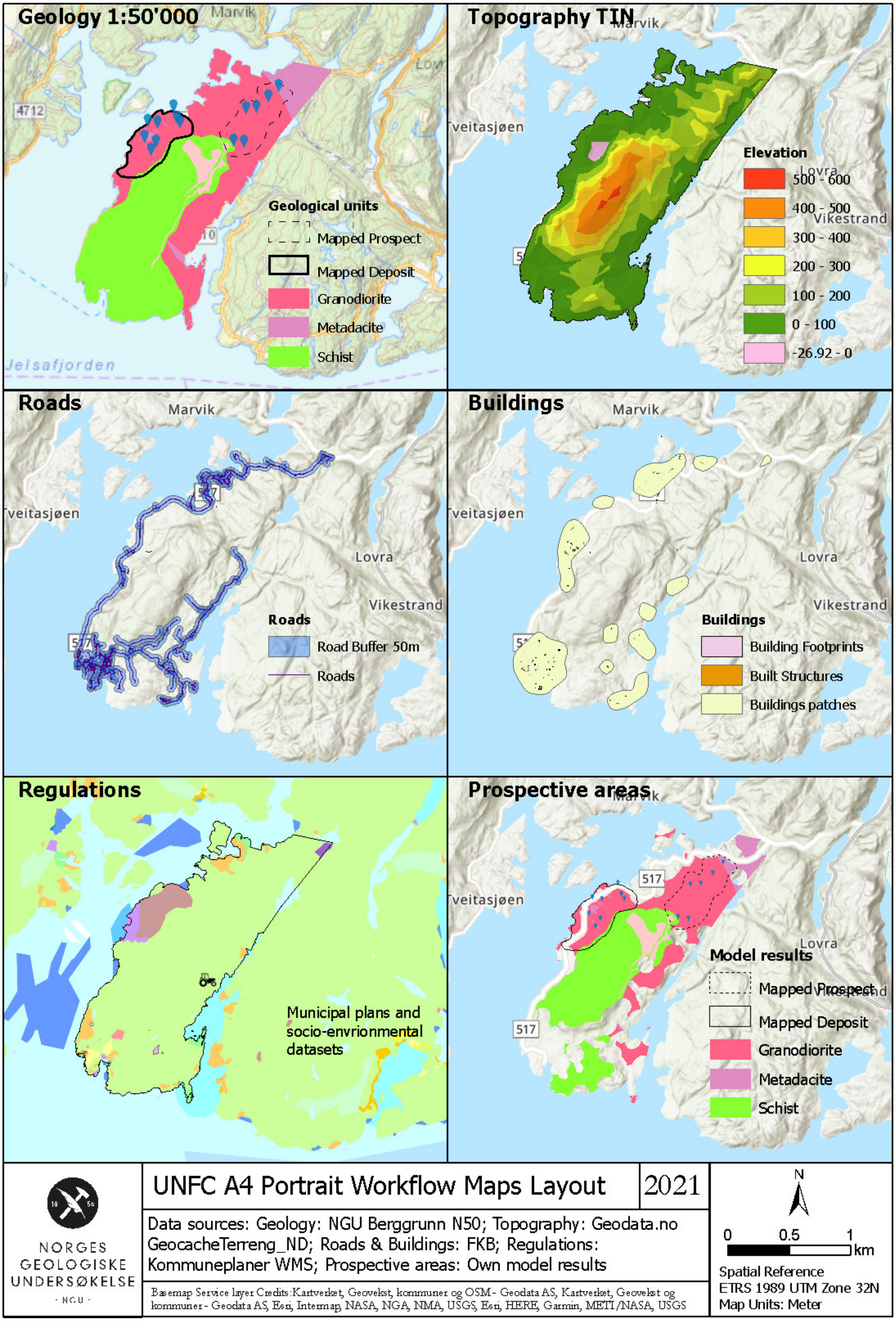
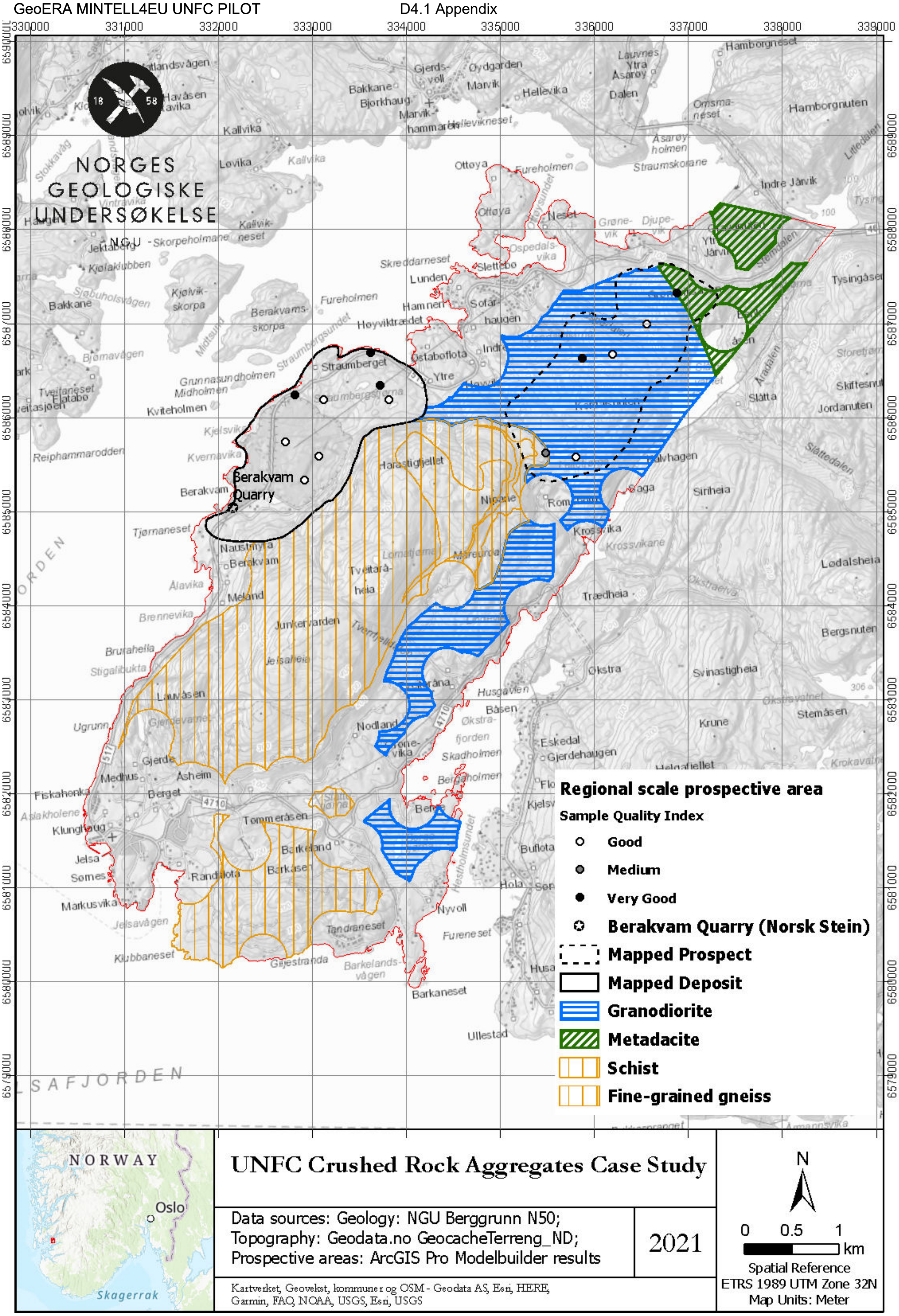
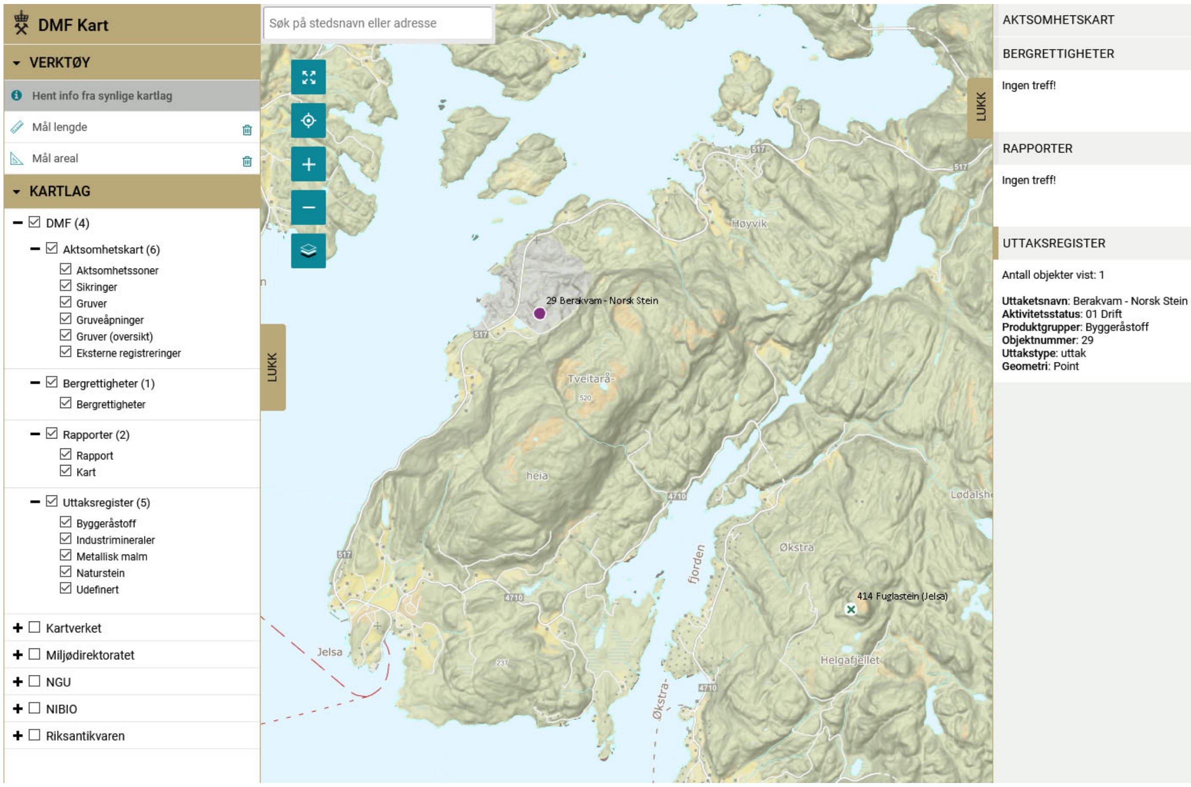


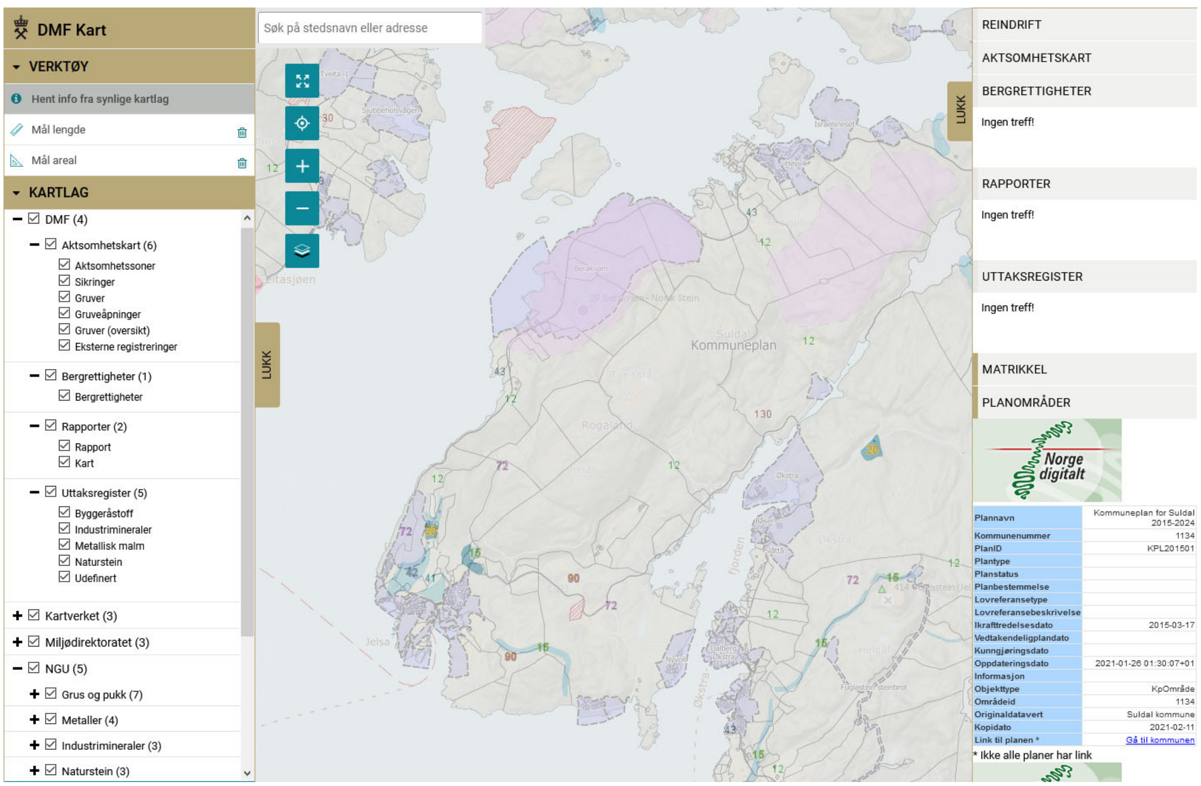
Appendix Figure 1: Compilation of data sources and analysis workflow results for the regional scale UNFC aggregates study.



Appendix Figure 2: Map of the geological units within the presumably conflict-free prospective area.



Appendix Figure 3: Screenshot of the data published by the Norwegian Directorate of Mining (https://minit.dirmin.no/kart/#) for licensed mining operations showing the (1) GIS location (point data only, cf. symbol on map) and the associated publicly available attribute information ('Uttaksregister' on the right, with site name 'Berakvam – Norsk Stein', status '01 In Operation', product group 'construction minerals', and type of operation 'extraction').



Appendix Figure 4: Screenshot of the online map of the Norwegian Directorate of Mining (https://minit.dirmin.no/kart/#) showing data layers provided by other institutions such as NGU (mineral occurrence polygons) and municipal planning authorities (right side link to PDF documents).

Appendix Table 1: As shown in Figure 2 in UNECE (2020), 'Sold or used production' and 'Production which is unused or consumed in operation' are part of the 'Total Products', as are also the 'Remaining products not developed from prospective projects'. For mass balance consistent material accounting these numbers also need to be publicly available such that they can be used for the required calculations.

Abbreviated Version of UNFC, showing Primary Classes

Total Products	**Produced**	**Sold or used production**			
		Production which is unused or consumed in operations[a]			
		Class	**Minimum Categories**		
			E	**F**	**G**[b]
	The project's environmental-socio-economic viability and technical feasibility has been confirmed	Viable Projects[c]	1	1	1, 2, 3
	The project's environmental-socio-economic viability and/or technical feasibility has yet to be confirmed	Potentially Viable Projects[d]	2[e]	2	1, 2, 3
		Non-Viable Projects[f]	3	2	1, 2, 3
	Remaining products not developed from identified projects[g]		3	4	1, 2, 3
	There is insufficient information on the source to assess the project's environmental-socio-economic viability and technical feasibility	Prospective Projects	3	3	4
	Remaining products not developed from prospective projects[g]		3	4	4

a. Future production that is either unused or consumed in the project operations is categorized as E3.1. These can exist for all classes of recoverable quantities.

b. G categories may be used discretely, or in cumulative scenario form (e.g. G1+G2).

c. Estimates associated with Viable Projects are defined in many classification systems as Reserves, but there are some material differences between the specific definitions that are applied within different industries and hence the term is not usedhere.

d. Not all Potentially Viable Projects will be developed.

e. Potentially Viable Projects may satisfy the requirements for E1.

f. Non-Viable Projects include those that are at an early stage of evaluation in addition to those that are considered unlikely to become viable developments within the foreseeable future.

g. Remaining products not developed from identified projects or prospective projects may become developable in the future as technological or environmental-socio-economic conditions change. Some or all of these estimates may never be developed due to physical and/or environmental-socio-economic constraints. This classification may be of less value to renewable resource projects but can still be used to indicate the amount of unrealized potential. It is emphasised that the remaining products are quantities which, if produced, could be bought, sold or used (i.e. electricity, heat, etc., not wind, solar irradiation, etc.).

UNFC Case study – A case study on Graphite

Introduction/Background

Define the resource

This case study was done on flake graphite deposits, and examines the Trælen deposit (active mine, Skaland Graphite AS) and the Bukkemoen deposit on Senja peninsula, in Troms county in Northern Norway (Figure 1). In addition, UNFC classification was applied for 24 graphite deposits (Table 3). All of the graphite occurrences are found in supracrustal granulite facies rocks of Archaean to Proterozoic age, comprising quartzites, migmatitic gneisses, iron formations, calcsilicates and graphite schist.

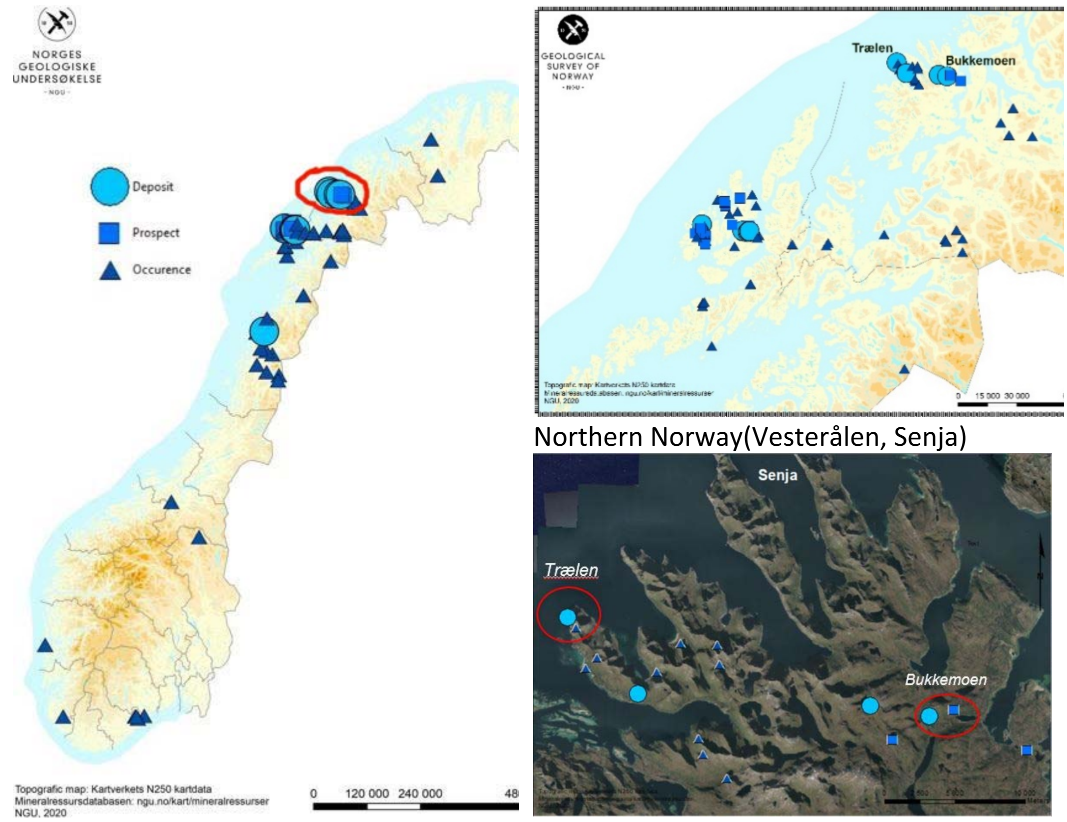


Figure 1 . Graphite occurrences in Norway, northern Norway (Vesterålen and Senja)

The Skaland mine has been in operation since 1922, producing about 10,000 tonnes per year with an average grade of about 30% TC. The Skaland mine was exhausted and closed in 2006.
From 2006 the mine at Trælen, 8 km north from the Skaland mine, have been active. This is the world's richest flake graphite mine in current operation.
In 2019 Skaland graphite mine AS was bought by the Australian company Mineral Commodities Ltd.

Bukkemoen graphite flake deposit is located approximately 20 km southeast from existing Skaland graphite operations. It comprises the largest continuous geophysical helicopter-borne anomaly known to be associated with graphite in Scandinavia. The geophysical anomaly is divided into three parts: Bukkemoen to the south, Bukken to the north and Litjkollen to the east.

Methodology

Bridging from CRIRCSO-compliant data is used for Trælen deposit, since it had JORC compliant resource estimates. Other graphite deposits in Norway are not classified by CRIRCSO.

Different available data sources are used to gather data and to define E, F axis, such as the Norwegian Water Resources and Energy Directorate https://www.nve.no/, the Directorate of mining https://dirmin.no/, and maps from https://www.nordatlas.no/ and https://kommunekart.com/ . For the Trælen deposit, available data from the company website of Mineral Commodities Ltd website *www.mineralcommodities.com/* is used.

Since 2015 and 2018 NGU has conducted detailed investigation employing different geological and geophysical methods to define mineral deposits in Northern Norway (Vesterålen and Senja). The following methods and data are used to define mineralized areas: Geophysical methods/Helicopter-borne electromagnetic (HEM), Charged Potential (CP), Self Potential (SP), 2D Resistivity (also called ERT), Induced Polarization (IP), Ground conductivity meter Geonics EM31 (Geonics 1984), Geological methods/Geological mapping, Structural analysis, Sampling, Chemical analyses TC, TS, Geological drilling. Results of the investigation have been outlined in reports and manuscript which can be found at the Geological Survey of Norways website. Geophysical data can be downloaded here http://geo.ngu.no/mapserver/GeofysikkWMS2. Reports can be downloaded from: Litteratursøk | Norges geologiske undersøkelse (ngu.no)

UNFC

For the Trælen deposit the company Mineral Commodities Ltd had access to 133 drill holes, 15.5 km drill core in total and 1245 analysed drill samples. Resources are classified by JORC as Indicated 106 000 t contained graphite and Inferred 291 000 t contained graphite resources. Based on that data and by using bridging from CRIRCSO-compliant data, G axis is classified as G3-G2. Since the Trælen is the world’s richest flake graphite mine in current operation, one can say that it shold be clasified as G1 by default, but the data on mineral reserves are not available. The Trælen deposit is located 8 km from the existing Skaland processing plant infrastructure. The mine has been in production for many years. Mineral Commodities Ltd company has commented on the following in the maiden JORC resource estimation, for the Skaland graphite project :
Mineral tenement and land tenure status/’ ‘The Skaland Graphite AS operating license for the Trælen Mine was renewed on 28 May 2019 for a duration of 10 years. To the knowledge of WAI, all licenses and permits are in good standing with no known impediments.’
Environmental factors or assumptions/’ WAI understands that all necessary environmental permits required to operate the mine and process plant are in place’(www.mineralcommodities.com/).

The proposal for UNFC classification for Trælen deposit is E1 F1 G1,2,3.

Regarding the Bukkemoen deposit, Norwegian geological survey (NGU) has employed different geological and geophysical methods (2015-2018). The main goal was to ground through resistivity anomalies discovered by a helicopter-borne geophysical survey during the project - Minerals in Northern Norway (2012-2014), funded by the Norwegian government (Figure 2). Fiftyone samples have been collected and analysed, with an average of 5% total carbon (TC%) and the maximum content of total carbon (TC) is 19,7%. Two drill cores have been drilled, to the depth of around 40m, and 20 drill samples have been analysed with total carbon (TC) from 3- to 5%.

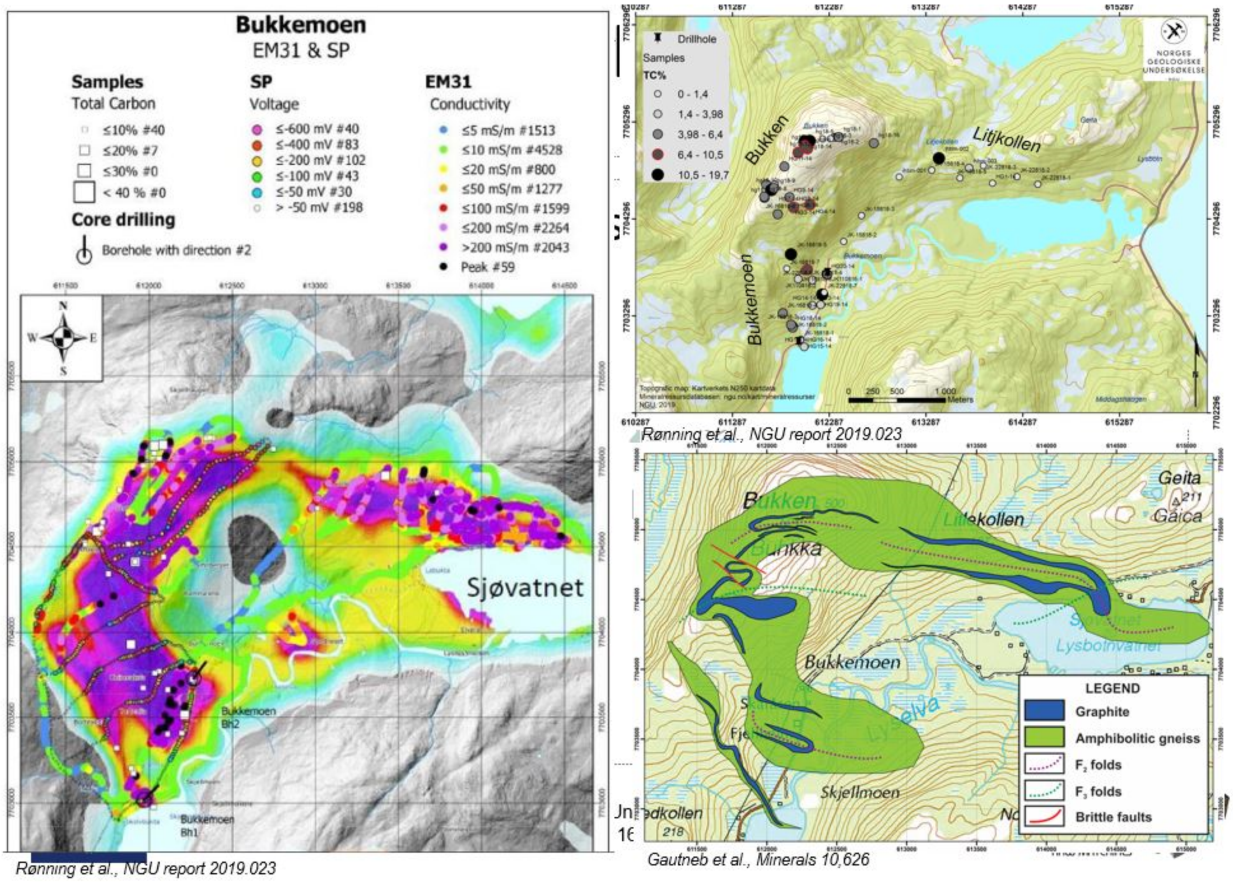


Figure 2: 1. Self-potential, EM31 conductivity apparent resistivity (7 kHz, from Rodionov et al. 2014; (Rønning et al., NGU report 2019.023), 2. analyzed samples, drillcores (Rønning et al., NGU report 2019.023), 3. structural mapping (Gautneb et al., Minerals 10.626)

Bukkemoen is devided in 3 graphite anomalies and sublocalities within the deposit, defined by geophysics and geological mapping. The total extentof the deposit 5.3 km x 0.6 km (included marine area in Sjøvatnet), Bukkemoen 0.5 km x 0.5 km, Bukken 1.5 km x 0.4 km, Litjkollen 1.6 km x 0.35 km. Variations in total carbon (TC%) and contained graphite are presented in Table 1 and Table 2.

Table 1 Variation in total carbon at Bukkemoen, Senja

Variation in TC Area/Sub-area	No. of samples	Average (%)	Max (%)	Min (%)	StdDev (%)	Median (%)
Bukkemoen						
Bukkemoen	20	5.2	14.1	2.2	3.3	4.0
Bukken	27	6.5	19.7	0.6	4.5	5.0
Litjkollen	4	5.3	16.3	0.6	7.4	2.1

Table 2 Tonnage and Contained graphite, Bukkemoen, Senja

Occurrence Name	% TC	Tonnage (Mt)	Contained Graphite (Mt)
Bukken	6,5	51,03	3,34
Litjkollen	5,3	34,54	1,83

Depth of the deposit is extrapolated down to 100 m. Volume estimation for Bukken is 3,34 Mt of contained graphite and for Litkjollen 1,83 Mt**. The G axis is classified as G3**. This area should be explored further, and detailed ground geophysics and deeper core drilling is recommended in all three areas (Rønning et al.,2019b).

Bukkemoen deposit is located approximately 20 km southeast from the existing Skaland graphite operations. The Mineral commodities Ltd company has signed a landowner agreement to explore the Bukkemoen graphite prospect, with exploration rights for 10 years. Our suggestion for F axis is therfore F 3.1- *Site-specific studies have identified a potential development with sufficient confidence to warrant further testing.* Bukkemoen area is in a reindeer grazing area and is about 5 km from a nature reservation area. The nature reservation area and reindeer grazing areas are not in conflict with the mineral deposit, but in the the Bukkemoen area, landslides might occur according to the The Norwegian Water Resources and Energy Directorate (NVE).

A proposal for the E axis is E3.2-*Environmental-socio-economic viability can not yet be determined due to insufficient information.*

The final UNFC classification proposal for Bukkemoen deposit is therefore E 3.2 F 3.1 G 3

UNFC classification have been applied on all graphite deposits in Norway (Table 1). We have used a combination of airborne and ground geophysics to estimate the dimensions of the mineralized areas, combined with sampling and analysis of the graphite content. For volume calculation the following have been used: L = length of mineralized zones in meters (from airborne and ground geophysics), W = average apparent width (m) of graphite zones (from EM31, drilling and observations), α = average dip in degrees from field observations (used to calculate real width). NGU do not have access to drilling data for almost of the graphite deposits, thus we have considered that the mineralization continues 100 m down the dip, the volume (V) of each occurrence would be: $V = L\ W\ (\sin(\alpha))\ 100$. The amount of contained graphite (Cg) is calculated as: Cg = V ρ (%TC); (ρ)= 2437 kg/m^{3} is the average density from petrophysical measurements, % TC is the average total carbon for each deposit. The depth of deposit is not measured, it is extrapolated down to 100m for all deposits, so a volume estimation has a low confidence level. See Rønning et al., 2019a; Rønning et al., 2019b; Gautneb et al., 2020 for details.

Table 3 UNFC applied to graphite deposits (from Gautneb et al., 2020)

Deposit/company name	Average TC	Tonnage (Mt)	Contained graphite (Mt)	E	F	G
Trælen*	22	1,785	0,4	1	1	1+2+3
Jennestad	9,6	3,44	0,33	2	3	2
Rendalsvik	11,1	1,9	0,21	3	3	2
Bukken area	6,5	51,03	3,34	3,2	3	3
Litljkollen	5,3	34,54	1,83	3,2	3,1	3
Vardfjellet	9,2	12,84	1,18	3	3,3	3
Grunnvåg	5,2	22,77	1,19	3	4	3
Smines	7,1	18,89	1,34	3	4	3
Nord-Værnes	4,1	0,6	0,02	3	4	3
Sommarland	12,5	0,85	0,11	3	4,1	3
Brenna	10,1	7,94	0,8	3	4,1	3
Skogsøya	20	1,42	0,28	3	4,1	3
Evassåsen	7,6	2,12	0,16	3	4,1	3
Vikeid Central	13,8	8,89	1,23	3	4,1	3
Vikeid West	11,3	29,63	3,35	3	4,1	3
Ånstad	36,8	0,21	0,08	3	4,1	3
Alsvåg	8,9	0,25	0,02	3	4,1	3
Instøya	9,3	14,82	1,38	3	4,1	3
Rødhamran	14,8	1,38	0,2	3	4,1	3
Romset	14,7	9,63	1,42	3	4,1	3
Hesten	5,8	2,07	0,12	3	4,2	3
Haugsnes	16,2	8,4	1,36	3	4,2	3
Møkland	13,2	3,4	0,45	3	4,2	3
Svinøya	11,7	0,17	0,02	3	4	3

*Based on company information (Minerals Commodity ltd 2020)

Challenges

It has been challenging to find data for E and F axis and to find data for land use. This is because, E and F data is collected in a more systematic way only in the early stages where mining are planned. In most places geological information is also limited for most early-stage exploration projects. Another challenge was to find good examples on how to apply UNFC codes and how to get more accurate depth and volume estimation for occurrences with less geological data.

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UNFC Case study – larvikite ornamental stone resources

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Innhold

Introduction

The term 'Larvikite' is applied for a range of peculiar monzonitic rocks within the southern part of the Carboniferous-Permian Oslo Igneous Province (Figure 1). They have for more than a hundred years been appreciated as one of the world's most attractive ornamental stones, and at present, its production and use is more extensive than ever. The main reason for the continuous success of larvikite on the world market is the blue iridescence displayed on polished surfaces, which is caused by optical interference in microscopic lamellae within the ternary feldspars.

The name 'larvikite' was first applied by the geologist Waldemar Christopher Brøgger (1852–1940). The name has its origin in the small coastal town of Larvik, situated almost right in the centre of the main plutonic complex of larvikite.

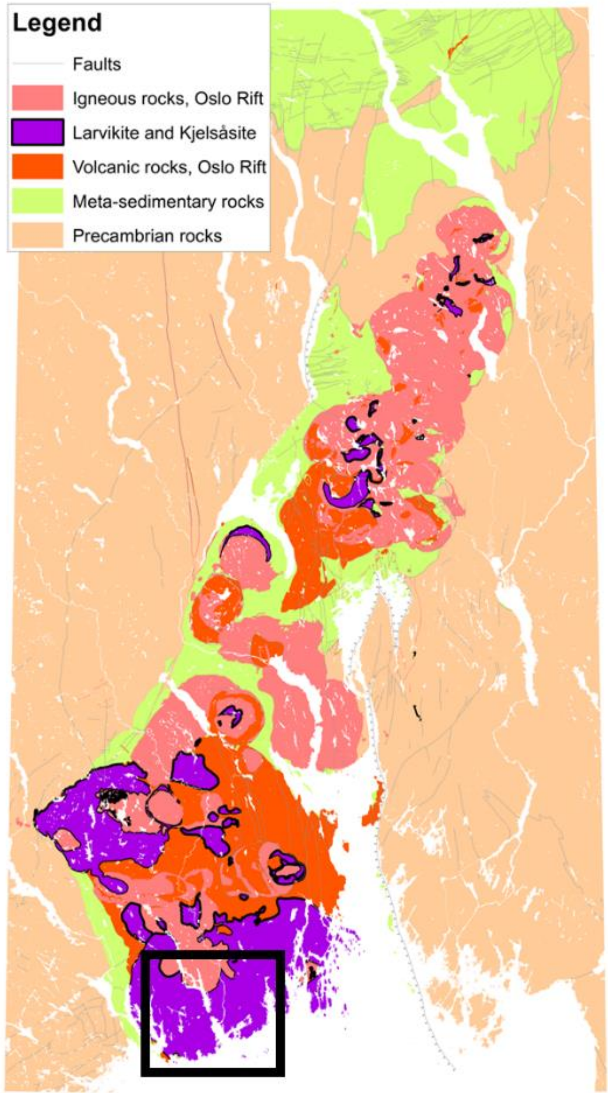

Figure 1. The Oslo rift and studied area (black rectangle).

The first recorded use of larvikite as dimension and ornamental stone dates back to the 12th century (Fig. 7). Many of the stone churches in the region are made of larvikite. It took several hundred years until larvikite again came on the agenda. In the 18th century, the Danish-Norwegian king initiated a hunt for ornamental stones – or 'beautiful marbles' – in Norway (Jansen & Heldal 2003). The iridescent larvikite was known to scholars at that time. However, the Napoleonic wars did put a preliminary end to such dreams, and modern period exploitation did not start until around 1820, remaining small scaled until the late 19th century (Børresen & Heldal 2009).

From about 1875 to 1895, Norway suffered an economic depression, which among other things led to a massive emigration, first of all to the USA. But this was also a time for exploring new opportunities, among those extraction and export of larvikite blocks. In 1886, larvikite won a gold medal at the world exhibition in Liverpool (Oxaal 1916). Since then, larvikite production for export has remained a significant industry in the area. The application of the stone all over the globe and the annual output of stone is comparable with other high-profiled stone quarry areas of the world, such as the Carrara marble.

Defining resources of larvikite

Primary larvikite production is mainly about extracting rectangular blocks of homogenous and high quality. The quality (and thus, market price) depends on the following factors:

- Technically homogenous rock (wide spacing of primary fractures and joints in the rock mass for achieving large blocks)
- Visually homogenous rock (little variations within the raw block)
- Type of larvikite (some gain higher market price than others)

A crude division of larvikite types are shown in Figure 2. More information can be found in Heldal et al. 1999, 2008, 2014 and Kjølle et al. 2003.

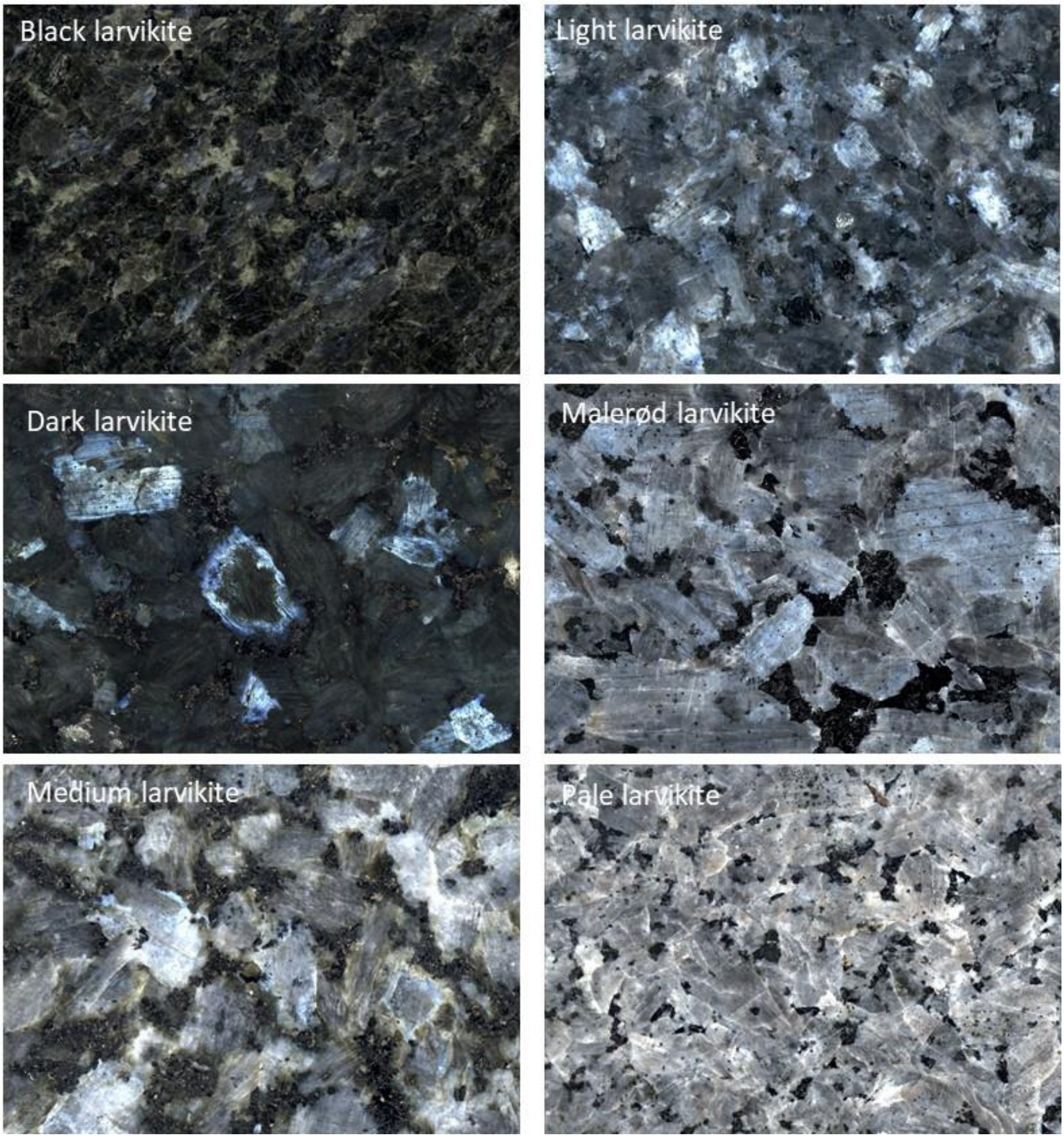

Figure 2. Six types of larvikite, as used in the further text and tables. Polished slabs, each approximately 15 cm wide. Black and pale larvikite are at present time not produced

Black larvikite: more fine-grained than the other types, dark colour with blue schiller. Mainly applied for outdoor applications. At the time of writing, there is no production, but regulations as a legal extraction site is still valid.

Dark larvikite: classic, dark larvikite with blue schiller that has been produced for almost 140 years, mostly known as “Emerald Pearl” (Figure 3). Several quarries and large production site in the eastern part of Larvik.

Figure 3. Larvikite often associates to exclusiveness and fashion.

Medium larvikite: Large grain larvikite medium grey, with blue schiller. There has most likely been production of this type since around 1900. Several large quarries in the area.

Light larvikite: mostly known as “Blue Pearl, light larvikite has been produced since the late 19th century. At present time, there are large production sites in the Tvedalen area, western Larvik.

Malerød larvikite: the “youngest” among the larvikite types in production, and also the northernmost. Clear blue larvikite with large grains known as “Royal Pearl”.

Pale larvikite: this type has been produced in a very small degree, and there is no current production. The colour is paler than the other types, and the chiller is more silvery than blue. Until present time this type has been looked upon as difficult to sell in the market due to the weak colour.

Most of the municipality of Larvik is on top of larvikite rocks (Figure 4). However, only parts of that area contain larvikite resources of high enough technical quality to produce large blocks. This is mainly due to significant faults and fracture systems responsible for the uneven terrain in the municipality. The hypothesis behind resource mapping was that the area most resistant to erosion (hills) are the less fractured parts, whilst the valleys and depressions in between the most fractured parts.

The resource mapping, carried out between 1999 and 2003 (Heldal et al. 1999, Kjølle et al. 2003), aimed at map the distribution of the different types and identify the best areas for quarrying each of them. In addition to the technical quality (fracture spacing), characterization of colour, composition and homogeneity were carried out. The resulting resource map is shown in Figure 5.

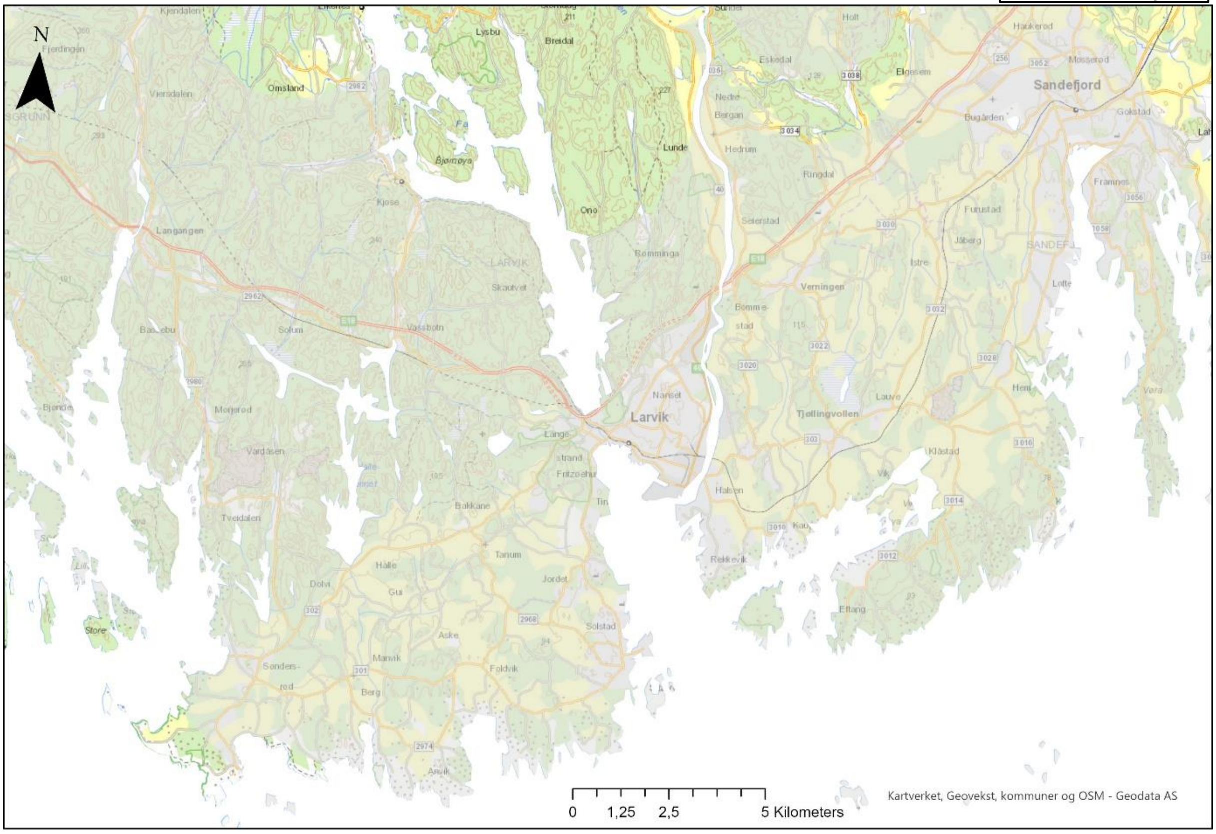

Figure 4. Map showing area covered by larvikite (shaded area)

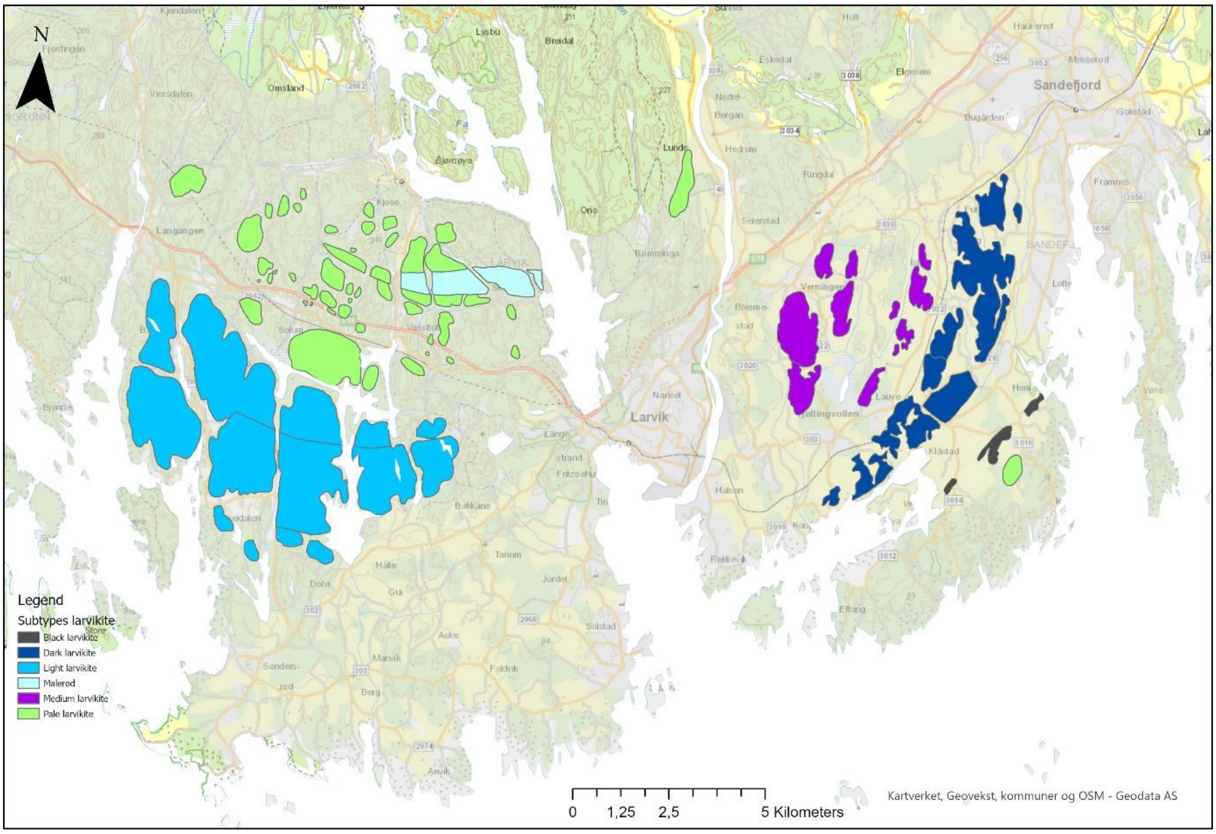

Figure 5. Map showing result of resource mapping and distribution of larvikite types

Methodology

The aim of this case study is to explore the application of UNFC (see description of method in UNFC main document for mineral resources and guidance for use in the Nordic countries) on the larvikite resources within one municipality. We have viewed this from the perspective of public entities, such as municipalities, regional authorities or geological surveys, as a tool for UNFC resource based management.

The first part of the case study uses disclosed data, published by authorities. The geological map, combined with published resource mapping and spatial management information makes the base of the study. However, voluntarily disclosed data from the larvikite producer Lundhs AS are used in calculations of "ore grade".

In this part, we have made some choices:

- Larvikite resources have been considered "exploitable" down to sea level. This is not completely accurate, since there are already quarries extracting stone below sea level. We have chosen to make this limitation due to the yet unknown variability of technical property variations among larvikites that can influence maximum depth of extraction, along with the geological uncertainty of resource quality at depth.
- The municipality of Larvik has made a quite detailed regulation plan for larvikite resources. Some areas are designated to larvikite exploitation in the short or medium long term; these, we consider to be open for quarrying projects without land-use conflicts. Other areas are designated to possible future exploitation. These areas we consider to be of low land-use conflict. The rest of the outcropping areas of defined resources of larvikite, we consider to be high-conflict areas, or areas were future larvikite production is not likely to happen.
- We have used a "direct evidence" method for evaluating the resources. This means, that we have used the obtained levels of knowledge within the area as the best possible, disclosed knowledge platform. For instance, the maximum certainty of resource calculations from disclosed data is G2, since we do not have access to internal company information.
- Using a probabilistic method could give a statistical more viable distribution of G1 to G4. However, in this case, it would most likely be based on decreasing certainty surface to depth. Since this approach has little evidence in the quarry areas, and since there are several other factors controlling exploitability changes on a lateral axis (of which we have limited data), we decided to use only deterministic method.

In the last part of the study, we have used data from the company Lundhs, disclosed for this work.

Evaluation of data and calculating volumes

The total area situated in larvikite (Figure 4) may be classified as G4. We have not made calculations of volumes, since the amount of larvikite resources with observed, higher confidence is significant.

The resource mapping creating the areas shown in Figure 5 did result in an assessment of resources, although with a rather low level of confidence, down to sea level. These volumes (from terrain surface down to sea level) are classified as G3.

By computing a tin-model (Figure 6) covering the area with larvikite resources, volumes could be calculated by applying "polygon volume" tool in ArcGIS Pro, when z-value of polygons equal 0. This resulted in a set of volumes for each polygon – *gross volumes* (Figure 7).

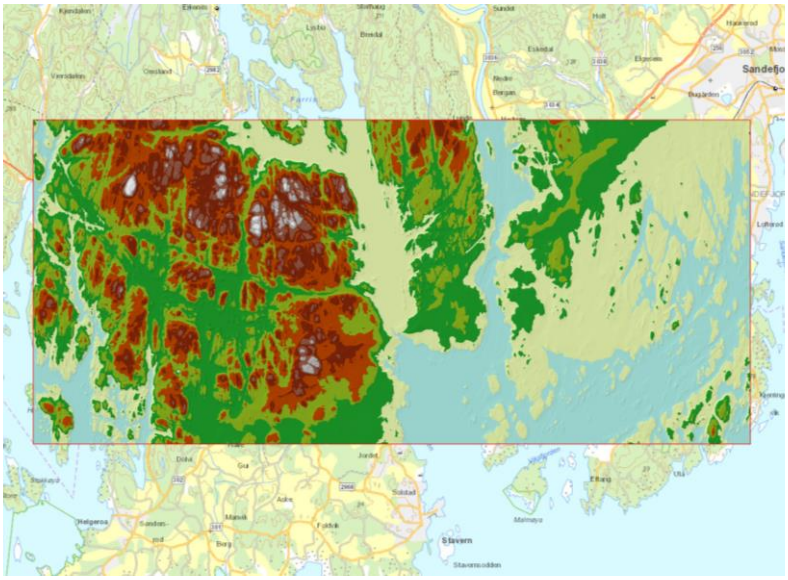

Figure 6. Tin-surface 10x10 metres made from dtm-model

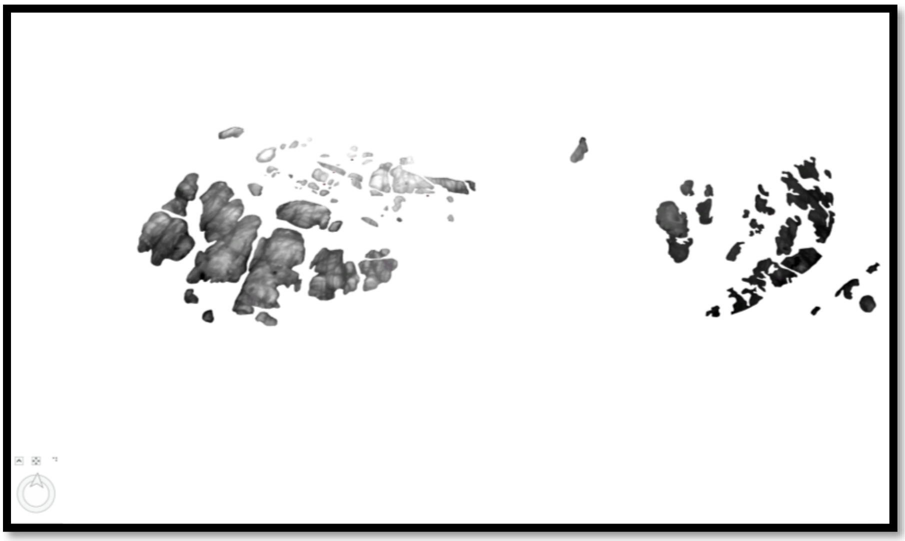

Figure 7. 3D-view of larvikite resource volumes calculated as volume between terrain surface and sea level

The *gross volume* for all the mapped potential resources is approximately 11 billion tons. However, the *gross volume* does not reflect a real situation, where volumes are decreased due to (inevitable) top layers, fracture zones and other parts not suitable for production. Viewing layout of the quarries in the area through history, at least 50% of *gross volume* will less likely be produced. We have used a conservative approach – reducing gross volume to 1/3 – the *reduced gross volume*.

Of the rock that actually will be produced, only a fraction will be sold as commercial blocks on the ornamental stone market. In the larvik area, this fraction is between 5 and 14 % (Lundhs, production figures) depending on the type of larvikite. The *net volume* will therefore be between 5 and 14 % of the *reduced gross volume*.

Thus, the formula for calculating will be:

Net volume = (*gross volume*/3) x (0,05 – 0,14)

Calculating E, F and G axes

As mentioned, the mapped resource areas can be classified at least as G3 (Figure 8). We have anticipated that the knowledge of the resource on a company scale is better in the active quarry areas; companies use core-drilling and consultants, and although this information is classified, we think it is valid to use G2 for resources within such areas (Figure 9).

This brings us to the E and F axes.

In the Larvik municipality, the geological mapping was fed into land-use planning, resulting in a priority of resource areas: some were discarded as non-negotiable no-exploitation areas, where other land-use interests have higher priority than stone production. These, we classify as E3 and F4. However, a significant part of the resource areas was considered to be “of future interest for larvikite production”, i.e. *awareness zones*. Although they are not secured for future larvikite production, it is likely or probable that they will in the future. Future larvikite production in such areas is negotiable. We have classified those areas as E2-F2.2.

The areas designated to larvikite production through concession (Norwegian mining act) and/or regulations according to the Norwegian Plan- and Building Act are classified as E1.1. and F1.1.

In one case (black larvikite) quarrying was recently stopped. Whether it will start again or not is an open question, but the quarry area remains regulated to such activities so far. We propose E1.1 and F2.2 for this particular area.

The proposed UNFC classification for the total larvikite resources is shown in Table 1.

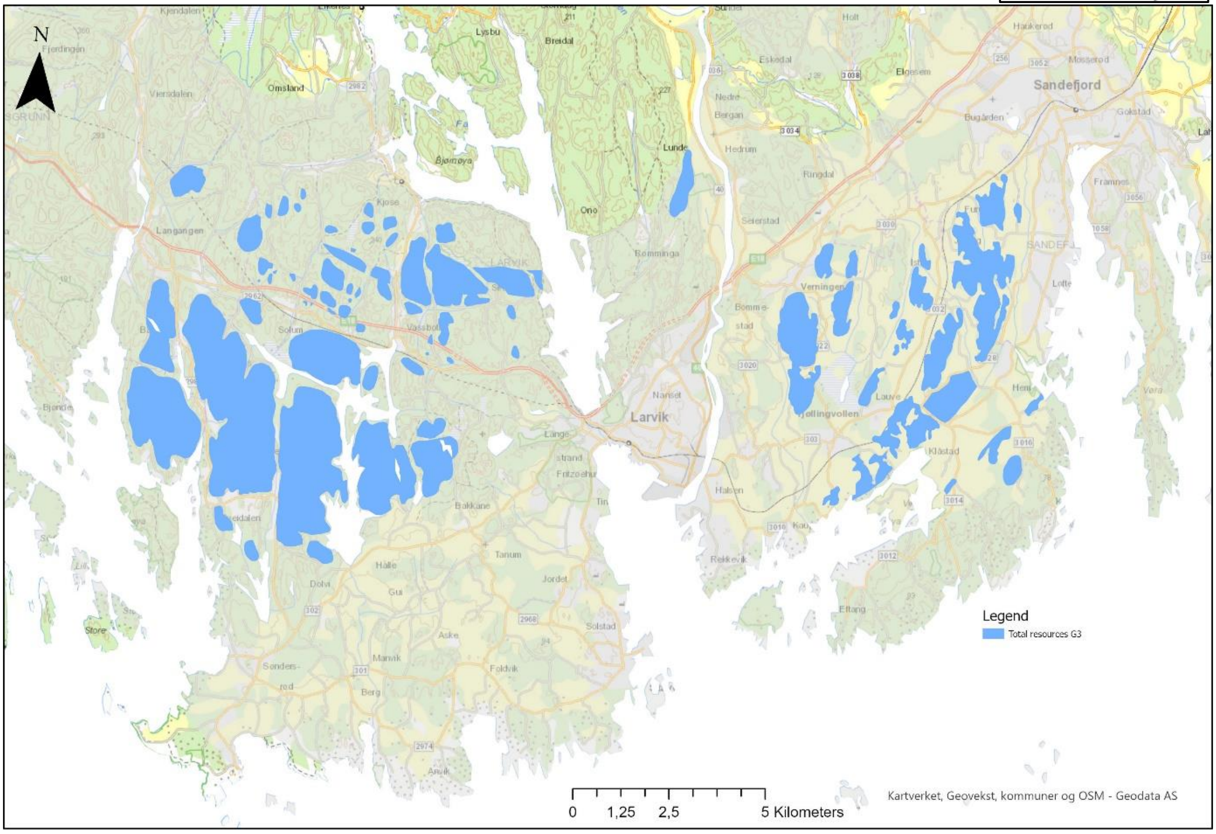

Figure 8. Map showing all defined potential resources - G3

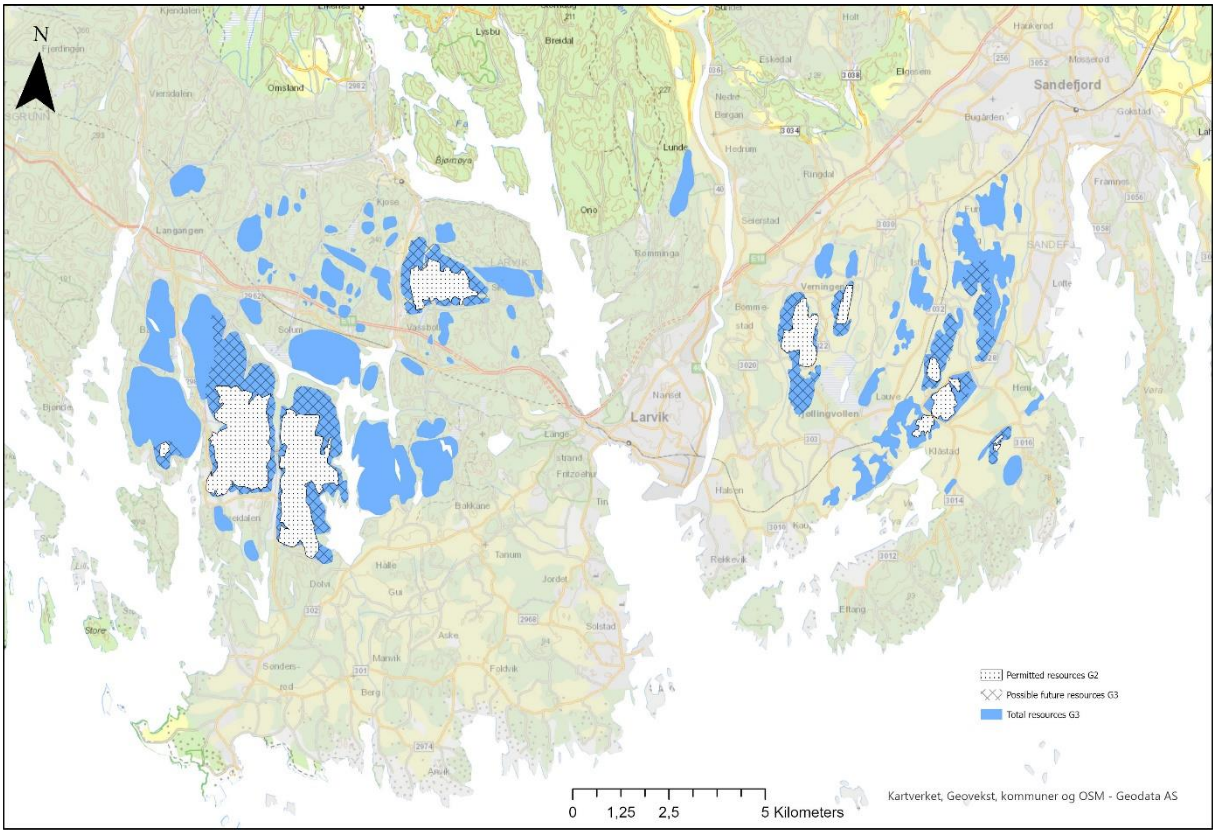

Figure 9. Map showing all resources, awareness zones (cross hatched) and mining permission areas (white with dots).

*Table 1. Proposed UNFC classification of total larvikite and broken down to the six subtypes, net volumes. *For the Malerød subtype, reduced gross volume is lower than the other ones, due to that this specific awareness zone covered more unproductive areas than the others.*

	E	F	G	Sales t	Non-sales t
	1.1	1.1	2	63 729 961	835 609 094
	1.1	2.2	2	97 411	
	2	2.2	3	36 702 836	
Larvikite total	3.2	4	3	122 331 950	
	1.1	2.2	2	97 411	876 702
	2	2.2	3	347 325	
Black larvikite	3.2	4	3	239 536	
	1.1	1.1	2	2 315 187	20 836 682
	2	2.2	3	5 142 412	
Dark larvikite	3.2	4	3	11 489 056	
	1.1	1.1	2	7 641 772	7 641 772
	2	2.2	3	6 917 749	
Medium larvikite	3.2	4	3	6 374 882	
	1.1	1.1	2	32 317 362	614 029 881
	2	2.2	3	23 447 861	
Light larvikite	3.2	4	3	43 009 366	
	1.1	1.1	2	21 455 640	193 100 760
Malerød	2	2.2	3	847 489	
larvikite*	3.2	4	3	5 478 327	
Pale larvikite	3.2	4	3	55 740 783	

Breaking down to subtypes of larvikite

As mentioned previously in this report, the larvikite resources do not define one single quality. There are at least six subtypes, each acting like different products in a demanding market. Thus, a breakdown of the generic UNFC classification to the six subtypes and even more, can be of great value for future land use management (Table 1).

Larvikite is a geological resource carrying longevity. It has been on the world market for nearly 140 years, and will likely be present for the next hundreds of years. In thousands of buildings, monuments and other constructions worldwide, larvikite is an important component. Thus, it is important to secure long-term production of larvikite.

From our figures, light larvikite resources may reach 500 years into the future within regulated areas (E1.1, F1.1). This may be seen as a “well done” management policy from the authorities. Dark larvikite, however, within regulated quarry areas, last approximately 45 years with the present production rate[1]. On the other hand, "awareness zones" (E2, F2.2) may stretch this another 100 years.

The breakdown of figures shown here is an example of how UNFC can be applied in several levels, from national to municipality and company scale. Using the UNFC in such ways will provide tools for long term planning of land use and resource exploitation. If resources are expected to run out in a foreseeable future, authorities can be motivated to make "awareness zones" that can be developed to future production areas.

The issue of "non-sales" – a resource stock model

We have analysed the larvikite production in the light of primary production of raw blocks. However, an increasing amount of the non-sales are being transformed to other commercial products. Larvikite not suitable for natural stone raw blocks can be applied for coastal protection blocks (armour stone), aggregate, dry-wall stone and even agricultural additives (Figure 10). It is important to note that the company owning the concession only produce raw blocks, while a cluster of other companies feed their business models on the non-sales from that company.

One way of studying the non-sales is by viewing it as a contemporary and future stock of products, aligned with the resource estimates described above. This is shown in *Table 2*. Note that we have only calculated this in the permission areas.

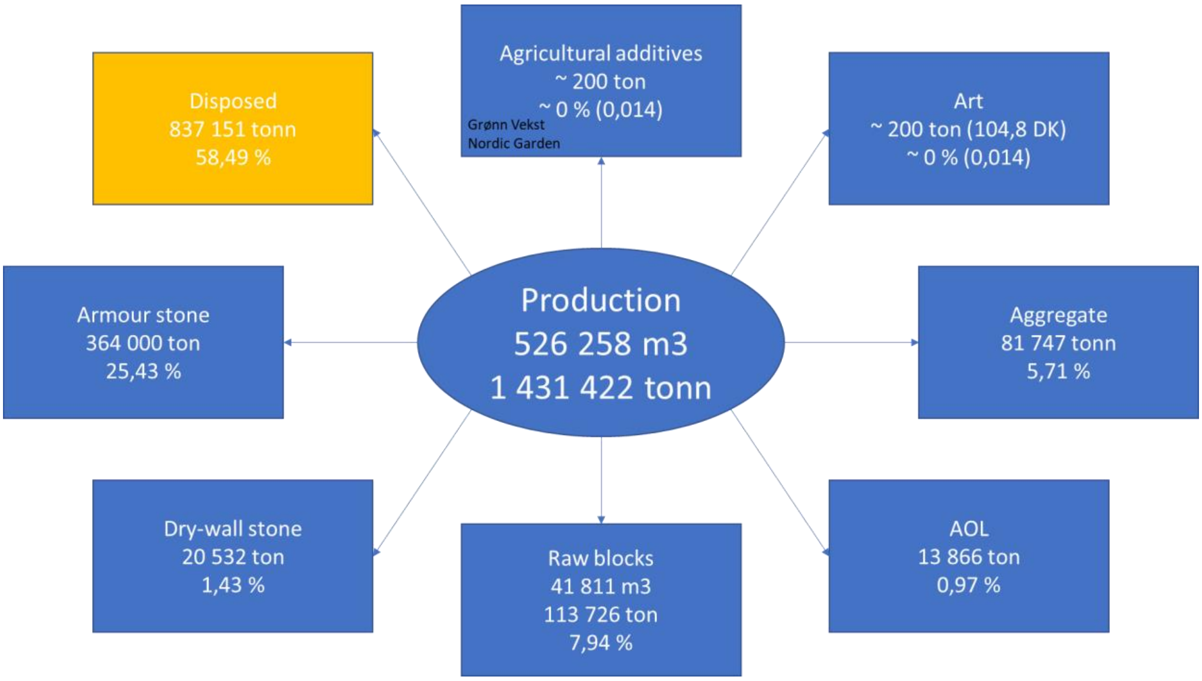

Figure 10. Additional use of larvikite in one company owning many quarries, figures from 2018

[1] Roughly in line with industrial calculations in that area

Table 2. Stock model UNFC for calculating use of non-sales. Based on figures from Lundhs.

	E	F	G	Non-sales t	Dry-wall stone t	Armour stone t	Aggregate t	Other t	Left t
Larvikite total	1.1	1.1	2	835 609 094	26 798 987	329 637 094	187 697 870	926 075	291 475 144
	1.1	2.2	2						
	2	2.2	3						
	3.2	4	3						
Black larvikite	1.1	2.2	2	876 702					
	2	2.2	3						
	3.2	4	3						
Dark larvikite	1.1	1.1	2	20 836 682			5 324 930	926 075	14 585 677
	2	2.2	3						
	3.2	4	3						
Medium larvikite	1.1	1.1	2	7 641 772	1 528 354				6 113 417
	2	2.2	3						
	3.2	4	3						
Light larvikite	1.1	1.1	2	614 029 881	14 542 813	329 637 094			269 849 974
	2	2.2	3						
	3.2	4	3						
Malerød larvikite	1.1	1.1	2	193 100 760	10 727 820		182 372 940		0
	2	2.2	3						
	3.2	4	3						

The issue of "non-sales" – a resource flow model

Another way of reviewing non-sales is by using a material flow model. Since the "biproducts" of larvikite raw block production totally depends on the latter (no raw block production – no biproducts) a flow model may be more appropriate to apply. Moreover, trends (of reducing waste) may come more clearly forward.

Table 3 and Figure 11 show Lundh's annual primary production in different larvikite types and non-sales for 2018 and estimate for 2020. Note that only E1 and F1 figures are displayed.

Table 3. Annual production and non-sales 2018 and estimate for 2020.

2018	Annual primary production t	Block yield %	Primary blocks t	Dry-wall stone t	Armour stone t	Aggregate t	Other t	Disposed t
Dark larvikite	352 566	0,12	42 308			81 747	13 866	214 645
Medium larvikite	195 528	0,14	26 460	17 709				151 359
Light larvikite	710 973	0,06	42 658	16 045	363 980			288 290
Malerød larvikite 2018	175 318	0,095	16 655	6 500				152 163
Total	1 434 385	0,09	128 082	40 254	363 980	81 747	13 866	806 456

Estimate 2020	Annual primary production t	Block yield	Primary blocks	Dry-wall stone	Armour stone	Aggregate	Other	Disposed
Dark larvikite	352 566	0,12	42 308			81 747	13 866	214 645
Medium larvikite	195 528	0,14	26 460	17 709				151 359
Light larvikite	710 973	0,06	42 658	16 045	363 980			288 290
Malerød larvikite 2020	175 318	0,095	16 655	6 500		151 943		220
Total	1 434 385	0,09	128 082	40 254	363 980	233 690	13 866	654 513

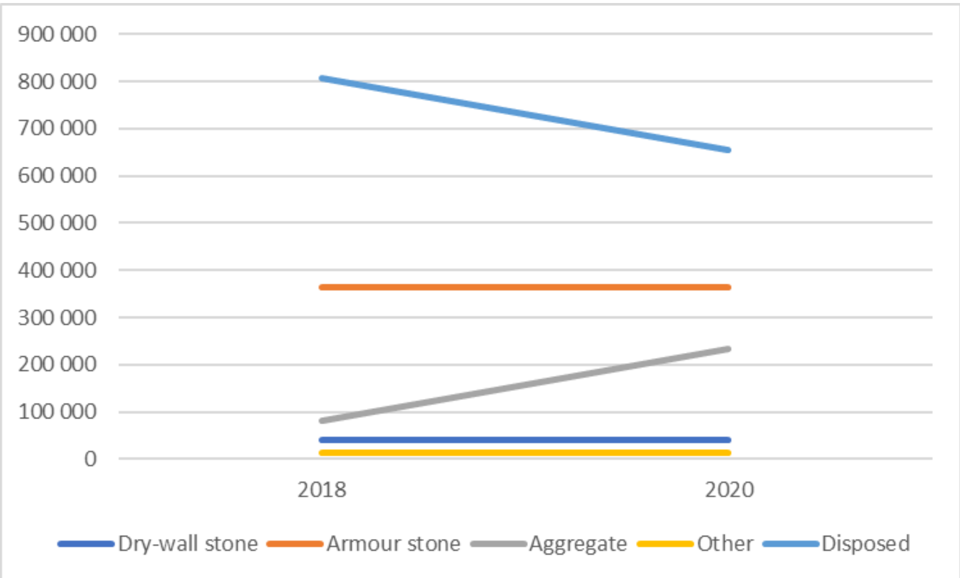

Figure 11. Graphic illustration of Table 3, showing increasing use for aggregate and decreasing disposals.

Challenges

In this case study, we did not start from scratch, but had good data available.

Geological resource mapping was carried out previously and available, identifying some qualities (G3) from poorer qualities (G4). G2 was assigned to all the active production and dedicated areas, of which, there may be several areas more correctly classified as G1; but since that information is not reported from companies, we have few possibilities of establishing such figures.

The Larvik Municipality have made significant work in their land-use planning, identifying dedicated short term extraction areas, longer term extraction areas and awareness areas for the future. This was crucial for establishing the E-axis. Dedicated and regulated areas are E1, whilst the awareness zones are E2. The remaining land on larvikite in the municipality must be regarded as E3. The work carried out by the municipality include the evaluation of many land use interests in the area, roughly identifying 1) no conflict areas where exploitation is supposed to take place, 2) low conflict areas where exploitation may be considered, and 3) high conflict areas where it is not likely to produce larvikite.

The weakest part of the case study is the F-axis. We do not have detailed figures or other information about industrial projects in the area, such information is not disclosed in Norway. However, we have assumed that the dedicated production areas have ongoing projects for expanding quarries or establishing new ones, and that low conflict zones may be open for possible new exploration.

On the one hand, UNFC may provide a good tool for resource management. And, in the case of Larvik, lack of detailed information about every project and industrial activity may not be a hinder for using UNFC in long-term planning, given that industrial data, although not-reported, have provided input to the land-use planning in the municipality.

In Norway, mineral producing enterprises owning mining concessions, are obliged to deliver annual reports of production and waste disposal to the government. They are not obliged to report resource assessments, and when other enterprises make their value chains on the non-sales, there are no reporting obligations at all. This makes it difficult to monitor the sustainability of the resource exploitation.

The application of UNFC may provide a solution to such issues, given that it is applied on non-sales in addition to sales.

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UNFC Case study – Phosphate resources in Norway

Introduction/Background

Define the resource

The most prominent phosphate bearing mineral in Norway is apatite of igneous origin.

There are several known deposits and occurrences. Some have been well-known for several years, other are less known.

Methodology

Only two of the deposits have JORC compliant resource estimates enabling bridging to UNFC: Kodal and Øygrei.

Other deposits have resource estimates that are non-compliant and not done according to known classification standards. Hence, bridging is not an option for most phosphate deposits in Norway.

Both published and unpublished data (geological reports and articles, company reports and more) have been compiled, mainly focusing on the quality, and performed activities at the various deposits.

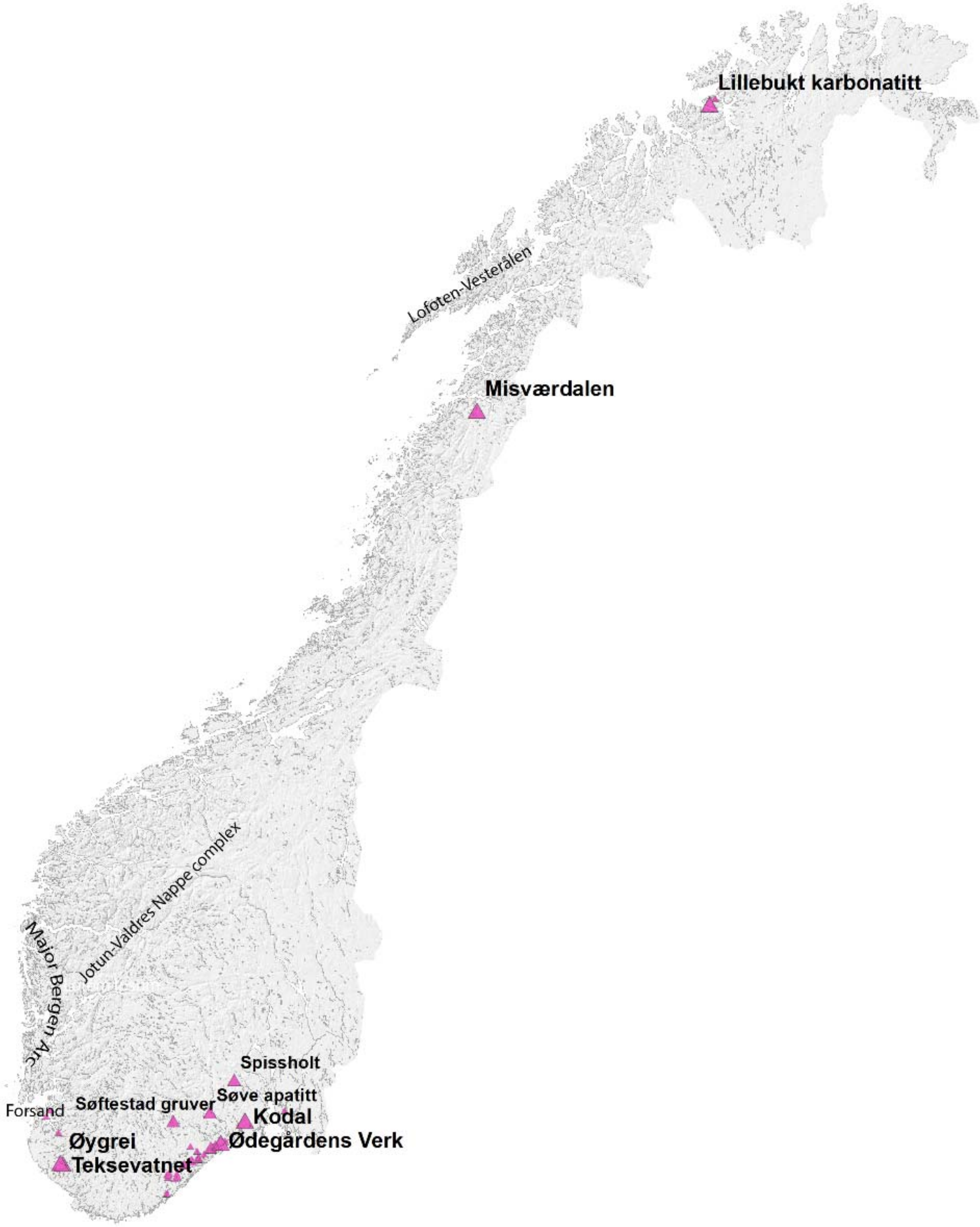

Figure 1 Overview of known apatite deposits in Norway.

UNFC

Kodal apatite and titano-iron deposit.

Status: Investigations by Norsk Hydro between 1959 and 1984 included 58 drill holes, beneficiation tests and apatite resource estimates. 1900 m long ore zone of closely spaced lenses of massive pyroxenitic ores, 18-20 m thick, that have been drilled to a vertical depth of 150m. Non-compliant estimates give an inferred open pit resource of 70Mt with an average content of 4.9% P_2O_5 or alternatively underground resources of 35Mt with an average of 6.8wt% P_2O_5. (Ihlen et al, 2014)

More recent and systematic core drilling by Kodal Minerals Ltd. according to JORC/PERC standards and advance ore dressing tests giving JORC compliant resource estimates (Kodal Minerals 2017). Investigations have been put on hold due to low prices on iron.

Table 1 Numbers and classification for the Kodal deposit.

	Gross				**Net**				**UNFC bridging**		
Category	**Mt**	**Grade**	**Mt**		**Mt**	**Grade**	**Mt**				
	P_2O_5 + Fe	**P_2O_5**	**P_2O_5**		**P_2O_5 + Fe**	**P_2O_5**	**P_2O_5**		**E**	**F**	**G**
Indicated	14,6	5,18	0,76		14,6	5,18	0,76		E2	F2.2	G2
Inferred Sub.	34,3	4,59	1,58		34,3	4,59	1,58		E2	F2.2	G3
Total	**48,9**	**4,77**	**2,34**		**48,9**	**4,77**	**2,34**		**E2**	**F2.2**	**G2+G3**

Bjerkreim-Sokndal layered intrusion ilmenite-apatite-magnetite deposits

Status: Mapped and sampled in late 1990s and early 2000s by NGU, partly in cooperation with Norsk Hydro (Yara). Shallow drilling was performed by NGU in 2004. The investigations identified 3 zones (A, B northern and southern and C) which are enriched in apatite, ilmenite and vanadium-rich magnetite. (Ihlen et al, 2014)

Follow-up studies and extensive drilling by Norge Mining in an area around Øygrei shows a continuity of the resource to at least 1500 m subsurface. A JORC compliant resource estimate (2021) has been performed for this area of the host intrusion.

Table 2 The NGU classification of the apatite-ilmenite-magnetite deposits in the Bjerkreim-Sokndal layered intrusion. Surface mapping and analyses have been extrapolated to 100 m below surface based on a predictable geology.

	Area	Apatite	Ilmenite	Magnetite		E	F	G	Comment
Zone A/MCU IBe	45 m x 3000 m	8,3 %	15,2 %	10,6 %		E2	F2.1	G3	3 km long, 60 m wide gradually thinning out at the flanks. Potentially extent poorly documented.
Zone B/MCU IIIe	100 m x 3000 m	7,8 %	11,4 %	6,9 %		E2	F2.1	G3	Two isolated resource areas; north and south
North		7.8%	11.4%	6.9 %					Maximum thickness 120 m, thinning towards the east to 90 m.
South		8.3%	13.4%	8 %					Estimated thickness 130 m, lateral extension ~1500 m.
Zone C/MCU IV	80 x 8500 m	10,2%	12,4 %	7,3 %		E2	F2.1	G3	50-170 m thick. Confirmed by two drill holes (NGU).

Recent press releases, dated January 25th, 2021, from Norge Mining refer to a JORC-compliant resource assessment of the Øygrei area, which includes mineralised rocks also outside zones B and C. The JORC-compliant assessment arrives at higher tonnages and lower grades, but with a stronger statistical certainty (Table 3). .

Table 3 UNFC of the Øygrei area within the Bjerkreim-Sokndal layered intrusion

	Mt in total			**UNFC bridging**		
Category	**P_2O_5**	**Grade P_2O_5**		**E**	**F**	**G**
Indicated	800	1,84 %		E2	F2.1	G2
Inferred Sub.	750	1,63 %		E2	F2.1	G3
Total	**1550**	**1,74 %**		**E2**	**F2.1**	**G2+G3**

Misværdal apatite-bearing alkali clinopyroxene complex

Status: Previously mapped and sampled on surface by NGU. Processing lab experiments including flotation, high-intensity magnetic separation and acid solubility.

Two bodies of apatite-rich biotite-pyroxenite covering areas of 6 km^2 and 2 km^2. In general, the bodies have low values of apatite. A richer zone, 200 m wide and 650 m long, have been identified with an average of 4.1 wt% P_2O_5 or 9.6wt% apatite. (Ihlen 2009, Ihlen & Furuhaug 2012 & 2013, Ihlen et al 2014, Johannessen & Ihlen 2018)

Table 4 Detail for the most promising area of the Misværdal deposit

Locality	**Area**	**Apatite**	**P_2O_5**		**E**	**F**	**G**	**Comment**
Coarse-grained zone at Skaråslia	200mx650m	9.6wt%	4.1wt%		E3	F3	G3	Volume estimated down to 100 m depth.

Ødegårdens Verk

Status: Mined 1872-1945. According to Korneliussen & Furuhaug (1993), variable amount of phosphate (1-15 wt% P_2O_5) based on 22 drill cores in the phlogopite-enstatite-rich sones (up to 1 m thick) in a metasomatic gabbro/amphibolite, with an average content of 3.28% P_2O_5 (7.8 wt% apatite). Crude estimations of tonnage to 150 depth, using a density of 2.8 (tons/m^3) give 50Mt. However, the apatite-bearing phlogopite-enstatite sones are probably scarce, thus average phosphate content is probably as low as 1% P_2O_5.

Table 5 Details for the Ødegårdens Verk deposit

Locality	**Area**	**Apatite**	**P_2O_5**		**E**	**F**	**G**	**Comment**
Ødegårdens Verk	1200 m x 100-200m	2.37wt%	1wt%		E3	F3	G3	Volume estimated down to 150 m depth.

Lillebukt Complex

Status: Surface sampling and detailed mapping by MSc students from the University of Bergen and explored by Elkem, Yara International and NGU.

The main apatite bearing rock type in the Lillebukt Complex are calcite-carbonatites and steeply dipping pegmatitic hornblende clinypyroxenite dykes. The dykes form a 50-600 m wide and 11 km long belt of sub-parallell dykes separated by ultramafic fenites and the apatite in the dykes appear as coarse-grained aggregates. The apatite occurs in the carbonatite as evenly distributed mm-sized prisms.

The carbonatites (218 samples) have an average of 2.33 wt% P_2O_5, with a maximum of 6.45 wt%. The pyroxenites (23 samples) have an average of 2.35 wt% P_2O_5, with a maximum of 13.49 wt%. All data combined give an average of 2.38% P_2O_5 or 5.62 wt% apatite.

In a well-exposed and well-sampled area of about 300x300 m of carbonatite, the spatial distribution of samples gives an average of 3% P_2O_5 (7% apatite) in the carbonatite. Neither in the carbonatite nor in the pyroxenite is it possible to find areas of any significant size (> 300 x 300 meters) where the grade is higher than 10% apatite. The average grades of 3.0 wt% P_2O_5 in both carbonatites and clinypyroxenites suggest that the Lillebukt complex is too low-grade to represent any important resource of apatite. (Gautneb & Ihlen 2009, Gautneb 2009 & 2010, Ihlen et al. 2014)

Table 6 Details for a sub-locality of the Lillebukt deposit

Locality	**Area**	**Apatite**	**P_2O_5**		**E**	**F**	**G**	**Comment**
Lillebukt	300 m x 300m	7 wt%	3 wt%		E3	F3	G3	Volume estimated down to 100 m depth.

Other deposits and prospects:

Currently non-economic deposits or not examined properly are described below.

Fen carbonatite complex/Søve apatite

Status: Apatite may represent a by-product of potential Nb and REE+Y minerals.

The different rocks in the carbonatite complex yield maximum values between 1.36 and 6.92 wt.% P_2O_5. Average values in the range of 1.86–3.69 wt.% P_2O_5 are typical for samples of nepheline pyroxenite (melteigite), calcite-carbonatite, dolomite-carbonatite, carbothermal carbonatite and biotite-amphibole pyroxenite (vipetoite), the latter giving the highest average probably due to presence of abundant apatite-rich segregations, veins and lenses of calcite and dolomite-carbonatites. It appears from the average values that the calcite-carbonatites (3.2 wt.% P_2O_5) are the main carrier of apatite, which in segregations yields concentrations exceeding 10 wt.% P_2O_5. Ore reserve calculations prior to the opening of the Søve mine gave an estimate of 1.4 Mt with 0.24 wt.% Nb_2O_5 and 3.21 wt.% P_2O_5 in the Cappelen and Hydro ore bodies (Ihlen et al. 2014, Coint & Dahlgren 2019, Dahlgren 2019).

Unfortunately, no estimates of current tonnages have ever been performed, and the size of this potential resources of apatite is still unknown.

Søftestad

Status: Closed mine of apatite bearing iron ore (test mining 1913-1920, active 1939-1965). Future potential only as by-product of iron-production. 3.02 wt% P_2O_5. In total 700108 t ore were produced from the mine. (Myhra 1967)

No estimates of remaining apatite tonnages have been performed; thus, the size of this potential resource is still unknown.

Other

There are also other apatite mineralisations that have not yet been defined as deposits and are greenfield explorations targets of apatite. These include mineralisations in metagabbros with disseminated iron oxides the Spissholt and Vinoren areas in SE Norway, stratiform carbonatite at Forsand in W Norway, P-rich iron ore deposits in N Norway, noritic gabbros and pyroxenite (Jotun-Valdres Nappe Complex and Major Bergen Arc areas of W Norway) and nelsonite dikes intruding mangerites in Lofoten-Vesterålen in N Norway. (Ihlen et al, 2014)

Summary

Table 7 Summary of UNFC classified apatite deposits in Norway

Deposit	Location		Mt in total	Grade		UNFC		
				Apatite [wt%]	P_2O_5 [wt%]	E	F	G
Bjerkreim-Sokndal	Zone A/MCI Ibe		43.1	8.30%	3.50%[E]	E2	F2.1	G3
	Zone B/MCU IIIe		95.7	7.8%	3.29%[E]	E2	F2.1	G3
	Zone C/MCU IV		216.9	10.2%	4.31%[E]	E2	F2.1	G3
	Øygrei (Constrained area containing mineralised rocks in MCU III and IV	Ind. res.	800	4.36%[E]	1.84%	E2	F2.1	G2
		Inf. res.	750	3.86%[E]	1.63%	E2	F2.1	G3
		Total	1550	4.12%[E]	1.74%	E2	F2.1	G2+G3
Kodal		Ind. res.	14.6	12.27%[E]	5.18%	E2	F2.2	G2
		Inf. res.	34.3	10.87%[E]	4.59%	E2	F2.2	G3
		Total	48.9	11.30%[E]	4.77%	E2	F2.2	G2+G3
Misværdal	Skaråslia		41.47	9.60%	4.05%[E]	E3	F3	G3
Ødegården	Ødegården		38.28	2.37%[E]	1.00%	E3	F3	G3
Lillebukt	Lillebukt		28.71	7.11%[E]	3.00%	E3	F3	G3

[E)] Estimated using this formula: wt% apatite = wt%P_2O_5 * 2.3695 to convert between wt% apatite and wt% P_2O_5.

Challenges

Challenges in classification have mainly been related to data.

- Variable quality and amount of data for each deposit.
- Several mineralisations in the southernmost part of Norway (Fig 1) are registered in the national database, but lack information other than name, commodity type and coordinate.
- For several mineralisations, as mentioned under "Other", there is not sufficient data to define them as deposits. In best case, they may be viewed as exploration greenfield targets.
- Inconsistencies, such as mix of wt% and vol% of P, P_2O_5 and apatite requiring normative calculations for comparable numbers as well as different conversation factors used in the calculations.
- Inconsistencies in data between different sources ranging from simple typographical errors, such as 9.7 wt% vs 9.6 wt% to erroneous calculations. If the background for the calculations done in the various reports have not been able to find, the numbers have been excluded from this case study.
- Lack of 3D data (i.e., depth) on deposits well mapped on the surface. In most cases, only non-compliant and crude tonnage calculations are available.

Additional Questions:

As a geologist, assessing the G axis was assumed to be the "easy" part compared to the E axis and the F axis. However, following previously developed decision flow tools such as the ones developed in the ORAMA project, such as by Brown et al 2019, make the job much easier for all the three axes when in doubt.

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UNFC Case study – Slovenia

Introduction/Background

Define the resource

What is your case study about , what kind of resource, location, situation, scale (project, local, regional or National) etc,

It is about Slovenian national reserves classification mapping to UNFC classification

The case was for limestone (aggregates-crushed stone), but the methodology is the same for all kind of MR (all mineral resources are in State ownership)

Methodology

Did you use *bridging from CRIRCSO-compliant data?NO*

How have data been gathered? GeoZS is a national mineral data manager authorised by ministry , all concessionaires are obliged to report to Ministry , further all mineral data gos to GeoZS

What kind of data have been used?

Availability of data sources GeoZS has the official permission/duty to manage and has the access to all national mineral data

UNFC

Evaluation of data and areas, calculation of volumes. Slovenia specific is , we valuate and calculate only mineral endowment within permitted areas (exploration and exploitation areas)

Defining the E, F and G-axis we prepared a "recipe" to transform national classification into UNFC (using E,F and G axis)

Challenges

Describe the challenges, harmonization issues and uncertainties one may encounter in this kind of work. What is the quality of the data? What are the issues concerning availability of data?

Additional Questions:

What have you learned from this work? That different countries have different stand points to what is mineral classification and its valorisation

What kind of challenges have you experienced during this work?

How can your work and experience be used into a UNFC guideline? We follow carefully UNECE guidelines for many years even though it is not a mandatory in a country

How can this case and your experience be used into the next deliverables and Milestones in Mintell4EU WP4:

D4.1 Case study review with practical guidelines/work flows and examples for applying UNFC to European mineral resources

D4.2 Report on harmonization issues, data gaps and challenges, reviewing also the quality of Pan-European aggregated inventories for selected commodities

References

List all the data sources and other relevant reports you used

National legislation

Expertise , Reports and news of UNECE

UNFC Case study- REE, exploration prospects and secondary resources in Sweden

Contents

Introduction/Background

The United Nations Framework Classification for Resources[1] has been developed for projects producing minerals, oil and gas, renewable energy, underground storage, and anthropogenic resources. Water is currently being added to the suite of resources to which UNFC applies. UNFC is established as a tool for policy formulation, government resource management, industry business process management and capital allocation. UNFC comprises the technical (F-axis) and geological (G-axis), as well as environmental, social and economic viability (E-axis) of a project, which makes UNFC very useful as a communications tool between companies and governments as well as the wider society.

Within the Mintell4EU project[2], under the umbrella of the EU-financed project GeoEra, Geological Survey of Sweden (SGU) has taken responsibility for doing a case study on REE projects. In this report, the application of UNFC to three, potentially economical deposits of REEs in Sweden (fig. 1) demonstrate how UNFC reflects the processes that form the projects. The report documents the principles in the cases presented. It does not necessarily reflect accurate estimates of the project quantities. As a geological survey we wanted to test classifying projects according to UNFC using only public data, and to our knowledge this report is based of the best data publicly available at the time being.

Many who wish to apply UNFC may be concerned that changing their reporting standard will create an undesirable break in the records. This can easily be avoided. The Horizon 2020 ORAMA (Optimizing quality of information in RAw MAterial data collection across Europe) project[3] presents tables that show straight forward way to translate CRIRSCO (the Committee for Mineral Reserves International Reporting Standards) classified objects to UNFC classified object[4]. Another practical example has been presented in a previous case study on Nordkalk limestone and Forsand sand and gravel mines resources that demonstrates how CRIRSCO inventories may bridge over to the UNFC classification (fig.2, tab.1), provided that both have been generated with the same professional diligence[5].

We have applied UNFC to three separate projects that differ in stage, maturity and type. Two of the projects are typical exploration projects (Olserum and Norra Kärr) and the third can be considered a secondary resources project (LKAB ReeMAP). For the ReeMAP project, a PERC classification is underway but not yet published, so therefore we have used the information published on the project web site for the UNFC classification[6] as well as published research papers. For the exploration projects we have bridged between UNFC and NI43-101, which is the CRIRSCO template applied by

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[1] United Nations Framework Classification for Resources Update 2019. https://unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/publ/UNFC_ES61_Update_2019.pdf

[2] https://geoera.eu/projects/mintell4eu7/mintell4eu-wp4-unfc-pilot/

[3] https://orama-h2020.eu/

[4] Optimizing quality of information in RAw MAterial data collection across Europe -ORAMA 2019. Kresse C. (ed) Technical Guidance note: Bridging document between CRIRSCO and United Nations Framework Classification (UNFC).

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[6] LKAB REEMap 2021: ReeMAP Home page ReeMAP | LKAB Minerals | ReeMAP project (ree-map.com)

companies for Olserum and Norra Kärr. Our experience is that this process is straight forward thanks to guidelines from the ORAMA project.

Mining on land often requires consideration of competing interests for land, water and other environmental resources handled through legal and regulatory framework conditions. The three REE projects in this report (the Norra Kärr and Olserum deposits and the REEMap project), demonstrate how environmental, social and economic conditions have been considered for reaching decisions and how UNFC reflects them. The guidance document on how to apply UNFC in the Nordic countries[7] has lead us in this work.

Norra Kärr and Olserum reflects exploration projects of different maturity and of different REE-compositions, whereas the ReeMAP project shows how UNFC reflects a planned mining waste operation.

One important issue is the type of mineralization involved and thus what elements constitute the mineralization and what processes are needed to extract these elements.

The Olserum object is characteristically a heavy REE object. It has an even higher concentration of the heavy rare earth elements (HREE) compared to the Norra Kärr object. The REEs are mainly found within the minerals monazite and xenotime instead of eudialyte that is the main REE-mineral at Norra Kärr.

[7] A guidance for the application of the UNFC.pdf (unece.org) 2018 by GTK, NGU, SGU and Svemin.

Figure 1. Overview of the three different examples in this report Norra Kärr, Olserum and the LKAB ReeMAP project of secondary resources. Note that the LKAB ReeMAP project is concentrated to several of LKAB mines such as Malmberget and Svappavaara.

Norra Kärr is a more mature project than Olserum. A mining concession has been applied for and at one stage granted, but due to several appeals in different courts, the company still awaits its final permits, to take the next step towards environmental permitting. During this procedure, the project moves up and down along the E axis of the UNFC coding. The Norra Kärr object is the one of the three objects that really highlights the challenges that accompany the chain of permits and appeals in Sweden and thus the difficulties with different interests of land use.

The Norra Kärr object is rich in HREE which are very attractive to the global market. Almost all of the REEs in the Norra kärr object are concentrated to the silicate eudialyte in a way that makes this mineralization almost unique in the world. The process of extracting the REE from eudialyte has been tested on laboratory scale but no full-scale test have been carried out as far as we know of.

The ReeMAP project of LKAB differs from the others by highlighting the possibility of extracting REE and phosphorus from mining waste and involves processes never used in an integrated full-scale project in Sweden.

UNFC Classification

The ORAMA project shows how to perform UNFC classification. In this report we give a short introduction.

The classification is based upon three criteria: Environmental-Socio-Economic Viability (E), Technical Feasibility (F) and Degree of Confidence (G; previously denominated the geological axis, but renamed to accommodate for other resources such as renewable energy and anthropogenic resources). These three parameters are visualized in a diagram with three axis (figure 2). These parameters are classified individually. Each parameter is divided into three to four subclasses based on maturity of the project.

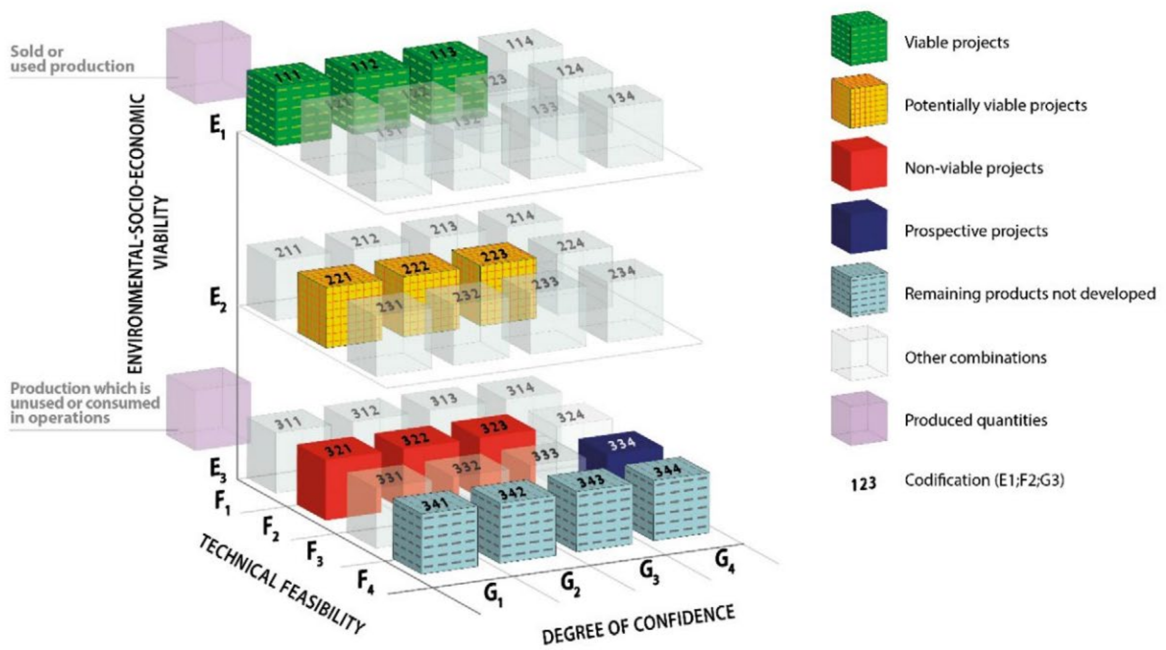

Figure 2. The UNFC classification system.

To classify a mineral deposit properly according to the UNFC code, a chain of features needs to be followed. This procedure is described in the final report 1.5 of the ORAMA project[8].

First of all, there has to be a source of material that is considered for future production. Before a project is conceived, the mineralization is categorized as E3[9] and F4[10]. The confidence in the estimates is reflected in the range of quantities where G1 reflects estimates with a high level of confidence, G2 a moderate level of confidence and G3 a low level of confidence. G4[11] is used for prospects where there is a probability of less than 1 that a source exists at all.

Once a project is conceived, it will be given an E category reflecting its environmental and socio-economic maturity. The project can move up and down along this axis depending on different permits granted and eventual appeals decided. It will also be given an F category reflecting how far the project is matured technically, from early studies to production and abandonment. Two sets of produced quantities are reflected:

- Quantities delivered outside the project for sale or use. These quantities are produced from the class defined by categories E1[12], F1[13].
- Quantities not delivered from the project and either not used, as is the case with mine tailings and flared gas or used in operations as is the case with quantities used for site remediation and fuel gas. These quantities are delivered from the class E3.1[14]F1

Material balance is preserved, so unless there is a re-evaluation of the initial product quantities not developed by identified projects (initial quantities in place) the sum of the quantities produced, remaining to be produced by projects and remaining products not developed from identified projects will be constant.

Bridging from other classification system

There are different ways of classifying a mineral deposit according to maturity. One important way is given by the CRIRSCO templates[15] (founded in 1994) aiming at transparency towards investors and stock markets. CRIRSCO provides international standard definitions for the reporting of mineral resources and mineral reserves, including provisions for country-specific requirements of, i.e., legal and investment regulatory nature, and agreed to be incorporated into the UNFC in 1999. Both Olserum and Norra Kärr have been classified according to the CRIRSCO code NI43-101 which is used in Canada. Thus in this report, we focus on bridging from NI 43-101 to UNFC.

A bridging of the CRIRSCO code can be done by using the classification scheme of the technical guidance note suggested by the ORAMA project (fig. 3).

[8] Optimizing quality of information in RAw MAterial data collection across Europe -ORAMA 2019. Deliverable 1.5 Good practice guidelines for harmonisation of resource and reserve data

[9] E3: Development and operation are not expected to become environmentally-socially-economically viable in the foreseeable future or evaluation is at too early a stage to determine environmental-socioeconomic viability.

[10] F4: Technical feasibility of a development project cannot be evaluated due to limited data.

[11] G4: Product quantity associated with a Prospective Project, estimated primarily on indirect evidence.

[12] E1: Development and operation are confirmed to be environmentally-socially-economically viable.

[13] F1: Technical feasibility of a development project has been confirmed.

[14] E3.1: Estimate of product that is forecast to be developed, but which will be unused or consumed in operations.

[15] http://www.crirsco.com/templates/CRIRSCO_International_Reporting_Template_October_2019.pdf

Geological knowledge and confidence (↑)

CRIRSCO Template		UNFC-2009 "minimum" Categories			UNFC-2009 Class
Mineral Reserve	Proven	E1	F1	G1	Commercial Projects
	Probable			G2	
Mineral Resource	Measured	E2	F2	G1	Potentially Commercial Projects
	Indicated			G2	
	Inferred			G3	
Exploration Target		E3	F3	G4	Exploration Projects

Figure 3: Mapping of CRIRSCO to UNFC-2009 "minimum" Categories and Classes[16].

Mineral reserves are the economically minable quantities and always correspond to categories E1 F1(G1 or G2). Proved mineral reserves are classified as 111. Probable mineral reserves are classified as 112.

Mineral resource estimates can also be classified as E1 F2 (in case there is no doubt of economic viability) or E2 F1 (in case there is no doubt in technical viability).

Mineral resources are in situ estimates of concentrations or occurrences of solid material of economic interest. Mineral resources are generally classified as E2 F2 (G1, G2 or G3). Measured resources are classified as 221, indicated resources are classified as 222, inferred resources are classified as 223.

Geological studies including estimates of tonnes, grade, quality, etc., enable the classification of the resources on the G axis based on the detail of the study and the degree of confidence in the geological model. Mineral reserves are classified as G2 (probable) or G1 (proven)

Mineral resources are classified as G3 (inferred), G2 (indicated) or G1 (measured) reflecting an increasing level of geological knowledge and confidence.

[16] Optimizing quality of information in RAw MAterial data collection across Europe -ORAMA 2019. Kresse C. (ed) Technical Guidance note: Bridging document between CRIRSCO and United Nations Framework Classification (UNFC).

Tabell 1. Abbreviated version of UNFC classification showing primary classes (source; D1.5.1. Technical guidance notes UNFC)

	Extracted	**Sales Production**			
		Non-Sales Production			
		Class	**Categories**		
			E	**F**	**G**
Total Commodity Initially in Place	Future recovery by commercial development projects or mining operations	Commercial Projects	1	1	1, 2, 3
	Potential future recovery by contingent development projects or mining operations	Potentially Commercial Projects	2	2	1, 2, 3
		Non-Commercial Projects	3	2	1, 2, 3
	Additional quantities in place associated with known deposits		3	4	1, 2, 3
	Potential future recovery by successful exploration activities	Exploration Projects	3	3	4
	Additional quantities in place associated with potential deposits		3	4	4

The Olserum REE mineralization

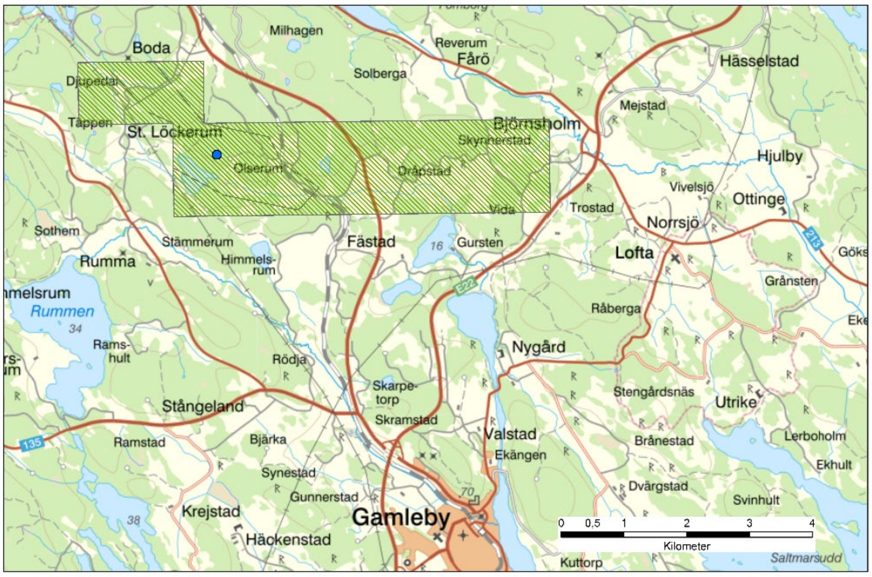

Figure 4. Locations for the exploration permit of the REE deposit Olserum. See figure 1 for a geographic overview.

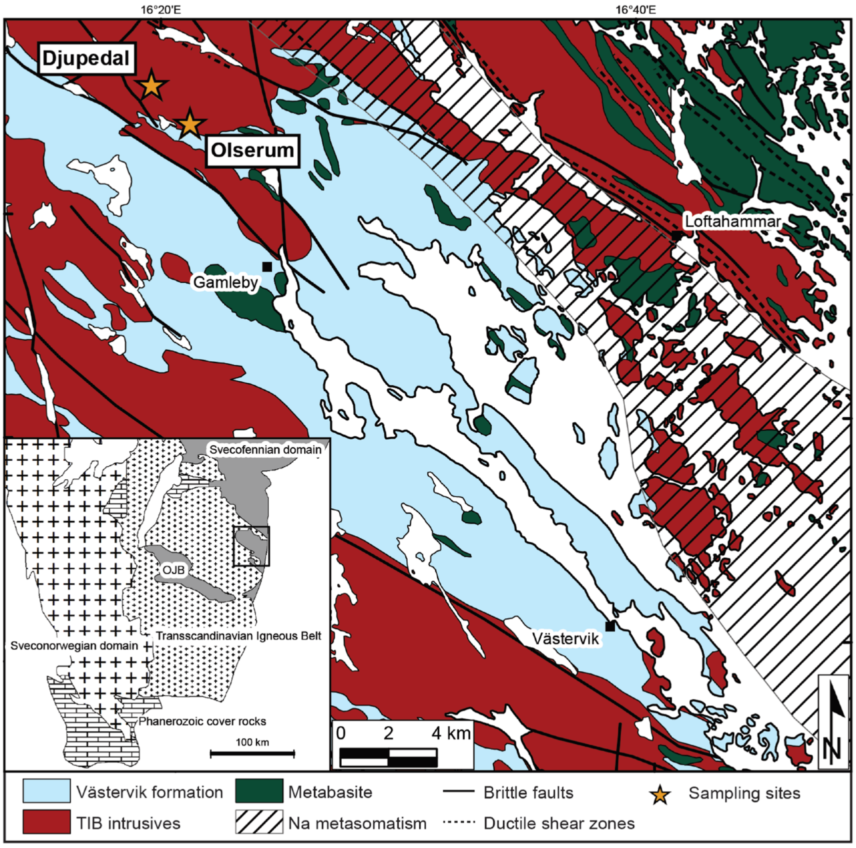

Figure 5. Geological map of the Olserum prospect[17]

The Olserum REE mineralization is situated in south-east Sweden (figure 1, 4), approximately 30 km northwest of the port town of Västervik, Kalmar county, 7 km northwest of the village Gamleby. The mineralization is situated at the border between metasedimentary rocks and granite (fig. 5).

History

The Olserum REE mineralization is well known due to exploration in the area ever since the 1950s, at that time with exploration for iron. In the 1970s, SGU continued to explore the metasedimentary package around Västervik for uranium. The exploration included boulder hunting, radiometric and magnetic ground surveys, mapping and sampling for geochemical and petrographical analyses. Apatite and monazite were identified together with anomalous values of yttrium. However, it was not investigated further for rare earths due to lack of demand at that time.

In the 1990s, SGU followed up earlier uranium exploration with the purpose to identify and classify rare earth occurrences in Sweden. The rare earth mineralization in Olserum was then noticed in close association with the uranium and magnetite bearing heavy mineral beds in a sedimentary rock.

In 2003 IGE Nordic AB claimed Olserum and commenced a drilling program. By 2005 a total of 5130 meters in 31 drill holes had been completed at Olserum and adjacent areas.

In 2013 Tasman Metals Ltd continued with an exploration drilling project. A classification according to NI 43-101 was also done in 2013 by Reed Leyton consulting, requested from Tasman Metals Ltd (now part of Leading Edge Materials). In total, 36 diamond drillholes and c. 6127 m drilled meters

[17] Andersson S.S., Wagner T., Jonsson E., Fusswinkel T., Leijd, M. and Berg J.T. 2018b: Origin of the high-temperature Olserum-Djupedal REE-phosphate mineralization, SE Sweden: A unique contact-metamorphic-hydrothermal system. *Ore Geology Reviews* 101, 740-764.

have been drilled in the area. The resource estimation is based on 18 of these drillholes. The project was drilled within an area approximately 400 m x 100-150 m. The mineralization was intersected on all the drilling sections and is so far known to at least a depth of 250 m below the surface. The mineralization strikes approximately NW-SE and the dips varies between 70 and 85 degrees to the NE.

In 2016 Tasman Metals Ltd choose to focus on Norra Kärr (see below) and did not to renew the exploration permits for Olserum. The project was at that stage paused and no work were done at Olserum for four years.

All the material and other information were taken over by the small private company Explora mineral AB when they applied for exploration permit in 2020 and continued the exploration. Explora mineral AB[18] is owned by former employees from Tasman Metals Ltd that focus on early stage exploration. Since the owners of the company previously were employed by Tasman Metals AB and furthermore, still work with assignments of Leading Edge Minerals (LEM), they have access to all previous material which were very useful since they could continue exploration without any delay or dataloss. The permit is valid until 2023. At exactly the same day, another company, European Mining Exploration AB send in an application for the same mineralization and same minerals. Both companies were granted permits to explore the object for skandium, yttrium and lantan. Whether that will have a positive or a negative impact on exploration and results, is not known.

Geology

Andersson et al.[19] [20] [21] describe the geology of the Olserum REE mineralization. A geological map is presented in fig. 5. The mineralization is mainly located to sediments of the Västervik sedimentary formation, specifically to layers containing heavy minerals close to the contact to a granite.

The Västervik formation is metasedimentary succession that was deposited in a delta at c. 1.88-1.85 Ga. At c. 1.8 Ga, the Västervik formation suffered high temperature–low pressure metamorphism due to intrusion of a red, medium-grained, massive or weakly foliated granite that is part of the Transcandinavian Igneous Belt (TIB). The Västervik formation forms a u-shaped synform with a horizontal fold axis trending to northwest. The Olserum deposit lies in the northwestern edge of this synform, completely surrounded by granite. On a regional scale, the synform coincides roughly with nortwest-southeast trending regional deformation zone.

Primary structures are quite common within the Västervik formation. However, no primary structures are preserved at Olserum. They are all wiped out by amphibolite-grade metamorphism. The metasedimentary sequence at Olserum has an E-W trend and is approximately 600 m by length and up to 100 m wide. The contacts to the surrounding granite are steep, dipping towards north. The principal lithologies that comprise the Olserum metasedimentary sequence are biotite and amphibole bearing quartzite, quarzitic gneiss, psammitic gneiss, and a biotite and magnetite bearing quartzite, the latter being interpreted as heavy mineral beds and now as paleoplacer deposits.

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[18] http://www.exloraminerals.com

[19] Andersson S.S., Wagner T., Jonsson E. and Michallik R.M. 2018a: Mineralogy, paragenesis and mineral chemistry of REEs in the Olserum-Djupedal REE-phosphate mineralization, SW Sweden. *American Mineralogist* v.103, pp 125-142.

[20] Andersson S.S., Wagner T., Jonsson E., Fusswinkel T., Leijd, M. and Berg J.T. 2018b: Origin of the high-temperature Olserum-Djupedal REE-phosphate mineralization, SE Sweden: A unique contact-metamorphic-hydrothermal system. *Ore Geology Reviews* v. 101 pp740-764.

[21] Andersson S.S., Wagner R., Jonsson E., Fusswinkel T. and Whitehouse M., 2019: Apatite as a tracer of the source, chemistry and evolution of ore-forming fluids: The case of the Olserum-Djupedal REE-phosphate mineralization, SE Sweden. *Geochimica and Cosmochimica Acta* v. 255. Pp 167-187.

Extensive metasomatism accompanied the metamorphic event, leading to hydrothermal overprint and redistribution of the REE-bearing phases.

The minerals and the abundance of the REEs are described in detail by Andersson et al.[22 23 24]. The rare earth elements at Olserum are mainly hosted by the minerals monazite and xenotime. The commonly REE-bearing fluor apatite occur in abundance but only carries REE to a minor extent. All of these three REE-bearing phosphates are of metamorphic origin, formed by hydrothermal processes, although a primary detrital of apatite is probable. Monazite and xenotime occur as inclusions in apatite, biotite and amphiboles, but also as medium and coarse, subhedral to euhedral grains in patches, veins and breccias. Monazite and xenotime crystals up to about 10 cm in size can be found. It is suggested that apatite was a major carrier of REE but was leached during metamorphism. Monazite and xenotime were precipitated as inclusions in apatite during hydrothermal processes. These inclusions occur mainly in the core of the apatites which suggest that the inclusions in the rims has at some stage been leached out and precipitated within the rock.

Due to the metamorphic and hydrothermal overprint the rare earth bearing phosphates have been widely distributed throughout the metasedimentary package, resulting in low grade but large tonnage mineralization with high percentage of heavy rare earth elements (HREE) which are mainly hosted by xenotime. The highest REE grade is associated with magnetite bands and veins hosted by biotite and/or amphibole rich quartzites. The host rock itself is mineralized through inclusions of monazite and xenotime in biotite and through thin irregular magnetite veins.

Classification according to NI43-101

The sedimentary sequence of interest, is approximately 600m by length and up to 100m wide. In total, 36 diamond-drill holes and 6127 meters have been drilled in the area. 15 of those holes were drilled before 2012. In 2012, five more holes were added and the rest after 2012. The resource estimation is based on 18 out of these 36 drill holes. In addition, 78 samples were taken from the drill core for geochemical examination.

The object is classified according to NI 43-101 by Tasman Metals Ltd. The results are shown in Table 2 and 3 (Tasman Metals Ltd press release 2013). At 0.4 % TREO cut off, Indicated Resource of 4.5 Mt @ 0.60 % TREO and an Inferred Resource of 3.3 Mt @ 0.63 % TREO.

Table 2: Indicated Resource Estimate for the Olserum Deposit.

TREO % Cut-off	Million Tonnes	TREO %	% of HREO in TREO	Dy2O3 ppm	Y2O3 ppm	Nd2O3 ppm	Tonnes of Contained TREO	
0.7	1.0	0.89	32.3	292	1800	1314	8,620	
0.6	1.7	0.78	32.9	262	1610	1146	13,360	
0.5	3.0	0.68	33.3	232	1420	996	20,650	
0.4	4.5	0.60	33.9	209	1283	878	27,260	BASE CASE
0.3	6.3	0.53	34.4	187	1146	769	33,530	
0.2	7.7	0.48	34.5	0.017	1042	700	37,030	

[22] Andersson S.S., Wagner T., Jonsson E. and Michallik R.M. 2018a: Mineralogy, paragenesis and mineral chemistry of REEs in the Olserum-Djupedal REE-phosphate mineralization, SW Sweden. *American Mineralogist* v.103, pp 125-142.
[23] Andersson S.S., Wagner T., Jonsson E., Fusswinkel T., Leijd, M. and Berg J.T. 2018b: Origin of the high-temperature Olserum-Djupedal REE-phosphate mineralization, SE Sweden: A unique contact-metamorphic-hydrothermal system. *Ore Geology Reviews* v. 101 pp740-764.
[24] Andersson S.S., Wagner R., Jonsson E., Fusswinkel T. and Whitehouse M., 2019: Apatite as a tracer of the source, chemistry and evolution of ore-forming fluids: The case of the Olserum-Djupedal REE-phosphate mineralization, SE Sweden. *Geochimica and Cosmochimica Acta* v. 255. Pp 167-187.

Table 3: Inferred Resource Estimate for the Olserum Deposit.

TREO % Cut-off	Million Tonnes	TREO %	% of HREO in TREO	Dy2O3 ppm	Y2O3 ppm	Nd2O3 ppm	Tonnes of Contained TREO	
0.7	0.9	0.85	31.8	288	1667	1294	7,947	
0.6	1.6	0.77	32.5	264	1547	1151	12,088	
0.5	2.5	0.69	33.6	242	1445	1018	16,960	
0.4	3.3	0.63	33.7	222	1320	925	20,770	BASE CASE
0.3	4.2	0.57	33.9	202	1205	841	23,820	
0.2	4.7	0.54	33.9	191	1134	790	25,050	

UNFC classification of the Olserum mineralization

The classification of Olserum mineralization according to UNFC has been bridged from the CRIRSCO classification NI43-101. As of now, the Olserum prospect is classified as an E2, F1-F2, G1-G2-project and in the following we will describe how we reached this conclusion.

E2 on the socio-economic axis

The Olserum object is classified as E2. One of the owners of the exploration permits, Explora Minerals AB have access to and refers to previous work and classification of Tasman Metals Ltd. This company has access to all significant data and they have a close relations to the company that made the classification. Therefore, they could continue the exploration without time- or dataloss. The project can still be classified as E2. Without this connection the project would slide down to an E3. The estimation of the REEs done in 2013 indicate an economical potential of the project, especially since the global demand of REE has risen. The REEs of interest are mainly HREE which are considered most critical. The Olserum object has large potential by contingent development projects.

However, as mentioned above, two separate companies have valid exploration permits to the same object. The reason for this is that both companies applied for an exploration permit at the same time and since both were considered qualified applicants, the Mining Inspector was obliged to grant them both a permit according to the Swedish administrative decree. This is a unique situation which can come to emerge in a difficult situation further along the chain of development of the project, if the time comes to apply for a mining concession. There are also potential challenges concerning land use in this area of Sweden.

F1-F2 on the feasibility axis

The object is classified as a strong F2 moving towards a F1. The REEs are concentrated mainly in monazite and xenotime, to some extent also in fluor apatite. There is a well-established, fairly simple method of extracting REEs from these phosphates. Successful tests have been performed to make a high-value mineral concentrate from the Olserum mineralization. No hydrometallurgic tests are done so far. When accurate full-scale testing is done the object may move into an F1.

G1-G2 on the geology axis

The geology of the REE mineralization is considered to be known. Regional mapping has been done by SGU and the area has been subjected to several rounds of exploration. A substantial amount of drilling and mapping has been performed by the previous owner and the current owner has access to this information. The deposit has been classified according to NI43-101. The Olserum object has also been the target of recent research projects and the process of formation of the mineralization is considered to be known.

The Norra Kärr, REE deposit

The Norra Kärr project is an intermediate stage exploration project. It is located in southern Sweden approximately 300 km SW of Stockholm, just outside the little town of Gränna, and just a few kilometres east of the highway E4 (figs. 1, 5). In all, the location of Norra Kärr and the chemical composition of the deposit means REE production, according to the prefeasibility study of Tasman Metals Ltd[25], can be done with a low environmental impact. The high grade of heavy REEs at Norra Kärr can provide a material and positive impact on the REE security within Europe for a long time.

Figure 5. The location of the Norra Kärr exploration permit (we refer to fig 1 for an overview of the geographical location.

The Norra Kärr alkaline intrusion was first discovered and described in 1906 by SGU during regional mapping program. During the 1940s, several scientific studies were done, including detailed petrographical work, to describe it.

The Swedish mining company Boliden started exploration for zirconium at Norra Kärr during the 1940s. The exploration stopped when the price of zirconium fell. Today, permits are held by Leading Edge Materials Ltd (previously Tasman Metals Ltd).

[25] GBM Mineral Engineering, Wardell Armstrong international Limited (WAI) and Golder Associates Limited 2015: Norra Kärr Project PFS, Gränna, Sweden. Amended & Restated Prefeasibility Study - NI 43-101 - Technical report for the Norra Kärr Rare Earth Element Deposit

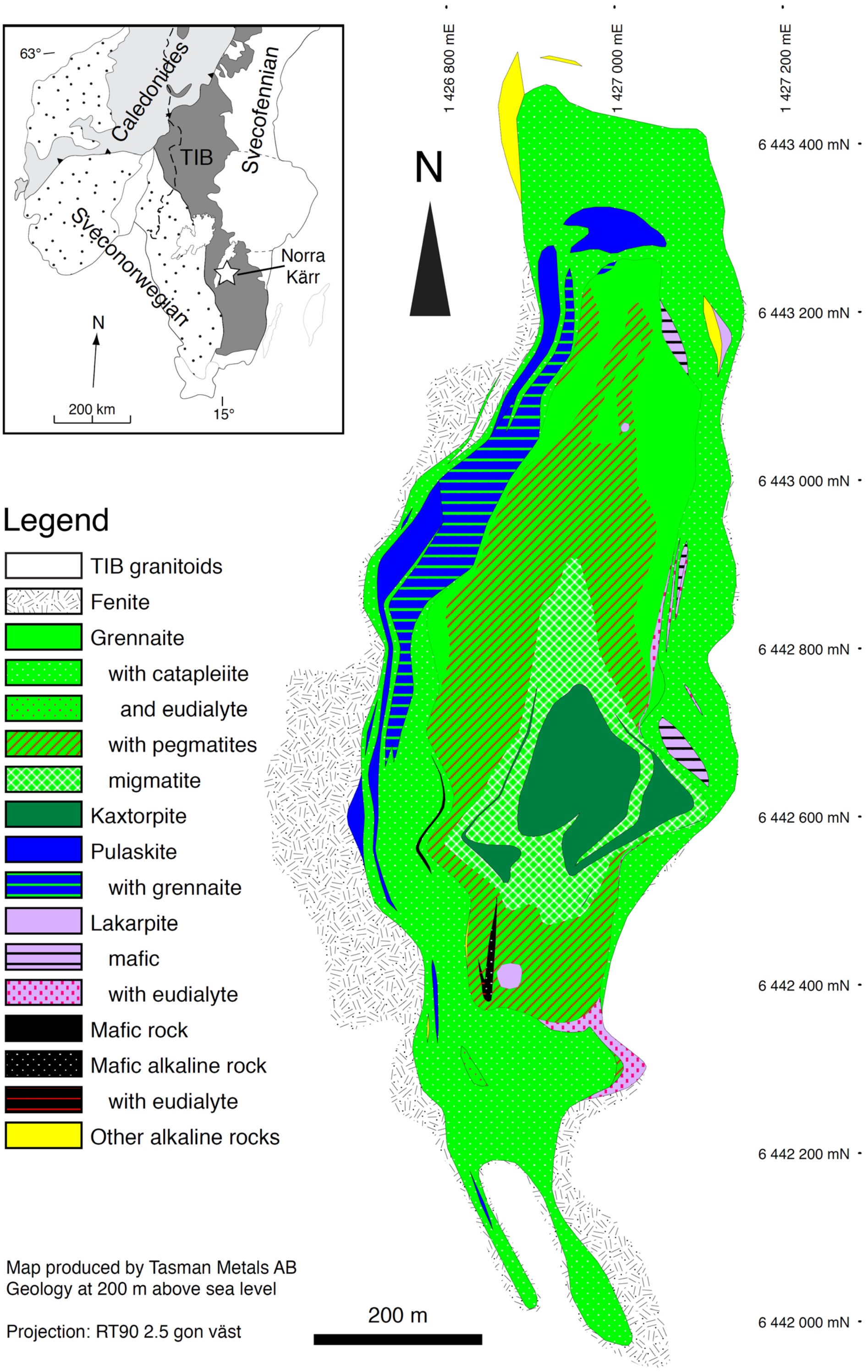

Figure 6. Geological map of Norra Kärr c[26]

The geology of Norra Kärr is shown in Figure 6. The surface has been disturbed only by exploration drilling, trenching and sampling. The Norra Kärr deposit is one of the world's largest known heavy REE resources, with an unusual enrichment in the most critical REEs that are essential for high

[26] Sjöqvist A. 2015: Agpaitic rocks of the Norra Kärr Alkaline complex: Chemistry, Origin and age of Eudialyte hosted-zirconium and Rare-Earth element ore. *Thesis for Licentiate degree. Gothenburg University, Institute of earthe sciences.*

strength permanent magnets (dysprosium (Dy), terbium (Tb), neodymium (Nd) and praseodymium (Pr)). It has a HREE/TREE ratio of 53 %, which makes Norra Kärr one of the highest HREE ratio of all large REE deposits in the world. The deposit has the capacity to supply all of the forecasted heavy REE requirements of Europe for more than 20 years and to considerably reduce reliance on imported REE mainly from China.

Information about production, tonnage, etc., stated here, refers to the PFS (prefeasibility study) published in January 2015 by GBM Minerals Engineering Consultants Limited (GBM), Wardell Armstrong International Limited (WAI) and Golder Associates (Golder) on behalf of Tasman Ltd. The PFS has been made public.

The PFS is a complete study, addressing in addition to mining and processing, all required on site and off site infrastructure, land access, reagent and fuel transport and storage, power access, water recycling and purification, waste rock and tailings storage, and final closure. The conclusions are supported by drilling, sampling and process testing. The PFS also includes the classification of the object according to NI 43-101.

Table 3. Timeline showing the prolonged procedure of receiving valid permits for the Norra Kärr project (Source; Leading Edge Materials).

2009	Exploration permit Norra Kärr No.1
2012	Prolonged exploration permits until 2015
2015	Prolonged exploration permits until 2017
2016	The Adminstrative Court repeals the decision of the Mining Inspectorate of Sweden
2017	The Court of Appeals repeals the judgement of the Administrative Court
2017	Prolonged exploration permits until 2019
2019	Prolonged exploration permits until 2024
2021	Prolonged exploration permits until 2025
2013	Mining Lease
2014	The government dismisses the appeal and decides not to repeal the Mining lease.
2016	The Supreme Administrative Court repeals the decision of the government
2016	The government returns the application of Mining lease to the Mining Inspectorate for a retrial.

In addition to REEs, Norra Kärr has the capacity to be a major supplier of hafnium (Hf) for super alloys, zirconium (Zr) for chemically resistive materials, and industrial mineral nepheline and feldspar for aggregates which would make the deposit well-utilized and minimize the waste.

According to the pfs of LEM the ore is planned to be processed via a simple flowsheet, comprising crushing, grinding, magnetic separation, sulphuric acid leaching and precipitation of a purified mixed

REE-oxalate which is calcined to form a mixed rare earth oxide product. An average annual REO output of 5,120 tonnes is forecasted, reflecting the recommendations of a market study for the most critical REEs. The PFS model provides for REE separation to individual saleable oxides by an external partner on a commercial basis. Such REE separation facilities operate within Europe today.

The Norra Kärr object is in the middle of a prolonged process of achieving all necessary permits to start mining. The process, so far, is shown in table 3. The permits have been appealed at several levels. The object has due to this process travelled up and down along the E-axis. During the process of getting all necessary permits, exploration continues on current permits.

Geology

Norra Kärr is a zoned, peralkaline, agpaitic, nepheline-syenite intrusive complex with a concentric layering (fig. 6) which has been emplaced in a rift setting. The intrusion covers an area approximately 450 m x 1 500 m in size and is more than 350 m deep, which dimensions have been confirmed by drilling. The intrusion has been dated at 1489 ± 8 Ma[27]. It intrudes older gneisses and granites of the Trans-Scandinavian Igneous Belt (dated to c. 1810–1740 Ma) in an extensional regime. It is located along a long-lived north-trending regional fault.

The Norra Kärr alkaline intrusion is enriched in zirconium (Zr), heavy REEs, yttrium (Y), niobium (Nb) and hafnium (Hf). These elements occur in minerals that are uncommon on a global scale. Mineralogical studies show that nearly all REEs are hosted by the mineral eudialyte. Eudialyte at Norra Kärr is also relatively rich in REEs compared to most other similar deposits globally. Furthermore, the eudialyte contains a high proportion of the highest value heavy REEs. The REE grade, mineral grain size and the HREE/TREE ratio varies only slightly across the deposit in a concentric manner.

It has been debated whether the Norra Kärr intrusion has been deformed and metamorphosed or not. Ar-Ar ages on sodic amphibole from Norra Kärr and muscovite and biotite from the country rocks give plateau ages at 1.1 Ga and 0.94 Ga, which correspond to ages derived for Sveconorwegian shear zones in the area[28]. Together with textural and crystal chemical evidence, these ages prove a Sveconorwegian overprint of the Norra Kärr alkaline complex.
Structural observations from Norra Kärr state that magmatic layering and orientation of early deformation fabrics suggest the body was emplaced as a sill. Three deformational phases can be observed.

- N-S to NE-SW compression giving a shallowly-dipping foliation
- E-W compression that developed a regional N-S trending synform, dipping to the west. A flattening foliation is overprinting the earlier fabric. In places, the foliation is associated with reverse thrust mylonites
- N-S compression developing a minor conjugate NE-trending kink folds.

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[27] Sjöqvist A. 2015: Agpaitic rocks of the Norra Kärr Alkaline complex: Chemistry, Origin and age of Eudialyte hosted-zirconium and Rare-Earth element ore. *Thesis for Licentiate degree. Gothenburg University, Institute of earthe sciences*.

[28] Sjöqvist A.S.L., Cornell D.H., Andersen T., Erambert M., Ek M. and Leijd M., 2013: Three compositional varietes of rare-earth element ore: Eudialyte-group minerals from the Norra Kärr alkaline complex, southern Sweden. *Minerals*, 3(1) pp 94-120

Classification according to NI 43-101

Norra Kärr is classified as a Mineral Resource according to NI 43-101. The estimation has been optimized to allow production of 5,000 tonnes per year of separated REO (rare earth oxide) over a mine life constrained to 20 years. Conventional open pit mining at an average annual rate of 1.18 million tonnes and a grade of 0.59 % total REO is assumed.
The reserves and resources of Norra Kärr are presented in table 4 and 5.

Table 4: Norra Kärr mineral reserve estimate (WAI, november 2014)

Classification	Ore Tonnes (kt)	TREO (%)	HREO (%)	% HREO in TREO	Ce_2O_3 (%)	Dy_2O_3 (%)	Er_2O_3 (%)	Eu_2O_3 (%)	Gd_2O_3 (%)	Ho_2O_3 (%)	La_2O_3 (%)	Lu_2O_3 (%)
Proved	-	-	-	-	-	-	-	-	-	-	-	-
Probable	23 571	0.592	0.314	0.531	0.124	0.0269	0.0184	0.00218	0.0196	0.00593	0.0551	0.00234
TOTAL	23 571	0.592	0.314	0.531	0.124	0.0269	0.0184	0.00218	0.0196	0.00593	0.0551	0.00234

Classification	Ore Tonnes (kt)	Nd_2O_3 (%)	Pr_2O_3 (%)	Sm_2O_3 (%)	Tb_2O_3 (%)	Tm_2O_3 (%)	Y_2O_3 (%)	Yb_2O_3 (%)	Zr (%)	U (%)	Th (%)	Hf (%)
Proved	-	-	-	-	-	-	-	-	-	-	-	-
Probable	23 571	0.0648	0.0161	0.0178	0.00396	0.00280	0.215	0.0172	1.36	0.00131	0.000663	0.0286
TOTAL	23 571	0.0648	0.0161	0.0178	0.00396	0.00280	0.215	0.0172	1.36	0.00131	0.000663	0.0286

Notes:

1) *Mineral Reserves are reported based on material contained within the Design Final Pit Shell.*
2) *Mineral Reserves are constrained a designed 20yr mine life.*
3) *Mineral Reserves are reported for combined GTM and PGT mineralisation only.*
4) *Mineral Reserves reported have been adjusted for Mining factors, at 3.5 % Dilution and 5.0 % Loss.*
5) *Mineral Reserves are reported to 3 S.F.*
6) *Total Rare Earth Oxides (TREO) includes: La_2O_3, Ce_2O_3, Pr_2O_3, Nd_2O_3, Sm_2O_3, Eu_2O_3, Gd_2O_3, Tb_2O_3, Dy_2O_3, Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3, Lu_2O_3, Y_2O_3.*
7) *Heavy Rare Earth Oxides (HREO) includes: Eu_2O_3, Gd_2O_3, Tb_2O_3, Dy_2O_3, Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3, Lu_2O_3, Y_2O_3.*

Table 5: Norra Kärr mineral resource estimate (WAI 2014)

Classification	TREO % Cut-Off Grade	Tonnes (kt)	Density (t/m3)	TREO (%)	% HREO in TREO	Dy2O3 (%)	Y2O3 (%)	Eu2O3 (%)	La2O3 (%)	Nd2O3 (%)	Ce2O3 (%)	Gd2O3 (%)	Tb2O3 (%)	Pr2O3 (%)	Sm2O3 (%)	Lu2O3 (%)
Indicated	0.2	36 821.60	2.71	0.55	53.18	0.02532	0.20053	0.00203	0.05190	0.06025	0.11560	0.01825	0.00371	0.01504	0.01647	0.00227
	0.4	31 109.16	2.70	0.61	52.60	0.02729	0.21775	0.00222	0.05729	0.06680	0.12823	0.01997	0.00403	0.01668	0.01815	0.00238
	0.6	17 124.71	2.72	0.68	52.23	0.02994	0.24290	0.00253	0.06214	0.07686	0.14413	0.02260	0.00447	0.01896	0.02083	0.00251

Notes:

1. Mineral Resources that are not Mineral Reserves do not have demonstrated economic viability
2. Mineral Resources are reported inclusive of any Mineral Reserves
3. The Mineral Resources reported have been constrained on the basis of a 20 yr. pit.
4. Mineral Resources are reported for the combined GTM, PGT, GTC and ELAK mineralisation only.
5. The Mineral Resources reported represent estimated contained metal in the ground and has not been adjusted for metallurgical recovery.
6. Total Rare Earth Oxides (TREO) includes: La_2O_3, Ce_2O_3, Pr_2O_3, Nd_2O_3, Sm_2O_3, Eu_2O_3, Gd_2O_3, Tb_2O_3, Dy_2O_3, Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3, Lu_2O_3, Y_2O_3.
7. Heavy Rare Earth Oxides (HREO) includes: Eu_2O_3, Gd_2O_3, Tb_2O_3, Dy_2O_3, Ho_2O_3, Er_2O_3, Tm_2O_3, Yb_2O_3, Lu_2O_3, Y_2O_3.
8. Preferred Base Case Mineral Resources are reported at a TREO % cut-off grade of 0.4 % TREO.

UNFC classification of the Norra Kärr deposit

The classification of the Norra Kärr project according to NI 43-101 is bridged over to UNFC classification in this report. The Mineral Reserve and Resource estimates were completed by Wardell Armstrong International Limited (WAI) and, according to them, Norra Kärr has a probable mineral reserve of about 23 kt and an indicated mineral resource of TREO with 0,4 % cut off of approximately 31 kt . “WAI is of the opinion that the Mineral Resource is robust and based on sound geological and sample data with the grade estimates representative of the sample data.”
Bridged over to UNFC classification Norra Kärr can be classified as an E2, F2.1, G2-project in accordance with table 1. In the following we will describe how we reached this conclusion.

E2 of the socio-economic axis

The exploration license of Norra Kärr project is claimed by Leading Edge Materials (LEM), previously Tasman Metals Ltd. The project was initially claimed via exploration permit "Norra Kärr No.1" valid for three years, first granted 31st August 2009. Today the project consists of four claims, Norra Kärr No 1, No 2, No 3 and No 4, in total approximately 5000 ha. These exploration licenses have been renewed on two prior occasions, and a request for a three year extension was submitted to the Swedish Mining Inspectorate ('Bergsstaten") during August 2019. This permit is valid until 2023. Today, LEM has received a prolonged exploration permit until 2025 due to the covid-19 pandemic. However, this permit has been appealed and LEM awaits the result.
A 25-year Mining Lease (exploitation concession) was granted to Tasman Metals AB covering Norra Kärr in 2013 following submission of substantial application documents. Both relevant permitting authorities ("Bergsstaten" and Länsstyrelsen) approved the granting of the Norra Kärr Mining Lease. The project is classified with a probable reserve which means that at this stage, the object moved upwards on the E axis to an E1.

In March 2015, Tasman published a comprehensive PFS for the Norra Kärr project. The project stands out as one of few advanced heavy REE projects globally, and the only one that can produce more than 200 tonnes per year of dysprosium oxide for more than 20 years with a capital investment of less than US$400 million.

In 2016, following an appeal to the Supreme Administrative Court of Sweden regarding the decision-making process of the Mining Inspectorate of Sweden (Bergstaten) and the subsequent decisions taken by the government, Bergsstaten has requested further information from the Company, including a Natura 2000 assessment regarding the potential future impact of a mine neighboring Natura 2000 sites in the region. Natura 2000 areas do not exist in the Mining Lease aApplication area. Due to the appeal, the Norra Kärr deposit reversed on the environmental socio-economic scale from E1 to E2. The project will move back to E1 if all the permits are granted and final plans for the REE open pit mine are done. A simplified timeline is presented in Table 3.

F2.1 on the feasibility axis

The project is a development pending project classified as F2.1[29]. Extensive metallurgical tests have been done on representative samples from Norra Kärr.

According to LEM, the Norra Kärr deposit is well suited to open pit mining which leads to a relative low cost of mining.
Mineralogy has shown that the only REE-bearing mineral with significant abundance at Norra Kärr is the zirconosilicate eudialyte. Eudialyte is weakly magnetic (paramagnetic) and dissolves rapidly in weak acid at low temperature. As a result, an uncomplicated flow sheet has been developed that can be achieved with standard mining and processing equipment and widely available chemicals. Furthermore, the non-magnetic fraction from the bedrock constitutes of nepheline and feldspar. It is probable that these "waste products" find a market of their own. So far, no full-scale experiments in processing REE from eudialyte are done. When these are done, the project will move up to an F1.

G2 on the geology axis

The geology of the area is considered to be known. Mapping and drilling have been done by several exploration companies. Mapping on a regional scale as well as local scale have been done by SGU and several detailed research project, have been published from Norra Kärr. Tasman Metals Ltd (now Leading Edge Materials, Sweden) has carried out an exploration program comprising geological

[29] UNECE United Nations Framework Classification of resources. Update 2019

mapping, geophysical surveys, structural mapping. In total, 119 surface diamond holes with 20,420 m in length has been drilled. The PFS by GBM and WAI is presented and concludes that the sample data is both accurate and precise and the risk of biased sampling affecting the Mineral Reserve and Resource estimates are low.

The Kiruna-Malmberget secondary resource deposit

LKAB

LKAB Minerals is an international industrial minerals company in a leading position in Sweden with a number of products. The company has two main business areas, iron ore and special products. LKAB Minerals is a part of LKAB, an international high-tech mining and minerals corporate group, mining and refining Swedish iron ore for the global steel market. The Swedish government is the sole owner of LKAB.

Sweden is the number one producer of iron ore in Europe with more than 90 % of the European production and LKAB is the main producer. Sustainability is the core of the company and its ambition is to be one of the most innovative, resource efficient and responsible company in the industry. The turn-over for the corporate group, was about 31 billion kronor in 2019. The group has approximately 4 300 employees in 12 countries, and includes industrial minerals, drill systems, train cargo, and real estate. In 2019-20 the company invested approximately 700 million kronor in exploration.

Mineral reserves and resources from all of LKABs mines are reported at LKAB website[30]. in 2018 the Kiruna mine reported a proven mineral reserve of 624 Mt and a probable mineral reserve of 62 Mt. Corresponing figures from Malmberget are 346 Mt and 23 Mt. From Leväniemi mine in Svappavaara corresponding figures are 87 Mt and 9Mt. LKAB is currently working on a PERC classification of the REEMap project. It will be published in 2021. When this is done it will be an excellent opportunity to see how well the UNFC classification correspond to the PERC classification.

The magnetite deposits with or without haematite of Kiruna and Malmberget have mineralogical and textural features that are different to most other types of iron deposits in the world. Most characteristic is the presence of apatite as an important gangue mineral, which contributes to high phosphorus content of the ores[31]. Apatite occurs mainly as disseminated grains in the ore or form band, schliren or veinlets. Disseminated apatite occurs interstitial to magnetite as subhedral and equidimensional or prismatic grains up to 0.5 mm large[32].

REEs from mining waste from iron ore operations in Northern Sweden

In a press release from 29 of May[33] 2020 LKAB present a pilot study in how to produce apatite from mining waste. Furthermore, LKAB states that they expect to produce about 400 000 ton apatite /year from using only falling waste from Kiruna and Malmberget.

[30] https://www.lkab.com/en/about-lkab/from-mine-to-port/exploration/mineral-reserves-and-mineral-resources/

[31] Frietsch R. & Perdahl J.-A. 1995: Rare earth elements in apatite and magnetite in Kiruna-type iron ores and some other iron ore types. *Ore geology reviews v.9* p. 489-510.

[32] Pålsson B.I., Nartinsson O., Wanhainen C. & Fredriksson A. 2014: Unlocking rare earth elements from European apatite iron ores. ERE2014 First Euroean rare eath resources conference. Milos.

[33] https://www.lkab.com/en/press-releases/lkab-produces-apatite-from-mine-waste-in-a-new-pilot-plant/

In late September 2020, LKAB Minerals announced its plans to invest in a new fossil-free industrial park (ReeMAP) to produce, e.g., REEs, gypsum, and phosphorus-based mineral fertilizer from its mining waste, originating from its significant iron ore production [34] [35]. Within the ReeMAP-project, LKAB is now developing techniques for recycling its waste and has decided to increase its ambition to also switch to producing DRI (direct-reduced iron) instead of today's pellets and to produce input goods, including hydrogen gas, and to electrify the processes to eliminate CO_2 emissions in the process.

The industrial park is aimed to contribute with to up to 30 % of Europe's present demand of REEs. The operations will ship one million tons of products a year in total and therefore the existing infrastructure with trains and connecting harbours is of essence. At the moment, LKAB is looking at the municipalities Skellefteå, Luleå and Helsingborg with well-functioning harbours, for establishing the industrial park.

Waste Deposit

The iron ore of the LKAB mines is mainly magnetite, associated with apatite (a calcium phosphate). Apatite of the Kiruna ores shows a common pattern with 2000–7000 ppm REE, with a weak to moderate LREE/HREE fractionation[36]. Total contents for rare earth element oxides (REO) in fluor apatite such as the apatite from Kiruna and Malmberget including only La, Ce and Nd are in the range of 0.04 to 0.91 with an average of 0.25 percent by weight.[37]

REEs are mainly found in apatite which is thereby the main mineral of interest. To a lesser extent other REE bearing minerals are found. Due to the relatively low content of REE in the apatite, recovery of REE will be done in conjunction with fertilizer production as well as gypsum, which increases the operation's resource efficiency and decreases its economic risk. According to Pierre Heeroma and Niklas Johansson, LKAB (pers. comm.), the economic calculations for the industry development are insensitive to world market prizes on REEs. Also, after intense investments in exploration over the last few years, the life of mine now reaches beyond 2060. For the entire development project, LKAB plans on investing between one and two billion euros yearly for 15 to 20 years to come.

[34] https://www.lkab.com/en/about-lkab/technological-and-process-development/research-collaborations/reemap--dagens-avfall-blir-morgondagens-resurser/

[35] https://ree-map.com/

[36] Frietsch R. & Perdahl J.-A. 1995: Rare earth elements in apatite and magnetite in Kiruna-type iron ores and some other iron ore types. *Ore geology reviews v.9* p. 489-510.

[37] Pålsson B.I., Nartinsson O., Wanhainen C. & Fredriksson A. 2014: Unlocking rare earth elements from European apatite iron ores. ERE2014 First Euroean rare eath resources conference. Milos.

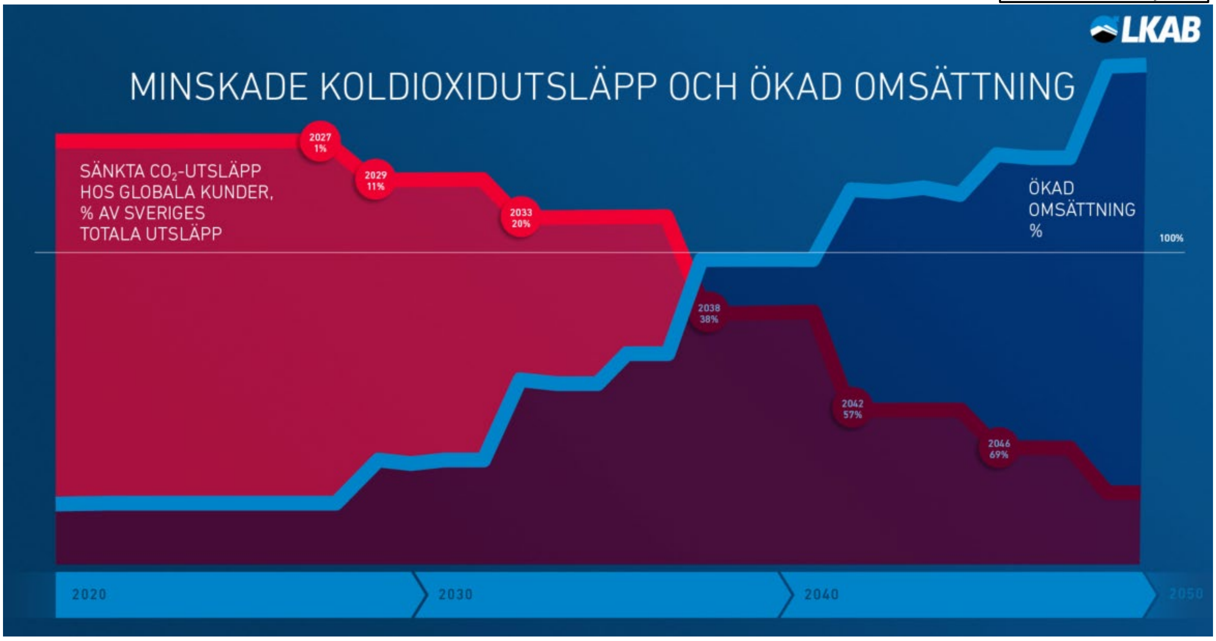

Figure 7. Diagram showing decrease of CO2-emissions with global customers with each step of development (in red), and simultaneous increased turnover (in blue). Source: LKAB.

Sandström and Fredriksson (2012)[38] described a procedure with leaching of REE from apatite residue from LKAB mining waste, where an apatite concentrate is produced by flotation.
Different acids were used in experiments of leaching the REE from the apatite concentrate. Both hydrochloric and nitric acid resulted in good results. Nitric acid is preferred due to a less corrosive media than hydrochloric acid. Sulphuric acid resulted in a huge amount of gypsum. With proper pH control, REE can be effectively precipitated from the nitric acid leachate by ammonia addition, thus providing possibilities of producing both REE and fertilizer.
Furthermore, Sandström and Fredriksson (2012) showed that the recoveries, of the heavier elements were slightly higher than those for the lighter ones. The work of optimizing the extraction of REE from the apatite by hydrometallurgical means is still in progress.

UNFC of the LKAB waste deposit

As of now, ReeMAP can be classified as an E2, F2, G1-G2-project and in the following we will describe how we reached this conclusion.

E2 on the socioeconomic axis

The ongoing feasibility study is expected soon to be completed. The plan is to reach full production capacity of REEs in 2027, if environmental permits are granted and construction can start.

A mine can't be moved since its location must be where the ore is, and hence there are often issues related to the competition of land that needs to be solved for such an operation to be fully permitted. An industry like the one LKAB is planning, to refine REE concentrate, is less restricted when it comes to location, nearness to infrastructure is a key but apart from that there is less restrictions for location than for an ordinary mining operation. It will make it possible to look into places in industrialized areas, more or less prepared for new industries to move in. This means that the permitting process should be much more straight forward than for a mining operation.

[38] Sandström Å. and Fredriksson A .2012: Apatite for extraction-leaching of Kirunavaaraapatite for simultaneous production of fertilizer and REE. International Mineral Process Congress (IMPC) 2012. India

Once the location has been decided, the application for environmental permit can be finalized and the process be moved forward. For this there are no obvious obstacles in terms of low predictability that can be identified at this time.

Also, since the mining waste at hand originates from ongoing operations with full permits, it will be more straight forward than would be the case with historical mine waste if concessions and environmental permits are absent. As of now it is not clear from Swedish legislation how historical waste should be treated from a legal and permitting perspective if someone would like to use it as a resource.

However, there are challenges, especially when it comes to time constraints. Environmental permitting processes for the mining and minerals industry have developed to be long and fairly unpredictable in Sweden. In this case LKAB has an ongoing application for comprehensive permits for the operations in Malmberget and Kiruna. This is also where LKAB will locate the apatite plant extracting the apatite from the waste before it can be processed to REE concentrate. The comprehensive permitting process for the mine sites can potentially affect the entire timeline for the REE project.

Government agencies as well as the company have the ambition to achieve a high degree of environmental performance. LKAB hope to, aided by the authorities, being able to satisfy all requirements and that the process will be efficient and helps to create environmental benefit by realizing the ReeMAP project.

With all permits in place to become operational ReeMAP will be transferred to an E1.

F2 on the Feasibility axis of the UNFC

With the announced investment plan the financial part of the F-axis is clearly a F1. However, there is still development of the processes going on within ReeMAP, and the construction plans are not finalized so therefore we would say the project is in the F2-stage, safely on its way to an F1 later this year.

What will be key to the success of the ReeMAP project is the development of the hydroprocess, where most of the new technology will be developed. According to LKAB there is currently no comparable upgrading process that creates high-grade products while utilising by-products.

Several of the sub-stages make use of known and proven process technology but the challenge is in matching them to an effective and economically sustainable process which meets high expectations for product quality.

As of now the development takes place in a lab setting and in bench-scale tests. The results are planned to be forthcoming in 2021, will be a decisive factor for realising the project.

The ongoing feasibility study is expected to be completed by the end of 2021. The idea is to reach full production capacity in 2027, if environmental permits are granted and construction can start on plan.

The G-axis on the geology axis- G1 + G2

The waste that is going into this process is considered well known, there are several research studies done throughout the years[39] [40] [41]. The mineral character as well as the REE content is known and described in those studies. In the light of these studies and research within LKAB, the company can announce that it will be able to contribute with 30% of EUs present REE-demand.

In addition to that and according to LKAB, the facility will produce five times the present need of phosphorous fertilizer for Sweden, with the opportunity to save up to 700 000 tons of CO2 emissions (corresponding to 1% of Sweden's total emissions in 2019) compared to the alternative of increasing the production of mineral fertilizers with the technique that is traditionally used today.

Conclusions, Challenges and Experiences

This report demonstrates that classification of a mining or exploration project from public information is possible and fairly straight forward. Furthermore, bridging over from a project classified according to CRIRSCO codes is also quite easy., The ORAMA guidelines has proven to be very helpful in this project. The UNFC is not a competing system to the CRIRSCO codes, however, it adds the environmental and socio-economic viability to the classification. In doing classification based on public information, CRIRSCO templates are essential and makes the UNFC classification easier and more accurate.

Looking at the tree projects classified above, it is clear that a challenge and maybe one of the largest risks of a Swedish mining or exploration project failure, is the permitting process. Several projects in Sweden have been delayed due to complicated permitting processes with far-reaching possibilities to appeal decisions from legal instances. The delay in the process is costly and can itself cause a failure.

In March 2021, the Swedish government announced a governmental study to improve permitting processes in terms of transparency and predictability with the aim of ensuring access to innovation critical raw materials. The outcome of this work will be reported in October 2022.

[39] Frietsch R. & Perdahl J.-A. 1995: Rare earth elements in apatite and magnetite in Kiruna-type iron ores and some other iron ore types. *Ore geology reviews v.9* p. 489-510.

[40] Sandström Å. and Fredriksson A .2012: Apatite for extraction-leaching of Kirunavaaraapatite for simultaneous production of fertilizer and REE. International Mineral Process Congress (IMPC) 2012. India

[41] Pålsson B.I., Nartinsson O., Wanhainen C. & Fredriksson A. 2014: Unlocking rare earth elements from European apatite iron ores. ERE2014 First Euroean rare eath resources conference. Milos.