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# Gold assay precision in different geological environments: nugget and cluster effects

Esa Sandberg

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**GEOLOGICAL SURVEY OF FINLAND**

Bulletin 413

# Gold assay precision in different geological environments: nugget and cluster effects

by

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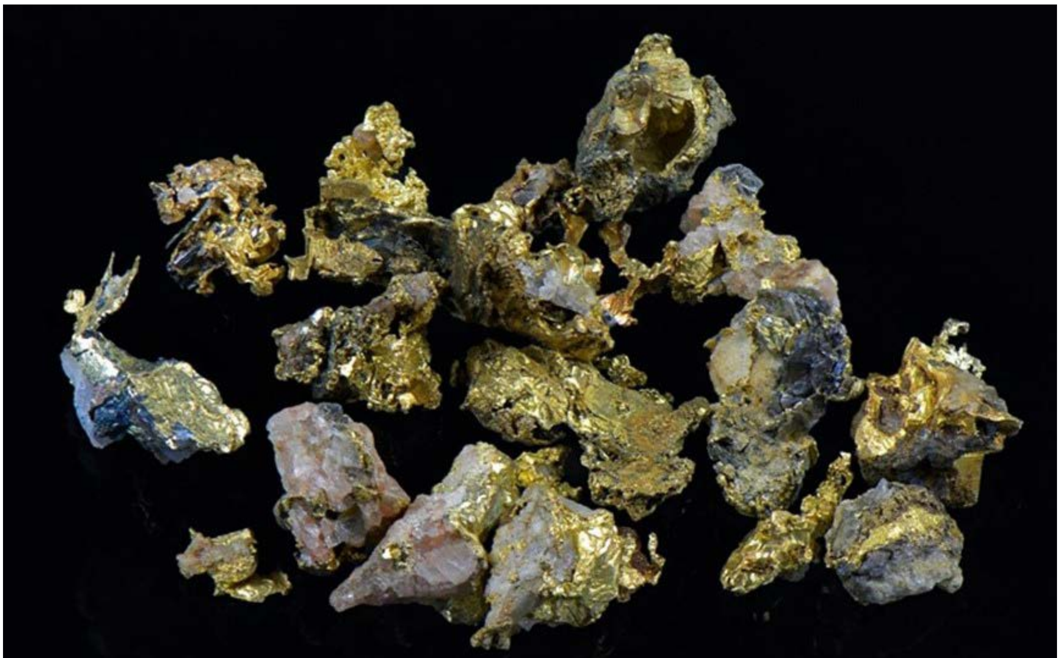

Panned gold from weathered bedrock at Pampalo, Finland.

Unless otherwise indicated, the figures have been prepared by the author of the publication.

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The precision and accuracy of analysed grades are key factors when interpreting geochemical data. The poor precision of gold grades has caused many problems and errors in the history of exploration and mining. The precision of natural gold grades with a special emphasis on nugget and cluster effects, was investigated in three areas in Finland representing different geological formations and gold occurrences. The Pampalo and Rämepuro deposits in Ilomantsi belong to the Late Archean Hattu Schist belt. The host rocks are intermediate andesitic tuff with feldspar porphyries in Pampalo and a sheared contact of sedimentary and volcanic rocks intruded by feldspar porphyry and a quartz-tourmaline breccia vein in Rämepuro. The grain size of the mainly native gold is below 100 µm in both deposits. The Juomasuo and Hangaslampi deposits are located in the Kuusamo Schist Belt. The host rocks of gold are strongly altered quartzites, sericite schists and greenstones. Gold is mainly native and the grain size is also mainly below 100 µm. The Suurikuusikko deposit in Kittilä is situated in the Central Lapland Greenstone Belt. Gold occurs as submicroscopic inclusions in pyrite and arsenopyrite.

Altogether 2525 bedrock samples from drill cores were included in this study, and 1130 till samples collected from pits for this study. Additionally, data on 2928 rock and 4355 till samples from regional studies, carried out by different organizations, were available and used in the analysis. The total number of samples was 10 938. Various analytical methods for Au were applied in different phases and for different sample materials.

The precision of gold grades in un-weathered bedrock was examined by using both replicates and duplicates of drill holes, drill cores, crushed rock and pulp samples in Ilomantsi, Kuusamo and Kittilä. Data from 75 globally located gold deposits was used for references and for comparison with the study deposits. The precision of half-core samples was used to compare and confirm the nugget effect of variograms in geostatistics. Precision improves in the four-step processing chain of twin holes–half cores–crushed rocks–pulps because of the reduction of the cluster effect in the chain. Most of the variances arises in primary sampling, and the variances are in the size order: sampling > preparation > analysis. Bedrock precision results were compared with the 75 reference gold deposits. Precision was found to generally improve from field replicates/duplicates to crushed coarse rejects and finally to pulp duplicates. The primary grain size of gold in the deposits correlates with precision, and precision is commonly poor in deposits with coarse-grained gold.

Precision tests on till included the analysis of replicate and duplicate samples from excavated sampling pits and a sampling system of till panels on excavated pit faces in the three target areas. Variances in the test panels between the different sampling sets were small, and a similar clear separation of the nugget and cluster effects as for the rock samples could not be made. Variances of the Kittilä panel were slightly smaller than for the other panels, perhaps reflecting the primary fine grain size of gold. The distributions of gold and a few other elements are compared with the regional datasets. In general, gold was found to have no or a weak correlation in the dataset with other till sample types or fractions or accompanying elements. Moreover, the replicate and duplicate tests indicated no correlation, with a few weak exceptions. The analogous correlations of the other studied elements were clear and positive. The means and distributions of gold grades in the till panels were close to the regional till data. For the other elements, the difference in these grade means and distributions was very clear, highlighting the dissimilarity with gold. Variances in the process chain of sampling–preparation-analysis differed from those of the bedrock samples. Most of the total variance was included in analysis, and the size order of variances was: analysis > primary sampling > preparation. The whole chain should be supervised and assessed, but a special attention should be focused on analysis and sampling. The precision of 60 Canadian till sampling projects examined for reference in this study was found to be quite similar. A low precision of gold seems to be typical in both field replicate and laboratory duplicate tests, resulting in significant uncertainties in regional gold sampling data.

Understanding and acceptance of the poor precision of gold in bedrock and till samples is essential in both exploration and mining. In exploration, this can be compensated for, but only to some extent, by utilizing pathfinder elements or other indications of gold. In mining, the precision of gold mostly affects stope estimations, for which commonly only few analyses are available. All the other indications of gold should be used to help in the estimation.

Keywords: precision, gold, nugget effect, cluster effect, geochemistry, bedrock, till, sampling, preparation, analysis, Ilomantsi, Kuusamo, Kittilä, Finland

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# 1 INTRODUCTION

The reliability of a chemical analysis or other measured result is a necessary basis both for research and industrial activities. The Theory of Sampling (TOS) has been widely studied, because it has so many applications, of which geological sampling is only one. An analytical or other result is a combination of two factors: accuracy and precision. The first indicates how close a value is to the "*true*" value within acceptable error limits, and precision is the variation in the values when repeating analyses. Precision and accuracy are important in all sciences, in which the results, conclusions and interpretations are based on various types of measurement. They should also be clearly separated from each other and not only expressed as general variation or error. Precision is an important factor when interpreting results in both mining and exploration. In mining, it mostly has an impact on practical mining operations, where decisions often have to made with limited analytical data. In exploration, especially in greenfield exploration, ignorance of precision can lead to fatal interpretation errors in the selection of detailed sampling or drilling targets.

Precision is often investigated as a statistical phenomenon (Gy 1982, Pitard 1993), but less in practical geological sampling (Abzalov 2016). The Quality Assurance and Quality Control (QAQC) are commonly limited to reference assays for accuracy and laboratory pulp duplicate tests for precision. Often, statistical theories are too complicated to be applied under field work conditions. Gold differs from base metals in having poor precision and an almost non-existent correlation with other elements. These factors might also have reduced the use of proper precision in investigations. It is easier to interpret one number than two different numbers. Contradictory results are frequently only commented on as a possible nugget effect without further interpretation.

An analytical result is a combination of sampling and analysis. Sampling consists of primary sample selection together with sampling and sample preparation for the analysis. Dr. Pierre Gy´s theories about sampling (Gy 1982) have formed the basis for many practical applications in exploration and mining. Commenting on Gy´s theories, Francis Pitard noted as "*the work of Dr. Pierre Gy on sampling of particulate materials is unique, complete, statistically accurate, precise and unambiguous*" (Pitard 1993). In Finland, Pentti Minkkinen has studied the theory with many practical applications (Minkkinen 2004) and prepared a computer program for solving sampling problems (Minkkinen 1989).

Gold is the most commonly targeted element in exploration and mining. During the last decades, gold has had the largest exploration budgets globally. In 2011-2015, 40-50% of the total mineral exploration budgets in the world were focused on gold (Wilburn & Karl 2016). Gold is also one of the most studied elements (Boyle 1979, 1987). It has more problems due to variation in the grade than other common metals and minerals because of its high specific gravity, heterogeneous occurrence and rarity. The sampling of gold is one of the greatest challenges in the mining industry and there is probably no other material for which the sampling precision and accuracy is so critical (Chieregati & Pitard 2009). Problems in the interpretation of results are the reasons for common anecdotes in both exploration ("*Gold is where you find it*") and mining ("*You know the grade of a gold deposit first after you have mined it out*"). Furthermore, many gold swindles have occurred, the worst being the Bre-X Busang project in the 1990s (Danielson & Whyte 1997). Other common precious heavy metals include the platinum group metals and silver. However, they mainly form various minerals with lower specific gravities. Gold with economic value is mainly native, but the grain size and form considerably varies from roundish nuggets to flakes and fibrous forms.

In Finland, gold has been one of the most important commodities in both exploration and mining during the last 40 years. Reduced costs and improved analytical methods led to an expansion of gold exploration in the 1980s resulting in many new discoveries. Increased understanding of its behaviour in the procedure chain from sampling to chemical analysis has improved both interpretation in gold exploration and economics in mining. Problems have been noted in both exploration and mining (Hautala 1991, Kontas 1991, Lamberg 2003, Sandberg 2003a). In the 1980s, QAQC was not included in gold exploration programmes, but since the 1990s its importance has been widely accepted. Gold is such a problematic element that there are still many open questions to be resolved.

The following abbreviations and determinations are used in this text:

| | |
|---|---|
| Geological Survey of Finland | GTK |
| Outokumpu Mining Oy | OM |
| Arithmetic mean | $\bar{x}$ |
| Half absolute relative difference | HARD |
| Pearson correlation coefficient | r |
| Quality assurance / quality control | QAQC |
| Standard deviation | s |
| Theory of sampling | TOS |
| Precision (coefficient of variation) | $\sigma$, CV |
| Precision as a percentages | CV% |
| Variance (relative variance) | $\sigma^2$ |
| F-factor (variance ratio) | $\sigma^2_{Regional} / \sigma^2_{Local}$ |

| | |
|---|---|
| Metre | m |
| Square metre | $m^2$ |
| Cubic metre | $m^3$ |
| Centimetre | cm |
| Millimetre | mm |
| Micrometre | µm |
| Parts per million | ppm (= grams per tonne, g/t) |
| Parts per billion | ppb |

All the coordinates are national ETRS-TM35FIN coordinates and map sheets are based on the KKJ-coordinate system.

## 2 AIMS OF THE STUDY

This study has focused on three main topics:
- The precision of gold grades in sampling, compared to a few other common accompanying elements in different geological environments,
- The distribution of precision along the procedure chain of sampling – preparation – analysis, with an estimation of nugget and cluster effects,
- The effects of precision on gold grade interpretations in exploration and mining.

Under the first topic the precision of gold was compared to a few other elements, which are important pathfinder elements in gold exploration and mining. This study focused on three gold-mineralized areas in Finland. Un-weathered bedrock and till were the sampling media, because they are the two materials most commonly used in exploration in glaciated terrains. Precision was examined using practical tests conducted by the author during the last 30 years and the data of the Geological Survey of Finland. These test results were preferred to theoretical statistics to allow easy exploitation in practical exploration and mining. In addition, the QAQC data of mining companies, which are commonly for internal use of the companies only, were applied.

Under the second study topic, the aim to clarify precision differences and distributions starting from primary sampling and finishing with analysis. After identifying the steps with the lowest precision in the procedure chain, the targets for attention to increase the total precision were determined. Nugget and cluster effects are important interpretation tools for precision.

Poor precision increases the uncertainty in the interpretation of an anomaly and in assessing the importance of single analysis in both exploration and practical mining. This study aimed to increase understanding of this uncertainty and provide recommendations for how it can be resolved.

# 3 THEORETICAL BACKGROUND

## 3.1 Precision

The definitions of many fundamental terms in statistics are often variable and ambiguous. This study mainly followed the definitions of Pitard (1993) and Abzalov (2016).

Precision or repeatability is the variation in grade when sampling, preparation and/or chemical analysis is repeated. Sometimes, it is erroneously used as a synonym for accuracy. Accuracy is the difference from the true or correct value. A good example of this difference is illustrated in Figure 1. The figure assumes that the correct value is in the centre of the dartboard.

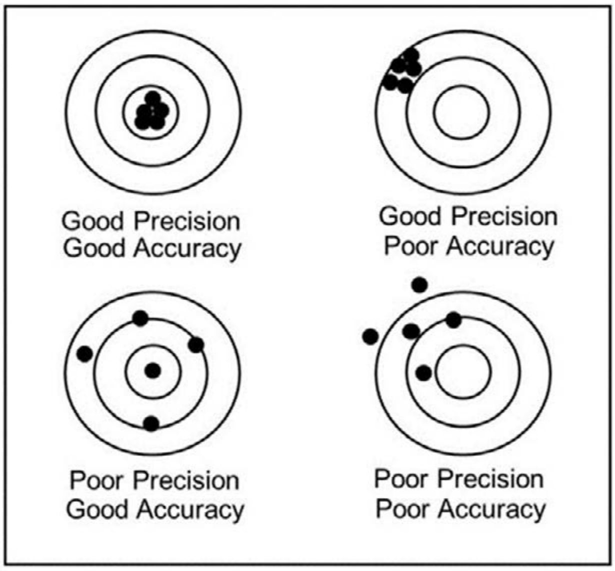



Fig. 1. A practical example illustrating the concepts of precision and accuracy (Abzalov 2011).

Total precision can be subdivided into natural precision (Fundamental Sampling Error, Pitard 1993, Abzalov 2011) and "*man-made*" errors. Fundamental Sampling Error cannot be avoided, but can be estimated, if relevant factors are known. The second error group includes errors in sampling and preparation procedures, including delimitation, extraction, preparation, weighing and human errors (Abzalov 2011). The errors and precision in chemical analysis comprise the third group of errors, but they were excluded in this study. Since the first theories of Gy (1967), in TOS (Theory of Sampling) the term "*error* " has been used instead of "*uncertainty*". Error indicates mistakes and Pitard (2017) proposed the world "*uncertainty*" should be reserved only for those who have worked very hard to use correct sampling methods and practices and attempted to minimize errors. This would be a reward for working appropriately. In this study, precision was regarded as the combination of uncertainty and error, because errors (such as mistakes) can only be minimized but not completely excluded. *Precision* or *variation*, as terms, are used here instead of *error*.

In geological samples, variation is commonly presented as relative variance (the power two of the precision), and can be easily divided into:

– sampling,
– preparation and
– analytical variances.

Together they form the total variance. Based on the author´s experience in various projects, these variances are usually in decreasing size order: sampling > preparation > analysis. They consist of fundamental sampling (FSE) and grouping and segregation (GSE) errors, which all are irreducible random errors related to the inherent heterogeneity and characteristics of the material (Clark & Dominy 2017). Other errors arise as a result of the sampling practice and instruments. FSE and GSE are included in both sampling and preparation. They are likely to contribute between approximately 50% and 90%, and extraction and analytical errors up to 25% of the total sampling error (Pitard 1993). A test by the author on an Iranian copper (chalcocite) deposit resulted in variances of 50% of the total variance in sampling, 30% in preparation and 20% in analysis, which is consistent with the estimates of Pitard. These three steps are usually carried out in a separate place and time, and this splitting is then practical to apply. Abzalov (2011) distinguished three groups of errors:

– sampling protocol (planning of sampling, site, sample size, sampling method),
– sampling practice (running of sampling, contamination, mis-sampling, etc.) and
– analytical errors.

Dominy (2017) classified errors in a similar way into: 1. correct sampling error (CSE) and 2. incorrect sampling error (ISE). The first two groups of errors proposed by Abzalov and Dominy are included in both the sampling and preparation phases. Moreover, in the analytical phase the first group (sampling protocol) estimates whether the method and instruments are suitable and unbiased for the material and element analysed and the second group (sampling practice) whether the analytical practice is appropriate and errors are minimized.

The relative variance, calculated as the standard deviation to the power two divided by the mean, is additive in each step. The power nature points out the importance of the highest standard deviation in the procedure chain. It is essential to determine which parts are included or where the precision test procedure starts, because each step has its own variance. The fourth variance source in each of the three groups listed above is always "*human factor or error*", which includes mixing of samples, contamination, and other results of irresponsible or unprofessional working practices. It is included in the second group of Abzalov (2011) and Dominy (2017).

Precision and concentration also have an established relationship (Thompson & Howarth 1978). Concentrations near the detection and upper limits have poor precision compared to the optimal level for the instrument used in the analysis (Fletcher 1981). Commonly, precision is an average over the concentration range.

This study concentrated on precision. Variation or biases in accuracy naturally also add to the total precision, but both the analytical accuracy and precision are expected to be stable and unbiased. Precision was not determined "*senso stricto*" but in a broad way from a practical sampling point of view: when sampling one particular point or one centimetre or one meter to the side of it, what is the influence? In this sense, it could also be referred to sampling variance or sampling error (Abzalov 2011). Precision decreases when the distance between analysed samples increases. This was tested from the metre to the micron scale and subdivided into four categories (Table 1).

Table 1. Heterogeneity categories in the testing of variation related to the sampling material. Cluster and nugget effects are defined in the chapter 3.2, and replicates and duplicates in chapter 3.3.

| Sampling material | Distance between samples | Testing method | Dominating heterogeneity |
|---|---|---|---|
| **Drill holes** | m | Variography | Cluster effect |
| **Half or quarter core** | cm | Replicate tests | Cluster + nugget effect |
| **Crushed sample** | mm | Duplicate tests | Nugget + cluster effect |
| **Pulverized sample (pulp)** | µm | Duplicate tests | Nugget effect |

A drilling grid usually varies in mines or developed deposits from 10 to 50 metres. This is too large a distance to test precision in the sense usually defined, because geology and mineralogy change over this distance. Grade variations are often tested by variography, first introduced by Matheron (1963). Variography indicates the correlation between element grades from hole to hole, giving an indication of the deposit structure. In a variogram, the range means the maximum distance at which the correlation or covariance drops to zero. The nugget value is the theoretical amount of precision at the zero distance (David 1977, Guibal 2001). It is an extrapolation of the variogram curve in variogram modelling and commonly presented as a percentage of the total variance, the sill value. Some disagreement exists whether the sill value can be used as an estimate of the population variance (David 1977, Barnes 1991, Abzalov 2016).

In practice, a drilling grid is never so tight that a real nugget value in variograms can be estimated, and samples taken at close to zero distance apart (here referred to as replicates) do not exist in the data base. The nugget value in variography is caused by sampling errors and geological factors reflecting the microstructures, whose continuity is shorter than the smallest distance between the samples (Abzalov 2016). The nugget value is determined using metre-scale drilling data, often giving excessively high nugget values. The closest samples are in the direction of drill holes, which commonly is the same as the shortest range direction of variography. Combining variography and half-core replicate data could give more accurate figures for the real nugget value. Abzalov (2016) presented the nugget effect as a combination of sampling error and a geological factor, which could be separated using a pair-wise relative variogram for total precision and an average coefficient of variation of the duplicated samples for sampling error. The difference is the geological factor of the estimated distance. If the pulp duplicates are defined as duplicated samples by Abzalov then the "sampling error" is the same as the "nugget effect" referred to here by the author and the "geological factor" is the "cluster effect".

A typical core diameter in diamond drilling is 50-60 mm. The mean particle distance between half or quarter cores is 20-25 mm. The smallest clustering textures are millimetres in size and the cluster effect is dominant, connected with the varying size of the nugget effect, depending on the gold mineralogy type. Replicate sample pairs are either half core-quarter core or half core-half core. The former is likely to produce lower precision than that of half core-half core replicates (Abzalov 2016). In coarse-grained gold deposits, sampling of the whole core can yield higher gold grades than half core samples obtained by sawing, because the saw blade removes of gold and gold-bearing sulphides from the cut surfaces (Pitard 2009, Dominy 2014). The gold grade of the cuttings can then be much higher than the grades of the halves, reducing the real grade of the core halves (Dominy 2017). In this present study this was not a problem because half-core samples were not compared with whole-core samples and the grain size of gold was not very coarse.

The preparation procedures of drying, crushing, grinding and splitting, in various phases, are important stages affecting the total precision. After crushing, the maximum particle size is 2-5 mm and the mean particle size approximately 1 mm. The nugget effect is now dominant, but in a fine-grained gold deposit with strong textural deformation, the cluster effect significantly affects the total precision.

In a pulverized sample, most of the grains are below a few tens of microns and the gold is present either as free nuggets or as mixed gold-bearing particles, depending on the gold deposit. Then, the cluster effect has practically no effect on precision.

### 3.2 Nugget and cluster effects

Nugget and cluster effects are the two main factors in precision. The principles of these two factors influencing grades are illustrated in Figure 2. The nugget effect arises when a sampling material contains few desired particles and these are randomly located in the sampling material. The cluster effect occurs when the particles are enriched in one or many spots, which in geological material is commonly in a certain structure or texture. This is often referred to as the *distribution heterogeneity of the material* (Pitard 1993, Dominy & Platten 2007), but the cluster effect as term better describes the heterogeneity style of gold particles. The heterogeneity is not statistically random, because it is

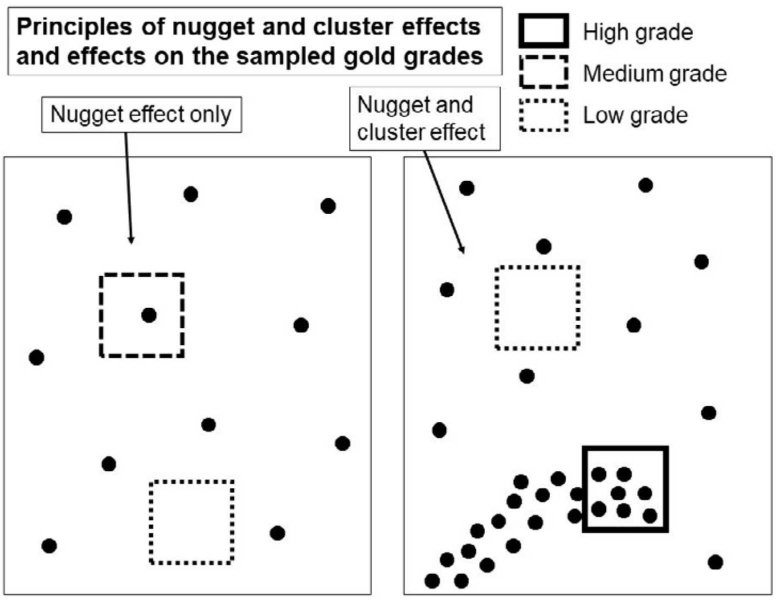



Fig. 2. Principles of the nugget and cluster effects and their influence on the analytical results by the author. Black points indicate rare mineral grains, for example gold grains. Squares denote theoretical blind sampling sites.

determined by the geological history of the sampled material. Villanova et al. (2017) proposed the definition of a cluster as "*an agglomerate of nuggets, associated or not with a discontinuous structure, which could not separate in any comminution stage*". Often, this cluster effect is also known as "*clustering of nuggets*". The nugget effect is always also included in the cluster effect, but in this report the combination in which the cluster effect is the dominant factor is only referred to as a cluster effect.

The influence of the nugget and cluster effects on precision depends on the distance between replicate/duplicate grains, as illustrated in Figure 3. In pulp samples, the precision entirely consists of the nugget effect. Increasing the mean distance between grains also increases the relative size of the cluster effect. Precision always includes some nugget effect (the constant nugget effect), because a sample is practically always pulverized or sieved for analysis. The size of this constant nugget effect depends on the mineralization type and the grain size of gold. In a fine-grained and homogeneous gold occurrence it is presumably higher relative to the cluster effect than in coarse-grained and scattered type cases. The high specific gravity and the varying mineral shape of gold strongly the styles of clusters in both primary formation processes and the procedure from sampling to analysis.

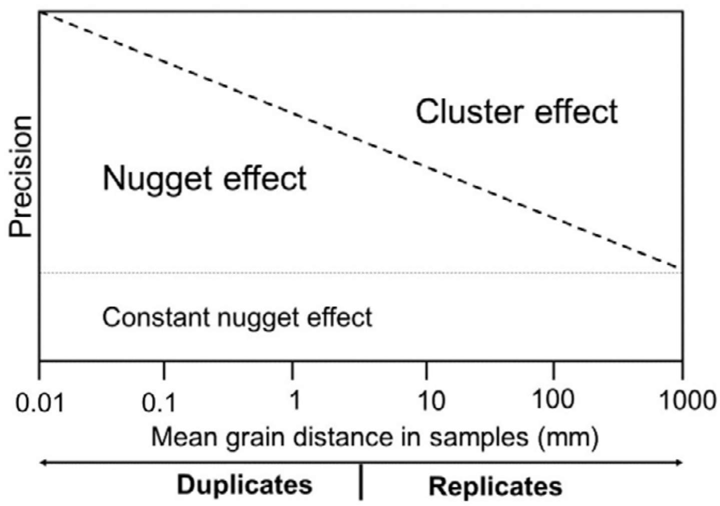



Fig. 3. Nugget and cluster effects related to the mean distance between grains in primary and duplicate/replicate samples.

### 3.3 Replicates and duplicates

Precision is tested by using duplicates and/or replicates. The terms duplicate and replicate have no unambiguous definition. Sometimes, they are used as synonyms. The website Dictionary.com (accessed in 2018) defines a duplicate as "*a copy exactly like the original*" and a replicate as "*something that is replicated, as an experiment or procedure*". A duplicate is thus theoretically closer to the original than a replicate. In this study, duplicates were used to test either the combined preparation and analytical variance or only the analytical variance. Replicates also include the primary sampling variance, testing all three variance sources. Replicate variances are thus greater than duplicate variances. This definition of a replicate has been in common terminological use by the author in various exploration and mining companies during the last 30 years.

In this report, concerning bedrock samples, a replicate is defined as an adjacent piece of similar bedrock, for example a pair consisting of half drill core–half/quarter drill core or grab sample–grab sample. Often, this type of replicate is referred to as a "*field duplicate*" (Abzalov 2016). After crushing and grinding, the split subsamples are duplicates. The distribution of replicates and duplicates is displayed in Figure 3, in relation to the mean grain distances in samples. In till, a replicate is a vertically or horizontally adjacent till sample of a homogeneous till layer, and a duplicate is a split from the same homogenized till sample. In this definition, a replicate is again more or less the widely used term "*field duplicate*".

# 4 MATERIALS AND METHODS

## 4.1 Study areas

Three areas with a mining or test mining history were selected for this study. The mining areas were included because of adequate data and suitable till profiles. They represent different styles of mineralisation, grain sizes of gold and glacial histories. The study areas of Ilomantsi, Kuusamo and Kittilä, together with their gold deposits, are listed in Table 2, and their locations are indicated in Figure 4. The author has 14 years of exploration and mining experience in Ilomantsi and three years in Kuusamo. Kittilä was selected because of the very fine grain size of gold. The largest amount of data was available from Ilomantsi which also include heavy mineral data from till for comparison with the traditional fine fraction of till.

Table 2. The study areas, deposits and the phase of mining. FS = Feasibility study phase. FF = fine fraction of till, HM = heavy mineral fraction of till. Data on bedrock and till samples from these areas and deposits were used in this study.

| Area | Deposit(s) | Discovery. year | Operation phase | Bed-rock | Till FF | HM |
|---|---|---|---|---|---|---|
| **Ilomantsi** | Pampalo | 1990 | Active mining | x | x | x |
| | Rämepuro | 1985 | Mined out | x | x | x |
| **Kuusamo** | Juomasuo | 1985 | Test mining / FS | x | x | |
| | Hangaslampi | 1986 | FS | x | x | |
| **Kittilä** | Suurikuusikko | 1987 | Active mining | x | x | |

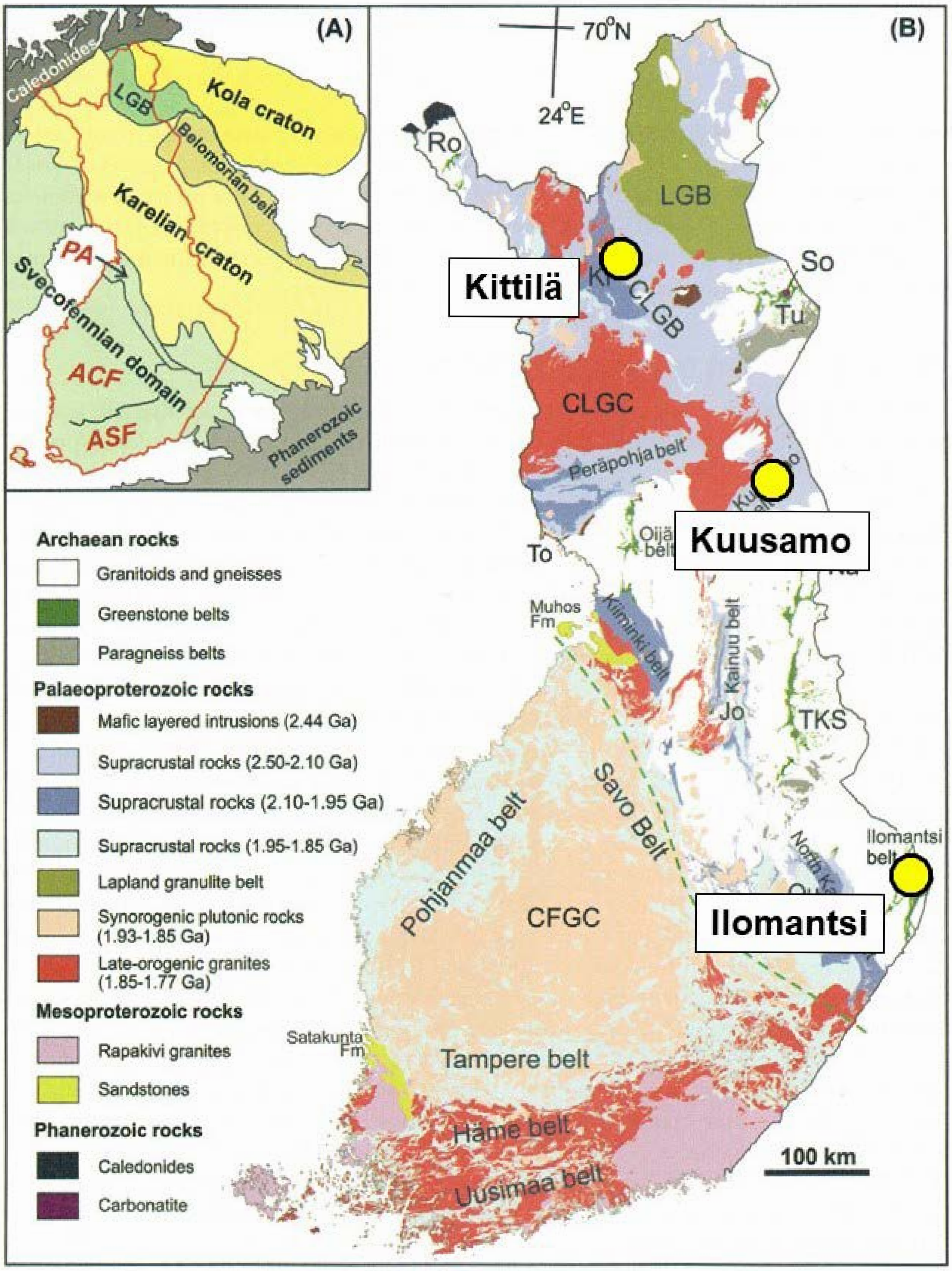



Fig. 4. Location of the study areas on a generalised geological map of Finland (basemap by Hanski 2015). Map abbreviations: PA = Primitive arc complex of central Finland, ACF = Accretionary arc complex of central and western Finland, ASF = Accretionary arc complex of southern Finland. Map B abbreviations: CFGC = Central Finland Granitoid Complex, CLGC = Central Lapland Granitoid Complex, Jo = Jormua ophiolite, Ou = Outokumpu ophiolite, RO = Rommaeno complex, So = Sokli carbonatite, TKS = Tipasjärvi-Kuhmo-Suomussalmi belt, To = Tornio, Tu = Tulppio.

#### 4.1.1 Ilomantsi

*Bedrock geology*

The two studied deposits, Pampalo and Rämepuro belong to the south-north orientated Hattu Schist Belt in the late Archean basement located in the easternmost part of Finland. The Belt principally consists of felsic and intermediate volcanic and epiclastic sediments. Regionally large and detailed lithological and structural mapping was carried out in the 1980s and 1990s by the Geological Survey of Finland (GTK). The project was one of the first efforts of GTK in which practical field exploration was conducted in close co-operation with research by GTK. The results were reported in 15 articles compiled in Nurmi and Sorjonen-Ward (1993).

The Hattu Schist Belt is one of the best preserved Archean supracrustal sequences in Finland. Isotopic data indicate that deposition, deformation and granitoid intrusion were very closely related in time. The ages of the earliest supracrustal units are 2754±6 Ma, effectively overlapping with those of syntectonic granitoids (Sorjonen-Ward 1993). The northern part of the belt is characterized by commonly coarse-grained feldspathic volcaniclastic deposits, with intercalations of andesitic, basaltic rocks and, in the uppermost part of the sequence, mafic and ultramafic lava flows. To the south of the Hattuvaara village there is less lithological diversity and mica schists and greywackes, including turbidites, predominate. No depositional basement to the schist belt is known, although isotopic evidence for older crustal material exists (Sorjonen-Ward 1993).

The structural geometry of the Hattu Schist Belt is characterized by upward-facing, generally steeply dipping structures. Depositional younging determinations are almost invariably upward facing and identified overturned strata are uncommon. There is a close relationship between regional folds and shear zones and much of the deformation may record accommodation to the emplacement of syntectonic granitoids (Sorjonen-Ward 1993).

*Gold deposits and mineralogy*

The Hattu Schist Belt has been systematically explored for gold over several decades, and the exploration history and strategies, as well as geological characterization, have been documented by Nurmi and Sorjonen-Ward (1993) and Sorjonen-Ward et al. (2015). The Hattu belt contains more than ten gold discoveries with a possible economic value, of which nine are indicated in Figure 5. Two of these have been mined (Pampalo and Rämepuro), but now mining is active only at Pampalo by Endomines Oy. Five other deposits have a published mineral resource estimate (Endomines Oy 2019). The present study concentrated on Pampalo and Rämepuro because the available precision data were almost entirely from these deposits.

*Pampalo*

The Pampalo gold deposit is located about six kilometres to north of Hattuvaara village. It was discovered by GTK in 1990, when visible gold was found in a small mylonitic seam with pyrite in an outcrop of quartz-plagioclase porphyry. This, together with geochemical till anomalies, led to the discovery of the deposit in the following drilling programme. The main mineralisation zone is hosted by a strongly deformed intermediate schist, referred to as andesitic tuff, between hydrothermally altered mafic schist in the west and ultramafic talc-chlorite schist in the east (Nurmi et al. 1993). Feldspar porphyry dykes have intruded into the andesitic tuff unit, shattered and boudinaged in shearing. Field, mineralogical, textural and Pb-isotope studies suggest that ore deposition at Pampalo was initiated by hydrothermal processes at the time of the emplacement of feldspar porphyry and tonalite intrusions and dykes, at around 2.72 Ga. K-feldspar alteration and remobilization of metals took place during the Svecofennian reactivation of high-strain zones during 1.7–1.8 Ga (Molnár et al. 2016).

The surface geology of the Pampalo area is displayed in Figure 6, including the location of the till sampling panel. The main ore zone in andesitic tuff is enveloped between mafic metabasalts and talc-chlorite rock. Minor and low-grade gold ore is hosted by feldspar porphyries east of the main ore zone, in the Pampalo East area.

The sulphide mineralogy of the Pampalo deposit consists of pyrite and minor amounts of chalcopyrite, pyrrhotite, galena and sphalerite. Native gold occurs as inclusions in potassium feldspar and between silicate grains intergrown with tellurides of Pb, Bi, Ag, Au and Fe, and with pyrite grains. The silver content of native gold is 1.0–24.8 wt% (Kojonen et al. 1993). Scheelite is common in mineralized zones. It shows a positive correlation with the gold content in ore and is used as a gold indicator during mining.

Native gold dominates at Pampalo. Minor amounts of gold are hosted by bismuth and gold tellurides, for example, in calaverite, petzite, montbrayite

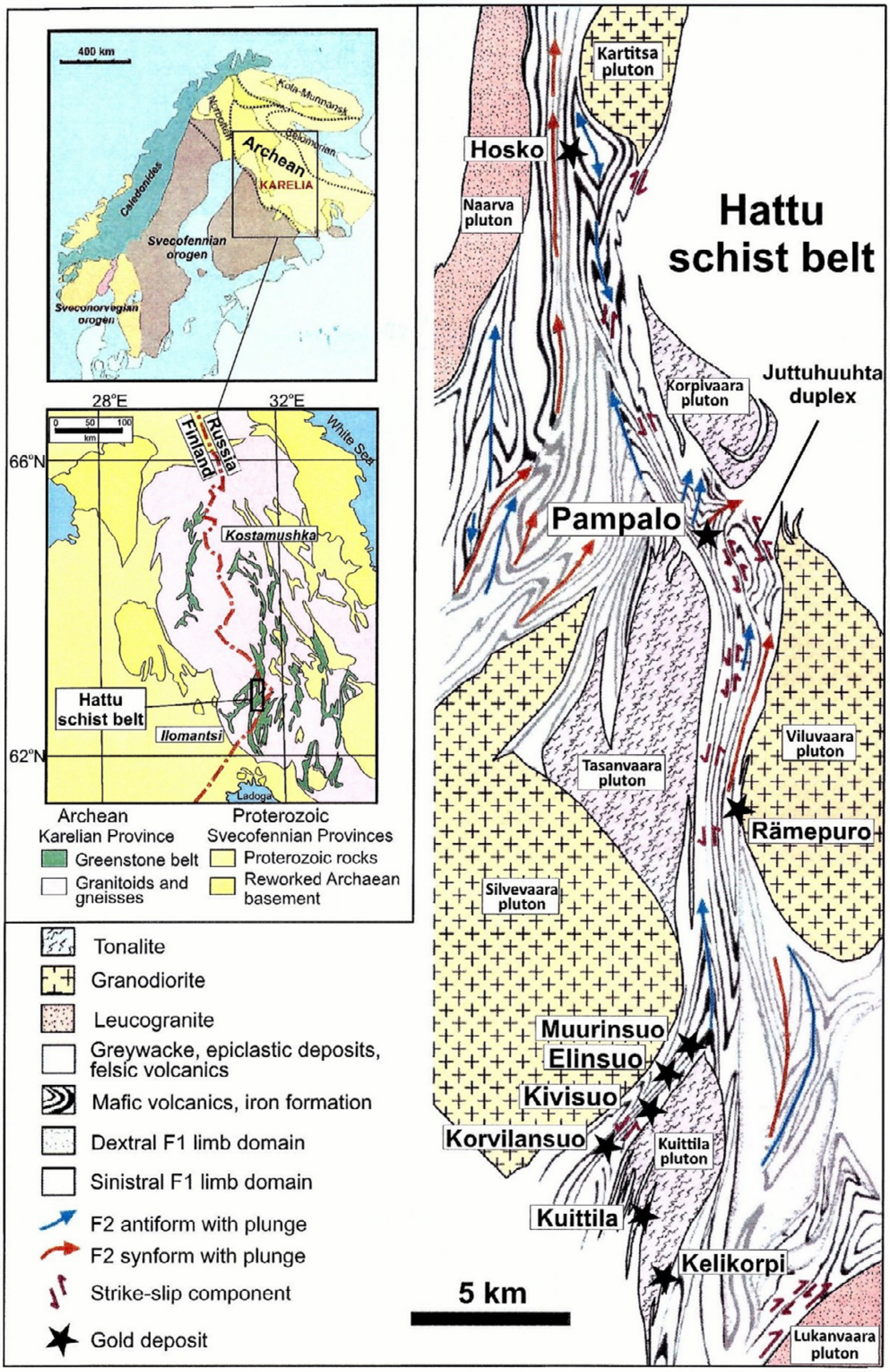



Fig. 5. Location of the gold occurrences and general geology of the Hattu Schist Belt (from Molnár et al. 2016).

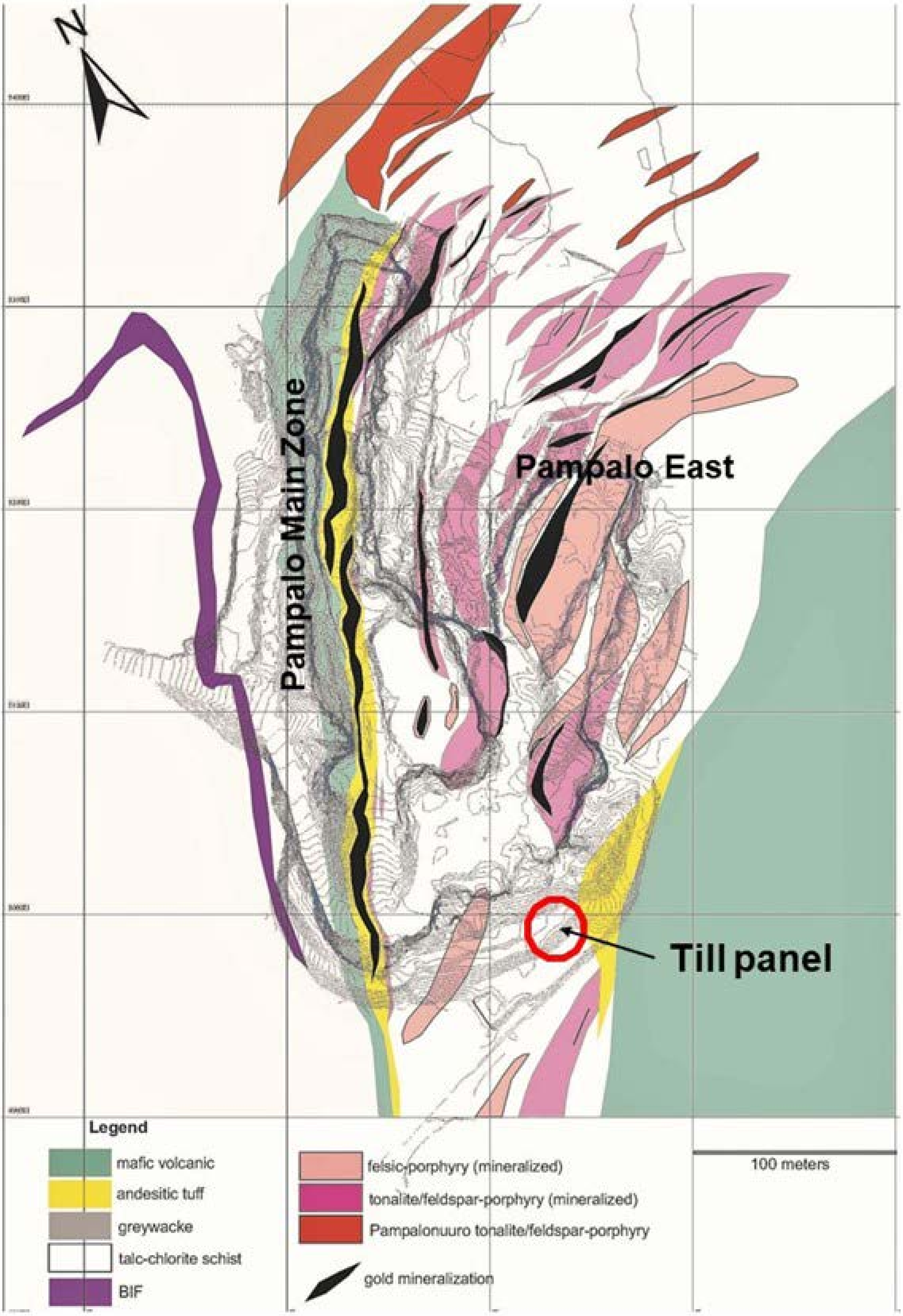



Fig. 6. Surface geology map of the Pampalo Mine area, prepared by Grigorios Sakellaris (Endomines Oy), including the location of the till panel.

and hessite (Kojonen et al. 1993). During the test mining phase by Outokumpu Oy in 1998, recovery with a shaking table varied from 20% to 30% of the total recovery of gold (Mörsky et al. 1998). This bulk sample of 400 tonnes grading 39 g/t Au was from the high-grade upper level of the deposit. Some larger, but very thin gold flakes were noticed floating in the tailings. In testing of a lower-grade composite sample, grading 9.3 g/t (Leppinen & Kalapudas 1998), most of the gold was found to be in the grain size class of 30-120 µm using the caustic dissolution method (Leppinen & Laukkanen 1998). During the late mining years, the gravity concentrate as a percentage of the total gold recovery was about 15% and the ore grade was only about 2 g/t (Endomines Oy 2014-2016). During that time, gold ore from the Rämepuro deposit was processed together with the Pampalo ore. With a decreasing gold grade, the percentage of coarse gold also seems to decrease. The concentrate grade in mining has been higher than in tests, also explaining the difference in the gravity recoveries.

In the heavy mineral concentrate panned by the author in 1997, most of the gold was below 100 µm in grain size, but many nuggets of up to 3 mm in diameter were also detected (Fig. 7). This concentrate is from the weathered surface of the southern ore shoot, where the grade was 20-30 g/t. The quantity of easily visible nuggets of gold (>0.5 mm) in this weathered surface was much higher than in the deeper located, lower grade ore. However, no secondary gold enrichment based on gold grades was found.

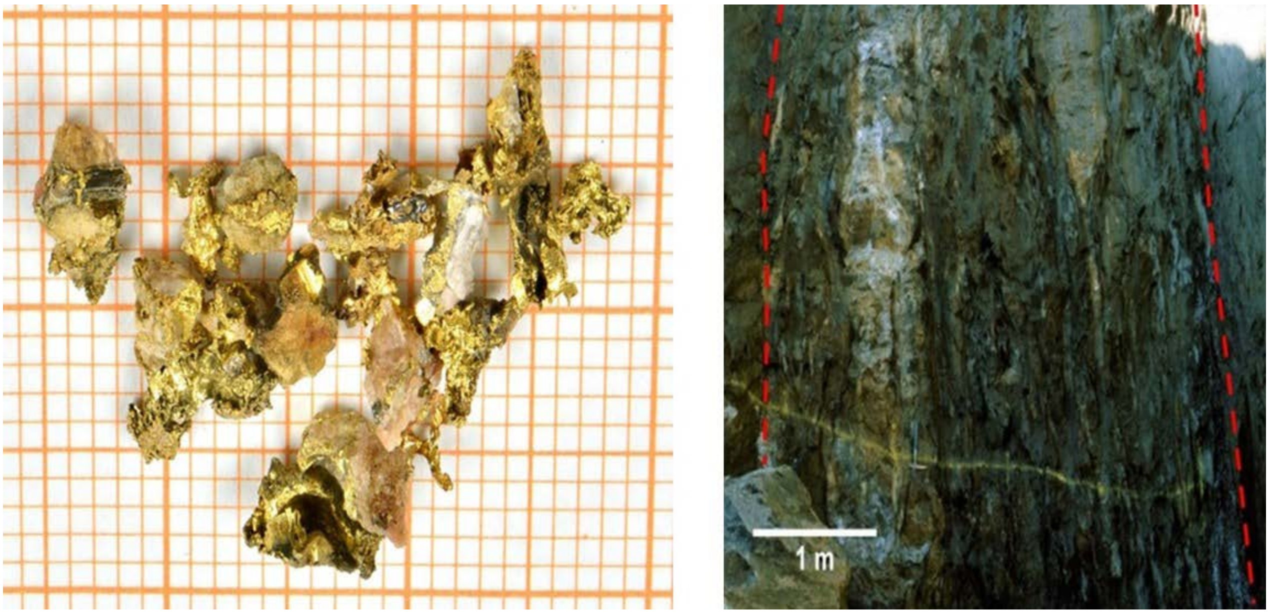



Fig. 7. Panned gold concentrate from the weathered surface of the Southern Ore Shoot at Pampalo, panned by the author in 1997 (left figure). The photo on the right shows weathered andesite tuff with one large feldspar porphyry dyke and a smaller porphyry lens from the southern end of the Southern Ore Shoot. The red dashed lines indicate ore zone contacts. The ore was loaded without blasting by an excavator. The photo is looking to the south and was photographed by the author.

### *Rämepuro*

The Rämepuro deposit is located 10 km south of the Pampalo Mine (5) and was discovered directly on an outcrop in 1985 after re-assaying old layman samples. The ore reserves and mineral resources before mining were 169 000 tonnes grading 2.1 g/t Au as reserves and 136 000 t grading 2.3 g/t Au as resources (Endomines 2014).

The deposit is in the sheared and siliceous contact of sedimentary and volcanic rock units intruded by a tonalite dyke (Fig. 8). Gold is mainly hosted by quartz-tourmaline breccia veins with some sulphides. Detailed geological studies were carried out by Outokumpu Finnmines Oy (Pekkarinen 1988) and with the University of Oulu (Ojala 1988, Ojala et al. 1990). Native gold occurs with pyrite and pyrrhotite and with minor amounts of chalcopyrite, sphalerite, galena, native bismuth and Bi tellurides. Native gold is commonly associated with native bismuth and hedleyite between tourmaline and quartz grains. It is also intergrown with sulphides. The Ag content of native gold is 0.4–12.1 wt% (Kojonen et al. 1993). The recovery of the gravity concentrate in the pilot plant tests varied between 30% and 45% of the total recovery (Klemetti 2012). This is higher than at Pampalo, also considering the low grade of the test material from Rämepuro, being 2.4 g/t gold.

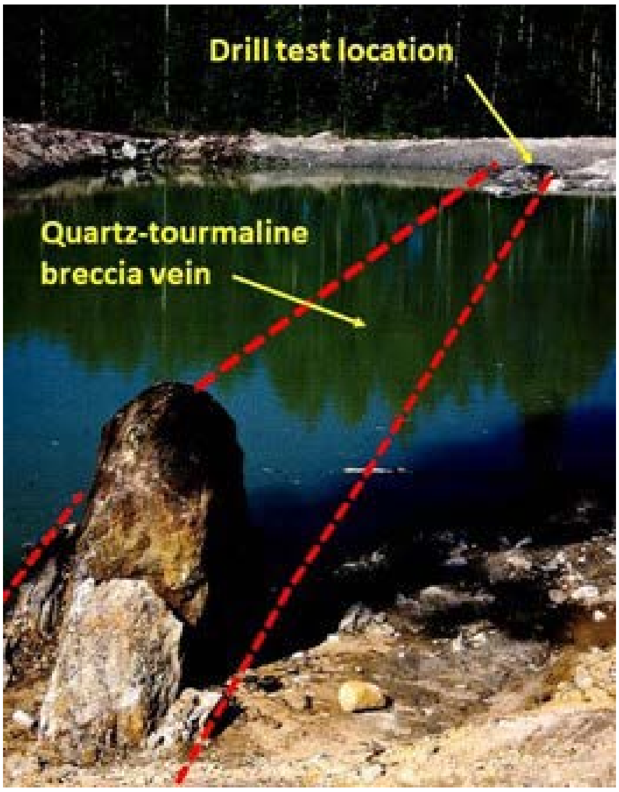



Fig. 8. A quartz-tourmaline breccia vein after the first overburden stripping in 1997. The base photo is looking to the north and was photographed by Antti Saarelainen.

### *Quaternary geology and till*

The study area is located within the area of the former North Karelia ice lobe, where the latest direction of the ice flow was from north-west. This is recorded by glacial striations, pebble orientation and drumlins trending 310–330° (Nenonen & Huhta 1993).

Basal till of variable thickness covers the study area. Geochemical sampling at a density of 16 samples / km² indicated a mean thickness of about five metres in the area (Hartikainen & Nurmi 1993). Till is generally unconsolidated and sandy including small amounts of clay-sized material. It is commonly stratified and contains sandy lenses and layers. The till is coloured brown by iron oxides in the B-horizon and is locally also brownish grey down to the groundwater level, and under this it is grey in colour (Fig. 9, right photo). Sometimes till is also grey above the ground water table (Fig. 9, left photo).

## 4.1.2 Kuusamo

### *Bedrock geology and gold deposits*

Pervasively albitized rocks are wide-spread in the intra-cratonic, rift-related Kuusamo Schist Belt and host numerous hydrothermal mineral occurrences (Vanhanen 2001). Two of these, Juomasuo and Hangaslampi, were included in this study. These deposits were investigated by Outokumpu Mining Oy (Anttonen 1993) and Dragon Mining Ltd (Dragon Mining 2014) after their discovery by the Geological Survey of Finland (Pankka 1992). The general geology and gold-copper occurrences around Juomasuo are presented in Figure 10.

Fig. 9. Typical basal till profiles in the Hattu Schist Belt. Intervals of the colored measuring stick 0.5 m. Coordinates E/N (ETRS-TM35FIN), left photo, pit M-319/320: 708 793 / 6924 967 and right photo, pit M-307: 707 727 / 6924 567. Photos are from the southern Hattu Belt and from the till sampling programme by Outokumpu Mining in 2002.

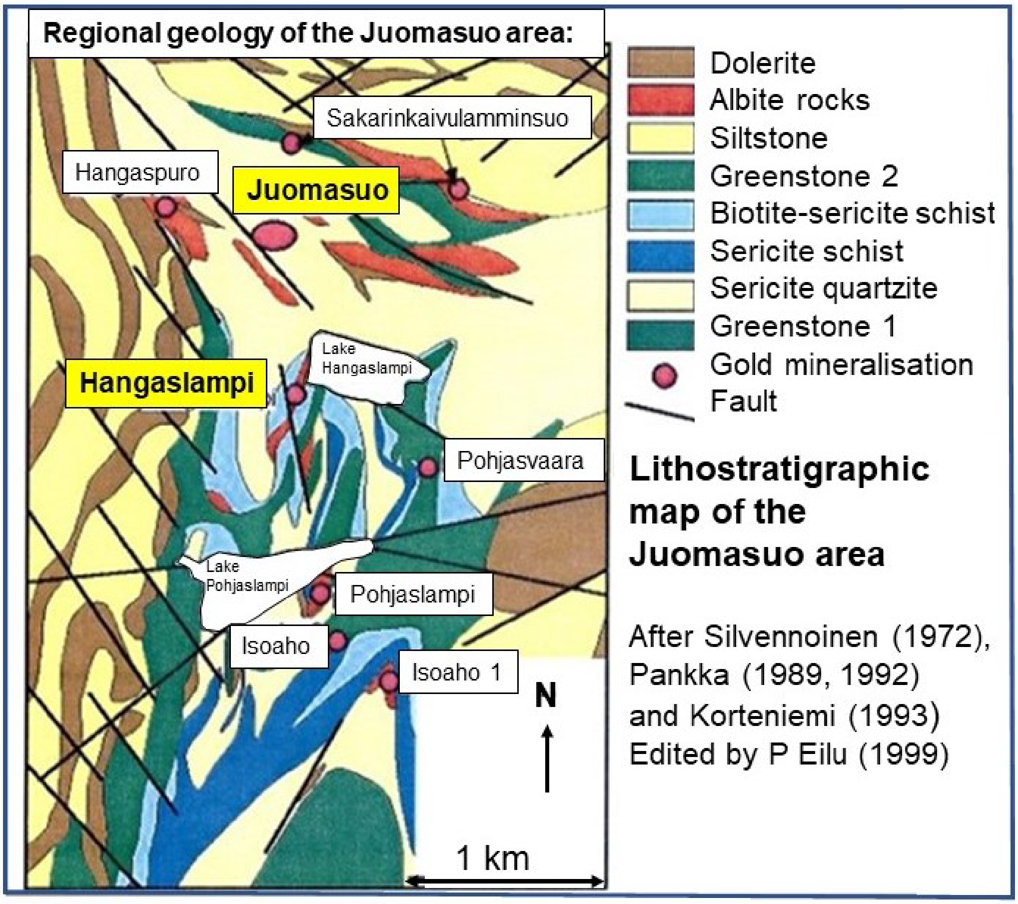



Fig. 10. Regional geology and the gold occurrences of the Juomasuo area in Kuusamo (Silvennoinen 1972, Pankka 1989, 1992, Korteniemi 1993) from the Mineral Deposit Report (Eilu 1999).

***Juomasuo***

The Juomasuo gold-cobalt deposit is situated about 45 km north of Kuusamo town centre. The deposits were intensively investigated by GTK until 1991 (Pankka 1992, Vanhanen 2001), when the mining rights were transferred to Outokumpu Mining Finnmines Oy. Outokumpu started exploration, test mining and metallurgical testing in 1992. Overburden stripping of 1.5 ha on the outcropping ore deposit was carried out and bulk sampling of three ore types was executed as channel mining (Fig. 11). In total, 17 645 tonnes ore were mined and transported to the Rautuvaara concentrator for metallurgical testing (Anttonen 1993). Exploration in the target area was reactivated by Dragon Mining Ltd and an extensive drilling programme was carried out in 2010–2013 by the company. After this campaign the mineral results were 2.37 million tonnes grading 4.6 g/t Au (Dragon Mining 2014).

The location of Juomasuo is at the NW end of the Käylä-Konttiaho anticline. It is hosted by the upper part of the Sericite-Quartzite-Formation (Silvennoinen 1972, Vanhanen 2001). The dominant rock types are quartzites and sericite quartzites, which have a strong hydrothermal alteration resulting in albite, sericite, biotite and chlorite-rich rocks. The other main type is chlorite-talc-amphibole rocks, which were originally probable ultramafic sills (Pankka 1992). The hydrothermal activity in various phases of deformation has altered the primary rock types to produce many variations, which are not easy to distinguish and follow in structural interpretation. Because of the special ore mineralogical composition of, the mineralization type is included in the class of "*Orogenic gold with anomalous metal association*" (Eilu 2015). Cobalt enrichment and geochemical mineralizing events have subsequently been investigated by Witt et al. (2020) and Vasilopoulos et al. (2021).

The main ore minerals are pyrrhotite and pyrite, with minor chalcopyrite, cobaltite, pentlandite, uraninite and native gold. The most common sulphide mineral, pyrrhotite, occurs both as dissemination and massive and semi-massive veins or bands. Pyrrhotite is more frequent in chlorite-rich parts and massive pyrrhotite often shows flowage structures (Pankka 1992, Lahtinen 1993a). Pyrite mostly occurs as cubic porphyroblasts and dissemination, usually less than 0.5 mm in grain size, and in places pyrite is flattened and elongated along schistosity (Pankka 1992).

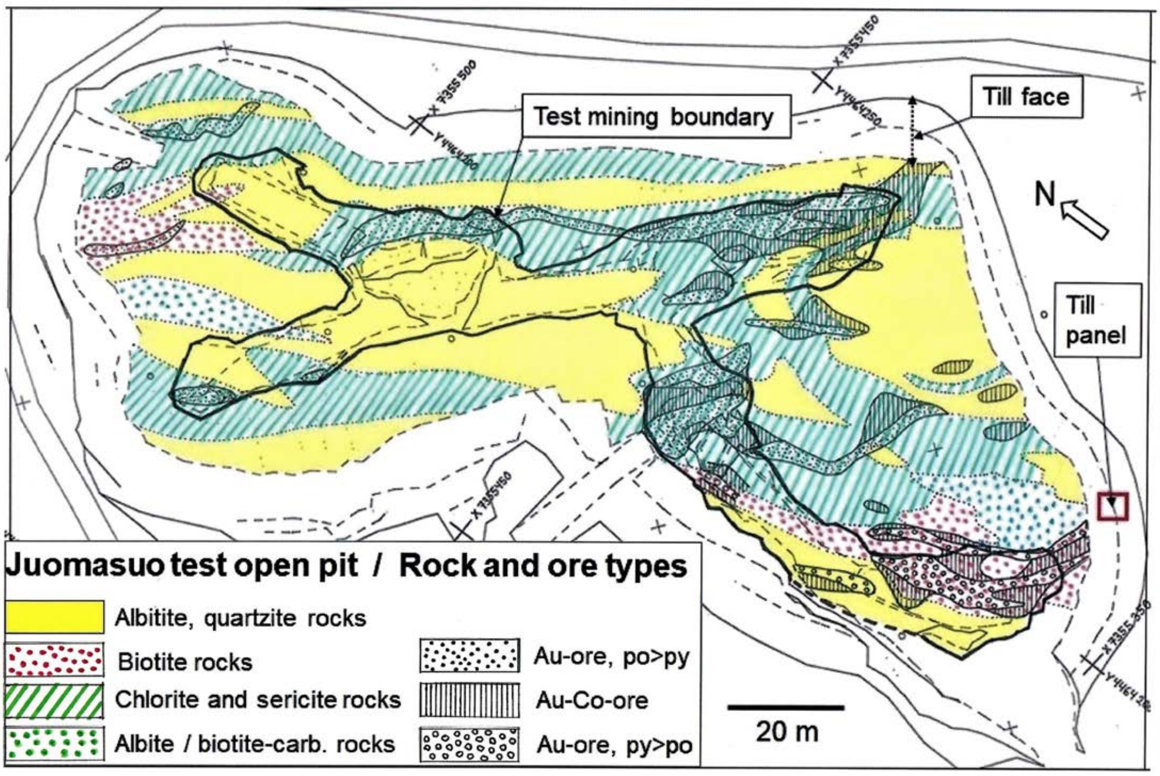



Fig. 11. Bulk sampling area of Outokumpu Mining Oy with surface rock and ore types (po = pyrrhotite, py = pyrite), interpreted by the author for Dragon Mining Oy in 2011 and the location of the till test panel in 2015. Till panel coordinates are as follows: N 7353 787, E 598 685.

Macroscopic gold is seen in a few parts of the deposit, often connected or intergrown with uraninite. Gold represents a later stage of precipitation, commonly also with tellurides. The silver content is low, from 1.1% to 4.3% (Pankka 1992). The observed gold grains are often thin flakes in mineral cracks. This form partly explains the low recovery in concentration with a gravimetric shaking-table in the Rautuvaara plant (Himmi 1993). In a Juomasuo ore sample, the gold grain size varied from <10 to 70 µm in diameter, but 85–90% of the counted gold grains were <20 µm. However, by weight, most of the gold is between 10–30 µm and the weighted mean grain size is 25–30 µm (Sotka & Toikkanen 1991). In tests of flotation concentrates, the amount of native gold as a proportion of the total gold was over 90% and the longest observed gold grain was 140 µm. The grains also often occur as flakes (Sotka 1993). In a later study, the maximum grain size of the Juomasuo ore was 35 µm (Johansson et al. 1995). Macroscopic gold was noticed in mining in the northern part of the area and there, the visible gold was mostly concentrated in mineral cracks as crack filling and filling network up to a few millimetres in size (Huhtelin 1992). A mineralogical study was conducted by ALS Ammtec and a strong association of gold and uranium minerals was observed (ALS Ammtec 2012).

***Hangaslampi***

The gold deposit of Hangaslampi was discovered after Juomasuo by GTK (Vanhanen 2001) and afterwards investigated by Outokumpu Mining Oy and Dragon Mining Ltd. The latest mineral resource estimate includes 0.40 million tonnes of gold ore grading 5.1 g/t Au (Dragon Mining 2014). The deposit is covered by 1 to 8 metres of till. The rock types have intense hydrothermal alteration, and completely unaltered country rocks are not found. The main rock types are sericite quartzite, biotite-sericite schist, albite rocks and greenstone (Vanhanen 2001). Due to intense albitization and hydrothermal alteration the rock units are not clearly distinguished from each other (Korteniemi 1993).

After the discovery, GTK drilled 43 core holes (2951 m) (Vanhanen 2001), and after the mining rights were transferred to OM, the company continued drilling with a further 37 holes (2878 m: Lahtinen 1993b). Dragon Mining Ltd continued drilling operations in 2010. Three small excavations were carried out in 2012 for detailed mapping and sampling (Bergström 2012). A generalized geological map of one of them with the till panel sampling location is presented in Figure 12.

The mineralogy of the Hangaslampi deposit is much the same as at Juomasuo. Pyrite is the most common ore mineral instead of pyrrhotite in

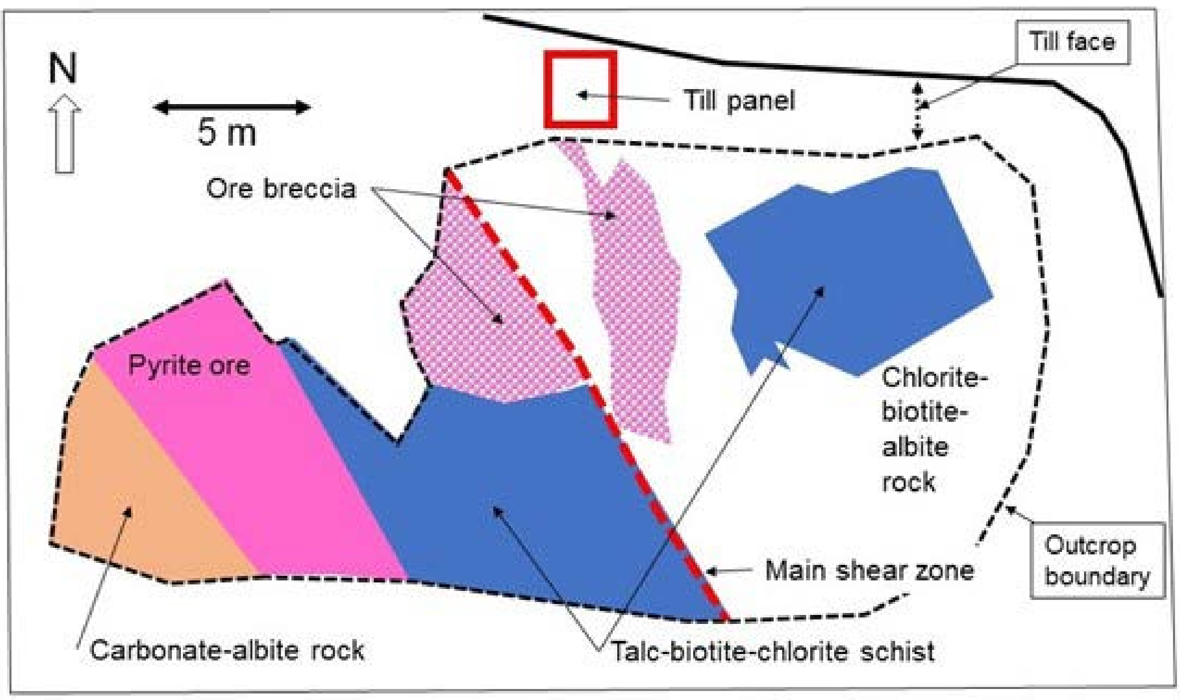



Fig. 12. Detailed geological map of the stripped bedrock and the location of the till test panel in the Hangaslampi trench M3 (Bergström 2012), modified by the author. The till panel coordinates are: N 7352 921 , E 598 906.

Juomasuo. It is formed in various stages, but the composition is quite stable (Vanhanen 2001). Pyrite has low grades of Co and Ni, but it is exceptionally radioactive (Mänttäri 1995). Cu and Co grades are low and the Cu-Co-minerals are also uncommon.

Gold is mainly native and the grain size of the native gold is commonly 1-10 µm. It occurs as irregular inclusions in pyrite and in contacts between sulphides and silicates. Macroscopic gold is uncommon. The fineness of gold is high and the silver content low. The only detected gold mineral in addition to native gold is calaverite (Vanhanen 2001).

#### *Quaternary geology and till*

The area around Juomasuo-Hangaslampi belongs to a basal till area without glacifluvial formations. The area is a part of the large Kuusamo drumlin field (Aario & Forsström 1979, Sarala & Räisänen 2018), but in the study area drumlins are weakly developed. No clear separate till beds were noticed in either Juomasuo or Hangaslampi. Till stratigraphic studies north of the Ruka area point to the youngest glaciation phase and the direction of till material is from 270-280° (Johansson & Nenonen 1990). The till thickness of the drilling areas varies from one metre to 30 metres. In the Juomasuo stripping area, it was from 5 to 10 metres.

### 4.1.3 Kittilä

#### *Bedrock geology and the Suurikuusikko gold deposit*

Lapland has been the main target for gold exploration in Finland during the last decades (Ojala 2007, Pulkkinen & Sarala 2009, Eilu 2015, Vanhanen et al. 2015, Wyche et al. 2015).

The Kittilä mine is located approximately 50 km northeast of the town centre of Kittilä. The name Suurikuusikko is used for the deposit. It was discovered by GTK in 1986. The first indication was coarse visible gold in quartz-carbonate veining along a road cut about 5 km south of the deposit (Härkönen & Keinänen 1989, Härkönen 1997). After intensive exploration and drilling by GTK from 1987 to 1991 the prospect was transferred to Riddarhyttan Resources AB in 1998 after a bidding operation by the Ministry of Trade and Industry (Riddarhyttan Resources 2000). During 2004, Agnico Eagle Mines Limited of Toronto became the largest shareholder of Riddarhyttan. Commercial gold production started in 2009 (Doucet et al. 2010). The total proven and probable reserves in 2019 were 30.53 million tonnes grading 4.50 g/t Au (Agnico-Eagle Mines 2019).

The Kittilä mine area belongs to the Central Lapland Greenstone Belt. The belt consists of Paleoproterozoic volcanic and sedimentary rock cove (age 2.5-1.97 Ga) on the Archean granite gneiss basement (age 3.1-2.6 Ga) (Lehtonen et al. 1998, Hanski & Huhma 2005). In 2021 one operating gold mine and tens of drill-indicated gold occurrences were located within the Belt, most of them belong to the orogenic type (Eilu 1999, 2007, Eilu & Pankka 2010). These occurrencess resemble in many features the large mineral districts of the Yilgarn region in Western Australia and the Superior Province of Canada (Patison 2007, Patison et al. 2008). A regional 3D model of the Kittilä terrane prepared by using geophysical, geological and geochemical data indicates a rough gold potential of up to 228 Moz (Niiranen et al. 2014). This amount of gold was estimated to be mobilized from the Kittilä Group rocks during the regional metamorphism in the Svecofennian orogeny. This gold potential figure is about 30 times greater than the reported gold resources of the known deposits of the area (Niiranen et al. 2014). The deposits and geological formations are presented in Figure 13.

The Suurikuusikko deposit is hosted by tholeiitic volcanic rocks of the Kittilä group of the Central Lapland Greenstone Belt. The host rock sequence is deformed by the subvertical to steeply dipping Kiistala shear zone (Wyche et al. 2015) The gold ore lenses are sandwiched in the shear zone between Fe-tholeites in the west and Mg-tholeites in the east. The separate gold deposits are associated with disseminated sulphides and hydrothermal albite and carbonate-sericite alteration in a brittle-ductile shear zone possibly developed during the Late Proterozoic (Doucet et al. 2010, Wyche et al. 2015).

The two main sulphide minerals at Suurikuusikko are pyrite (Py) and arsenopyrite (Apy). Their relative abundance studied by Chernet et al. (2000) is 77% Py and 23% Apy. Gold has a good correlation with arsenic in pyrite. The gold content of Py is 33-40 ppm and that of Apy is 215-218 ppm. These are slightly lower than previously analysed in concentrates, in which the contents were 46 ppm and 279 ppm respectively (Kojonen & Johansson 1999). Gold occurs as a sub-microscopic size or solid solution in Py and Apy, as electrum with 52-59 wt% Ag mainly in Py, and as gold alloays with 52-59 wt% Ag and 17.7-33.6 wt% Hg mainly in Py (Chernet et al. 2000).

Higher gold contents were measured by Aho (2009), whose mean Au-grades were 110 ppm in Py and 290 ppm in Apy. In a detailed study four separate generations of pyrite and arsenopyrite were noticed. The grain size of pyrite and arsenopyrite in this study varied from a few microns to 3 mm (Py) and 1.5 mm (Apy) (Koppström 2012).

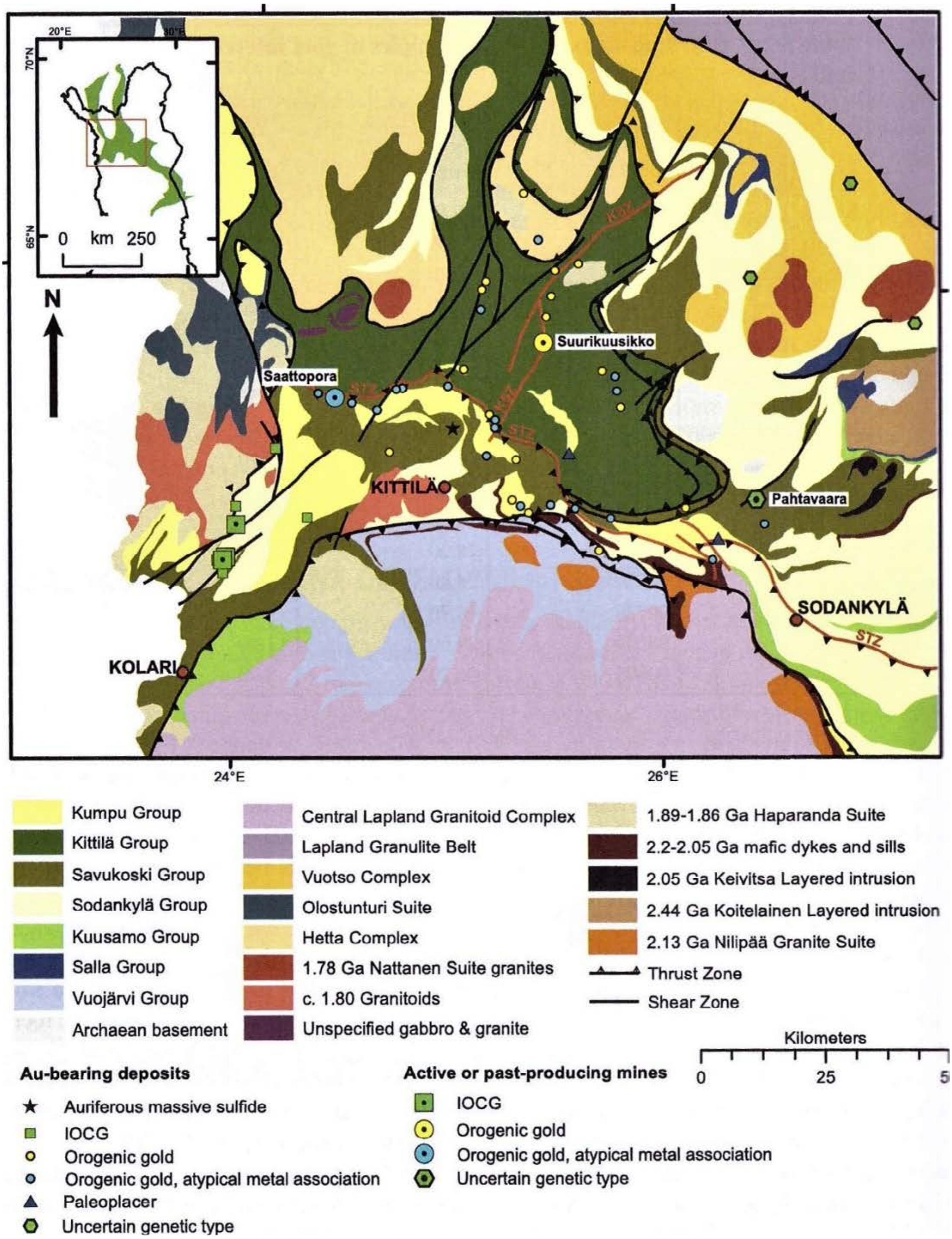



Fig. 13. Regional geological map of central Lapland and the Suurikuusikko deposit (Wyche et al. 2015).

***Quaternary geology and till***

The whole Lapland has been mapped at a scale of 1:400 000 (Johansson & Kujansuu 2005). The Kittilä mine area belongs to the central Lapland ice-divide zone, where at least five separate till beds have been recorded, in places occuring in the same sections (Hirvas et al. 1977). However, in the Suurikuusikko deposit area, only three till beds have been observed (Sarala & Pattison 2011). The transport distance of pebble-size till depends on the distance from the bedrock surface. Close to the bedrock surface, the material is local and the transport distance of till separated about one metre from the surface is from less than 1 km to 5 km (Hirvas et al. 1977). Geochemical till sampling by GTK has covered the whole area, indicating a general till thickness of 3-4 m (Äyräs 1979).

A detailed study of Quaternary geology in the Suurikuusikko mine area was conducted by Peltoniemi-Taivalkoski and Sarala (2009). Their work indicates that glaciogenic till is composed of three beds, of which the two uppermost beds represent the latest glaciation phase and the third is an older one. Based on the till geochemistry and stratigraphy, the transport distance of the till fine fraction and pebbles was estimated to be short in the bottommost till bed. The two upper beds reflect much longer transportation with no indication of underlying bedrock (Peltoniemi-Taivalkoski & Sarala 2009).

## 4.2 Sampling, preparation, analytical and statistical methods

### 4.2.1 Primary data and samples

Most of the data and analytical results used in this study were observed from tests planned, supervised and partly executed by the author during the last 25 years. The tests have been parts of the QAQC procedures for Outokumpu Mining Oy, Dragon Mining Oy and Endomines Oy. The QAQC data from the Kittilä mine are available for the year 2018 as duplicate samples. In all three study areas, the regional primary till sampling data by GTK were utilized as reference data.

Bedrock samples comprised unweathered bedrock samples either from drill cores or blasted drift runs in the Pampalo mine or their half or quarter core or crushed, grinded or pulverized products. Till samples consisted of glacial products in moraine formations without visible weathering, glaciofluvial or organic layers or lenses.

The number of both bedrock and till samples is presented in Table 3, subdivided into the projects of the author and data obtained from other organizations for comparison. In the author´s grade control projects, the author was responsible for planning and executing or supervising the activities.

Table 3. Number of samples according to type categories and organizations included in this study.

| | Rock samples | | Till samples | |
|---|---|---|---|---|
| **Author** | Whole core | 86 | Fine fraction | 702 |
| | Half or quarter core | 455 | Heavy mineral fraction | 428 |
| | Crushed samples | 798 | | |
| | Pulverized samples | 1 186 | | |
| | Total | 2 525 | Total | 1 130 |
| **Other** | Endomines Oy | 1 734 | Fine fraction by GTK | 4 059 |
| | Agnico Eagle Ltd | 1 194 | Heavy mineral fraction by GTK | 296 |
| | Total | 2 928 | Total | 4 355 |
| | Overall total | 5 453 | Overall total | 5 485 |

Gold and two pathfinder elements, copper and arsenic, as references were systematically studied. In Kuusamo, cobalt was used as the reference instead of arsenic because of the low arsenic grades. A few other pathfinder elements for gold were also referred to. Manganese was as an indicator of Fe-Mn-oxides and possible co-precipitation of the elements in till. The number of samples in some tests were small, and one sample pair can consequently have a strong influence on the results. For this reason, some results are more or less conceptual.

#### 4.2.2 Bedrock sample processing

The quality of crushing, grinding and splitting is the important factor when interpreting precision based on laboratory analyses. Under theoretical, idealistic conditions, the total precision does not decrease in preparation, but this is never the case in reality. Analytical laboratory procedures after splitting the analysed sample comprise the final part of precision, but these were not included in the present study.

All the bedrock samples in this study from Ilomantsi and Kuusamo were dried, crushed, split and pulverized at Outokumpu in the local laboratory. This was founded by Outokumpu Mining (OM) as the Geoanalytical Laboratory and after that operated by VTT Technical Research Centre of Finland Ltd. The work was continued in 2000 by a local contractor, Kalevi Räsänen, partly with the same personnel. In 2008, the laboratory joined the ALS-Global Group.

The preparation procedure followed two lines, the first up to the year 2003 and the second after that. The earlier procedure (Pre-1) included the following steps, after possible drying (Sandberg 2003b):

1. Crushing of the whole rock material with a jaw crusher (Retsch, type BB2) to -5 mm;
2. Grinding of the whole crushed material with a plate crusher (Morgardshammar, type B-92) to -2 mm;
3. Splitting of the ground material using a rolling bottle splitter (Retsch, 8 glass bottles à 500 ml): two opposite bottles were selected for further splitting and pulverizing;
4. Pulverizing of 150-200 g of ground and split rock material using a swingmill (Herzog, HSM 100P, 1990) resulting in the pulp for analysis.

This procedure (Pre-1) was used for all the Ilomantsi bedrock samples collected by OM until 2003.

The second preparation method line (Pre-2) included primary crushing to -5 mm and after that pulverizing of the whole material using a large pulverizing mill (Labtech Essa Mill LM5-C) with a maximum capacity of 4 kg. The sample for analysis was collected directly from the mill pot using a spoon as evenly as possible. This method was used for all the Kuusamo rock samples and samples from Ilomantsi collected by Endomines Oy.

Many tests were carried out to prove the high quality of preparation. In one of these, three large (6.4 kg) gold ore samples were selected from the Jokisivu, Pampalo and Orivesi gold deposits, owned by Polar Mining Oy. The samples were crushed and split into two identical subsamples. The two subsamples were prepared using the two preparation lines. In the first line (Pre-1), all the eight bottles were selected for analytical samples and were pulverized after splitting. In the second preparation line (Pre-2), eight pulp samples were collected directly from the mill pod after pulverization. All these 8+8 samples from the three deposits were mixed in a random order and analysed by Acme Analytical Laboratories Ltd for gold (two methods) and other elements. The summarized mean results from Pampalo for gold are presented in the next table (Table 4, Sandberg 2004). There were no significant differences between the gold data for these preparation methods

Table 4. The mean grades of the eight test samples, with the standard deviation (STD) and coefficient of variation as % (CV%), also including sieving test results. The assays were carried out by Acme Analytical Labs in Vancouver, Canada. The analytical methods for gold were: *Au* 1F+MS (Code A11, Table 5) and *Au6* (Code A12). The gold grade unit is ppm (g/t).

| | Pre-1 | | | Pre-2 | | |
|---|---|---|---|---|---|---|
| **Factor** | **Au** | **Au6** | **-0,075 mm %** | **Au** | **Au6** | **-0,075 mm %** |
| **Mean** | 18.2 | 20.2 | 71.5 | 18.5 | 20.3 | 83.4 |
| **STD** | 0.8 | 1.5 | | 0.8 | 1.0 | |
| **CV%** | 3.9 | 7.0 | | 4.2 | 4.5 | |

Pulps were also sieved to test the grain size distribution after pulverization (Table 4). Passing percentages of the sieve (-0.075 mm / 200 mesh) were from 72% to 83%. The total pulverization (Pre-2) products contain slightly more fine-grained material than those pulverized by Swingmill. A common laboratory standard passing % for a sieve of 0.1 mm (150 mesh) is 90-95%.

The grain size and mineralogy of gold affect the precision, together with both the primary sample size and analytical size. These factors have been investigated in various papers (eg. Gy 1967, 1982, Clifton et al. 1990, Garret 1969, Pitard 1993, Abzalov 2011). Commonly, statistical estimations and tables are based on how large the sample should be to include the necessary number of gold nuggets. By plotting the two procedures (Pre-1 and Pre-2) on nomograms by Gy, the differences become visible (Fig. 14). The procedure Pre-2 fulfils the theoretical requirements of not overrunning in any phase the "*Safety Line*" by Gy (Pitard 1993). Based on the theory, the fundamental sampling error should all the time be under the "safety line" to be theoretically acceptable. The common older procedure Pre-1 would need an extra crushing to -0.6-0.7 mm before splitting the pulverized 200 g. High-quality splitting by the rolling bottle splitter does not help in this theoretical deficiency. However, the test results indicate that the procedures are identical enough to allow the comparison of gold grades prepared by these two methods.

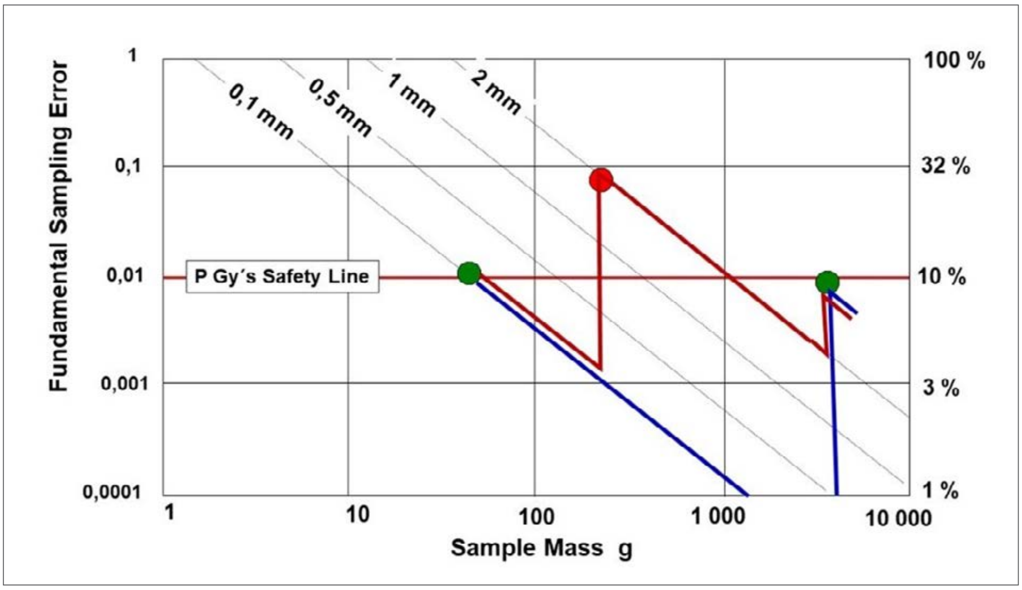



Fig. 14. A lognormal sample nomogram based on Gy`s theories, modified from Abzalov (2011). The red line denotes procedure Pre-1 and the blue line Pre-2. The green circles indicate the starting mass of about 4 kg and the final pulp mass of 30-50 g for analysis. The red circle is the splitting of 200 g for pulverization using a swingmill.

#### 4.2.3 Till sample processing

Till is a heterogeneous material at a small scale. Gold occurs in till as well as free native nuggets, and in other minerals containing gold in the crystal structure, locked inside other mineral crystals, in mixed multimineral particles or in precipitation products. The amount of each type depends on the parent material and the genetic history. Grade variation and precision were tested in the following six sampling and preparation cases:

– Till sample replicates prepared based on GTK´s sample and analytical data;
– Existing replicates of the authors data;
– Duplicates of homogeneous till samples;
– Duplicates of fine fraction samples of till;
– Replicates of heavy mineral fraction samples;
– Till test panels.

***Till sample replicates prepared based on GTK´s sample and analytical data***

The analytical data were obtained from tractor excavator sampling and analysis of till by GTK in Ilomantsi from 1986 to 1989 (Huhta 1993, and personal communication). Altogether 317 exploration pits or trenches were excavated during the GTK study covering an area of 115 km$^2$. From one to three vertical and continuous till samples were collected from the pit wall and extra samples from weathered bedrock immediately beneath the till. The vertical sampling length was 1.0–1.5 m. Two separate aliquots from each sample site were collected, the first, (size 12 l) into a plastic bucket for heavy mineral study and the second (size 100-200 g) for the geochemical analysis of the fine till size fraction.

The heavy mineral samples of GTK were wet sieved in the field through 6 mm and then 2 mm sieves. The passed fraction was concentrated using a motorized Goldhound spiral panner. The concentrates were examined under a binocular microscope and visible gold nuggets were picked for detailed study. The remaining heavy mineral fraction, weighing 5-10 g, was subsequently ground and analysed at the GTK laboratories in Kuopio for gold and base metals. The weight for analysis was 1.0 g (Code A1, Table 5). The fine fraction aliquots were sieved to –0.06 mm and the fractions of –0.06 mm were also analysed for gold (Code A1) and base metals (Huhta 1993). The data set is labelled in this report as GTK-1.

For this study, the pits with two or three samples in the same stratigraphical till layer, excluding samples from weathered bedrock, were included. Sample pairs “*upper*” and “*lower*” were formed. If three vertically collected samples existed in a pit, then two sample pairs were formed. The “*lower*” sample is defined as a replicate of the “*upper*” sample in each sample pair. These sample pairs cannot be considered as replicates according to a strict definition, but more as upper and lower samples in the till horizon. However, they can be compared with a blind random sampling in till, where the sampling depth can be from one to four metres in the same till horizon, without detailed knowledge of the till profile at the precise sampling point. In this case, the till profiles were visible and differences in till stratigraphy were noted. The principle is illustrated in Figure 15. This pairing system of *upper* and *lower* samples can be compared with the later panel sampling (Fig. 17).

The cluster effect was expected to be the dominant factor in the replicate sample pairs because of the different depths in the till profiles.

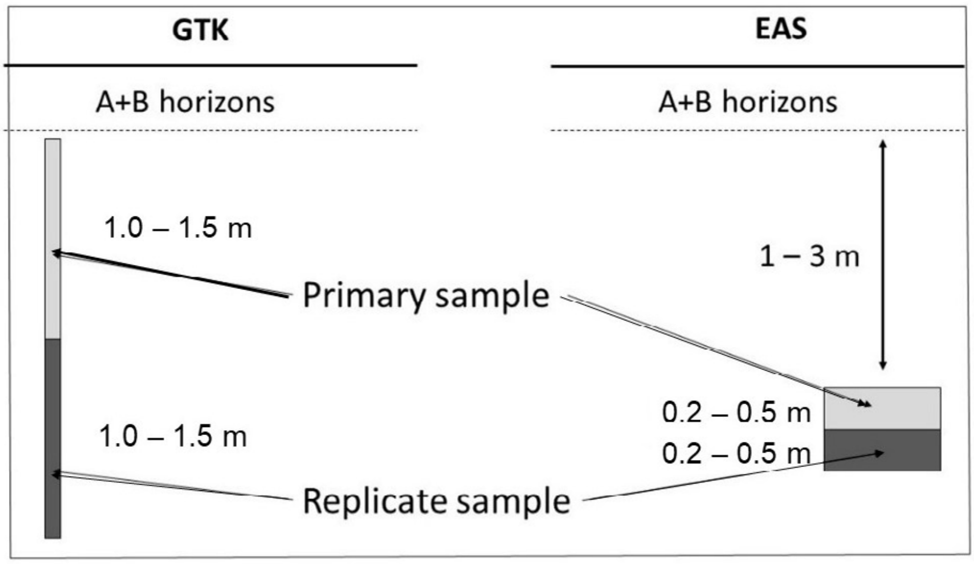



Fig. 15. Principles of till sampling by GTK and by the author (EAS).

### *Existing replicates of the author´s data*

The exploration organizations of Outokumpu Mining Oy, Dragon Mining Ltd and Endomines Oy carried out many till geochemical exploration programmes using exploration pits during 1997-2009, all of them planned and executed or supervised by the author (EAS) in the Ilomantsi Schist Belt area. The procedure was almost the same in all cases. The principle was to take large representative samples, in order to increase the representativeness, and the term “*bulk till sampling*” was used in the reports (Sandberg 2002).

The pits were dug using a tractor excavator or excavator to a depth of three to four metres, preferably under the ground water table. In the case of homogeneous till, a sample of 100-200 litres was lifted from the pit, representing the last half metre. After partial drying, some 20-30 litres of this was field sieved to the −8 mm or −10 mm size fraction (Fig. 16). Sieving also ensured good homogenization of the sample. Two aliquots were then collected from the sieved till heap: 10 litres for heavy mineral tests and 1 kg for analysis of the fine size fraction. A similar two-aliquot system was also used in Canada in reconnaissance till sampling programmes (McClenaghan 1990).

The fine fraction aliquots were dried in a laboratory and sieved to −0.060 mm for fine fraction samples. Both the fine fraction and heavy mineral fraction aliquots were analysed either in the laboratory of OM or VTT in Outokumpu using FA, with a sample weight of 40 g (Code A5, Table 5) or in the laboratory of GTK in Kuopio using GFAAS, with a sample weight of 5 g (Code A2).

Field replicate samples were collected, usually every $10^{th}$ sample. The replicate aliquot was excavated 0.2-0.5 m deeper than the primary sample in the same till profile and horizon, and prepared similarly to the primary sample. The replicate sampling principle is presented in Figure 15.

Fig. 16. Sieving of a bulk till sample to a fraction of −10 mm and channel sampling of the sieved fraction at Suurikuusikko, photos by the author.

#### *Duplicates in homogeneous till heap samples*

Some field duplicate ("blind duplicate") aliquots were collected from the sieved (-8 or -10 mm) and homogenized and flattened till heap. Both samples were collected with a small scoop along a line across the till heap. This has also been the normal procedure in till heap sampling (Fig. 16). Although the cluster effect can exist in coarse mineral particles or clayed lumps of till, this is mainly removed in sieving and the nugget effect is considered to be dominant.

#### *Duplicates of the fine fraction (-60–63 µm) samples of till*

Laboratory duplicate samples were prepared by splitting the sieved −60 or −63 µm till size fraction into two samples for analysis. Similarly, to the pulverized samples, most of the gold grains or gold-bearing minerals are free or occur as mixed particles in such samples. The nugget effect is dominant in precision with practically no cluster effect. This nugget effect of the split aliquots for analysis is included in all the samples (constant nugget effect, Fig. 3).

#### *Replicates of the heavy mineral fraction samples*

The heavy mineral samples of ten litres were wet sieved first to −3 mm removing the fraction of +3 mm by wet sieving and clay fractions by washing and decanting. Then, the -3 mm fraction was wet sieved to −1 mm. The fractions of −1 mm were panned to heavy mineral aliquots weighing about 50 g. A few aliquot sets were sent for processing with a Knelson laboratory concentrator of Outokumpu Mining (OM), operated by Martti Ollikainen.

Both cluster and nugget effects are important sources of variance. The samples are concentrates containing varying quantities of gold grains. Thus, splitting of the samples for analysis is a more important source of variance than in the fine fraction samples.

### *Till test panels*

The cluster and nugget effects were tested in subvertical till panels from the till walls of open pits in five separate locations in the Ilomantsi, Kuusamo and Kittilä mining areas. This test attempted to simulate blind till sampling with a sampling grid of ten metres or more. These mining areas had till walls large enough for this sampling system. To eliminate or minimize the effects of outcropping ore deposits, the lowermost layers of till were not sampled. A suitable and homogeneous subvertical till surface was first cleaned until the primary till was visible. A grid of 3 x 3 m was marked on the till. Because of the inclined position of the till section, the vertical, inclined grid distance was about 1.5 m, representing one metre vertically. In total, 36 aliquots were collected from the panel using a small scoop. The sampling system is presented theoretically in Figure 17 and in practice at Rämepuro in Figure 18. Furthermore, four samples (10 litres of the size fraction of -10 mm) were prepared, similarly as aliquots C, for heavy mineral tests from squares 1, 3, 7 and 9 at Pampalo and Rämepuro. The total number of analysed samples there was 49, including the fine fraction duplicates of the D aliquots. An extra panel from Rämepuro was sampled in 2017, including only nine C aliquots with the nine heavy mineral samples.

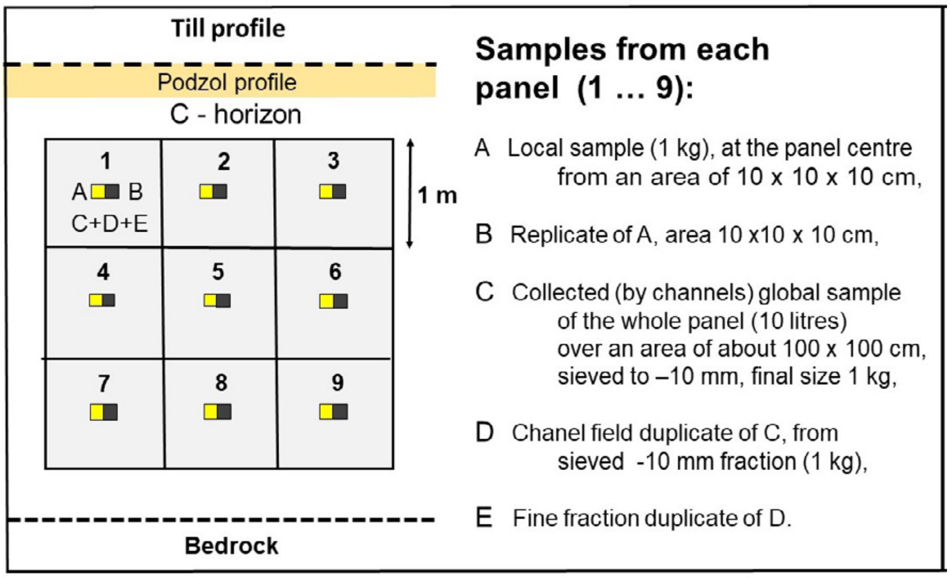



Fig. 17. Sampling procedure from the till panels.

Fig. 18. A till panel after sampling at Rämepuro in 2015.

Aliquots A and B were collected, avoiding pebbles, but were not sieved on site. The primary size of the C -sample was 10 litres, weighing 15-20 kg. It was sieved on site to −10 mm and a channel sample of about 1 kg was collected from the sieved till heap (Fig. 16). Another duplicate channel aliquot of a similar size was picked for sample D. They were first dried and then sieved to -0.85 mm by the author. The sieved aliquots, weighing 300-400 g, were sent to the ALS-Finland Laboratory in Outokumpu. After extra drying, the aliquots were sieved to −63 µm for laboratory analysis. The fine fraction percentage (-63 µm) was calculated from the weight of the −0.85 mm fraction.

The analyses of the fine size fraction aliquots were conducted at ALS Minerals in Loughrea, Ireland (Code A12, Table 5). The detection limit was 1 ppb for gold and 0.5-0.2 for arsenic and copper. This quite high detection limit for gold was selected so as to obtain a sample that was as large as possible for analysis. Larger samples in analysis of the fine size fraction of till tend to improve precision (Kontas 1993). The heavy mineral aliquots were analysed for gold by Labtium Oy, Kuopio, Finland (Code A2), and for the other elements using the method 515PM (Code A6). This same method for gold was also used by OM in the analysis of regional heavy mineral samples.

#### 4.2.4 Analytical methods

Various laboratories and methods for gold analysis were used for the samples included in this study from the 1970s to 2018. They are presented in Table 5 with the code that is quoted in the text. The other elements were analysed conventionally in the laboratories by nitric acid or aqua regia leaching and atomic absorption spectrophotometry (AAS) or inductively coupled plasma (ICP) analysis using a sample weight of 0.5 or 1 g.

Table 5. Analytical methods and codes used in the gold analysis data. The laboratory of GTK became Labtium Oy in 2007.

*Abbreviations:*

| | |
|---|---|
| GFAAS | Graphite furnace atomic absorption spectrophotometry |
| ICP | Inductively coupled plasma |
| FA | Lead fire assay |
| ICPOES | Inductively coupled plasma optical emission spectrometry |
| AAS | Atomic absorption spectrophotometry |
| FAAS | Flame atomic absorption spectrophotometry |

| Laboratory | Years | Method | Sample g | Analysis | Code |
|---|---|---|---|---|---|
| **GTK** | 1970– | 519U | 1 | Aqua regia diss. + GFAAS | A1 |
| **GTK/Labtium** | 1990– | 521U | 5 | Aqua regia diss. + GFAAS | A2 |
| **GTK/Labtium** | 1995– | 522U | 20 | Aqua regia diss. + GFAAS | A3 |
| **GTK/Labtium** | 2000– | PAL | 500 | Cyanide leaching + ICP | A4 |
| **Labtium** | 2018 | 704P | 25 | FA + ICPOES | A5 |
| **Labtium** | 2018 | 515PM | 5 | Aqua regia diss. + GFAAS | A6 |
| **OM / VTT** | 1990–2003 | | 40 | FA + gravimetric finish | A7 |
| **OM / VTT** | 1990–2003 | | 60 | FA + gravimetric finish | A8 |
| **ALS Global** | 2003–2013 | AA25 | 30 | FA + ICP finish | A9 |
| **ALS Global** | 2003–2009 | AA25 | 50 | FA + AAS finish | A10 |
| **ALS Global** | 2003–2013 | Au-GRA22 | 50 | FA + gravimetric finish | A11 |
| **ALS Global** | 2015–2017 | TL43-MEPKG | 25 | Aqua regia diss. + ICP | A12 |
| **ALS Global** | 2018 | AA25 | 25 | FA + AAS finish | A13 |
| **Acme Anal.** | 2004–2006 | 1F+MS | 30 | Aqua regia diss + ICP | A14 |
| **Acme Anal.** | 2004–2006 | Au6 | 50 | FA + gravimetric finish | A15 |
| **Endomines** | 2010–2017 | PAL | 500 | Cyanide leaching + FAAS | A16 |

The use of many laboratories and analytical methods for gold results in uncertainties in the comparison of the results. Fortunately, almost all the precision test campaigns utilized the same laboratories and methods, and widely used independent or check laboratory analyses of pulp samples were not included. Labtium, ALS Global and Acme Analytical are certified laboratories. More detailed descriptions of the methods in these laboratories are not presented here, because they can be found in the presentations of the laboratories.

The Pampalo mine laboratory is not certified and uses a PAL 1000 device, which contains 52 steel pots on four separate rotational axes. Each axis has 13 pots with a volume of 2.3 litres. The sample size is 500 g and the grain size <2 mm (75%). The pulverising and leaching time is 1.5 hours for gold to be leached as a cyanide complex. The gold content is analysed by flame atomic absorption spectrophotometry (FAAS) using a Perkin Elmer 400 AAS spectrophotometer (SRK Consulting 2016, Code A16).

#### 4.2.5 Statistical methods

The statistical methods were basically quite simple in order to focus attention on geological factors, instead of sophisticated statistical features, that might cover the geological reality.

The correlation coefficient (marked as r) measures the linear correlation or dependence between analytical or other result pairs, and was developed by Karl Pearson (Pearson 1895). The Pearson correlation coefficient was systematically used in this study. Because possible outliers strongly influence the coefficient values (Huber 2005), analytical result pairs are commonly also presented here as graphic plots.

The mean relative precision or coefficient of variation (CV) or relative standard deviation (RSD) is commonly used in statistics and determined as:

$CV = s / \bar{x}$
s = standard deviation
$\bar{x}$ = mean

In the text, the term "*precision*" refers to the coefficient of variation (CV). Precision is opposite to "*variation*"; high variation means low precision, and vice versa.

The percent coefficient of variation (CV%) is a practical number to compare different fractions and targets. It is the CV value calculated as a percentage, as presented, for example, by Abzalov (2011):

$$CV\% = 100 \times \sqrt{\frac{2}{N}\sum_{i=1}^{N}\left(\frac{(a_i - b_i)^2}{(a_i + b_i)^2}\right)}$$

N = number of replicate / duplicate sample pairs,
a = primary grade,
b = replicate / duplicate grade.

The half absolute relative difference (HARD) is also commonly used when comparing paired duplicate results. The difference is often presented as a function of the cumulative percentage difference. To compare duplicate data from different deposits, a cumulative percentage limit of 90% was selected. This is also a widely used limit in QAQC reports.

Relative variance is a power two function of CV ($\sigma^2_{RSV}$) and is calculated from CV or CV% values as (Abzalov 2016):

$\sigma^2_{RSV} = (CV)^2$ or $(CV\% / 100)^2$,

but is shortened as $\sigma^2$

F-statistics or F-factor are used to compare the local (within site) variance ($\sigma^2_L$) with the regional (between sites) variance ($\sigma^2_R$) as a ratio:

$\sigma^2_R / \sigma^2_L$

In the text "*precision*" always means CV or CV% and is used in comparing different fraction sizes. The term "*variance*" stands for $\sigma^2$ and is used in estimating the process chain of sampling-preparation-analysis.

# 5 RESULTS

## 5.1 Bedrock samples

The precision results for bedrock samples from Ilomantsi, Kuusamo and Kittilä are subdivided here into four categories as in Table 1:

– replicate variation between drill holes, which is examined through variations between densely drilled holes and connected to variography,
– replicate variation of half or quarter drill core samples,
– duplicate variation of crushed bedrock samples,
– duplicate variation of pulverized samples (pulp).

### 5.1.1 Replicate variation of drill core samples

#### *5.1.1.1 Ilomantsi*

*Variography*

Only a few variograms connected to the resource or reserve estimations have been constructed for the Pampalo deposit. The gold deposit plunges to the north and the longest ranges in variograms are usually in that direction. The down-plunge (40 degrees to the north) ranges vary in separate lodes from 10 to 30 m and the nugget value from 13% to 36% of the sill value (Payne 2004, WAI 2007). The densest drilling grid has been 10 x 10 m. The ranges cannot then be smaller than the drill hole distances, except in the direction of the main drill hole orientation. Variography at deep levels by SRK Consulting (2016) provided a minimum range in the down-dip direction (345°/43°) as 20 m and the nugget value as 31% of the sill value.

***Variation between densely drilled holes***

***Pampalo***

A more detailed drilling test was carried out in 1998 by the author. Ten parallel core drill holes were drilled through the homogeneous central lode at mine level 116, perpendicular to the ore zone, in a grid of 1 x 1 m. Logging and sampling followed exactly the same rock and mineralization type classification in each hole. The whole core (core diameter 42 mm) was used for the sample. The true thickness of the lode varies from 6.25 to 7.65 m. The intercepts were divided into eight segments as homogeneously as possible to ensure continuation from hole to hole. A special continuous skarn zone in the centre of the ore zone was a good marker unit. The hole positions and the ore profile are illustrated in Figure 19.

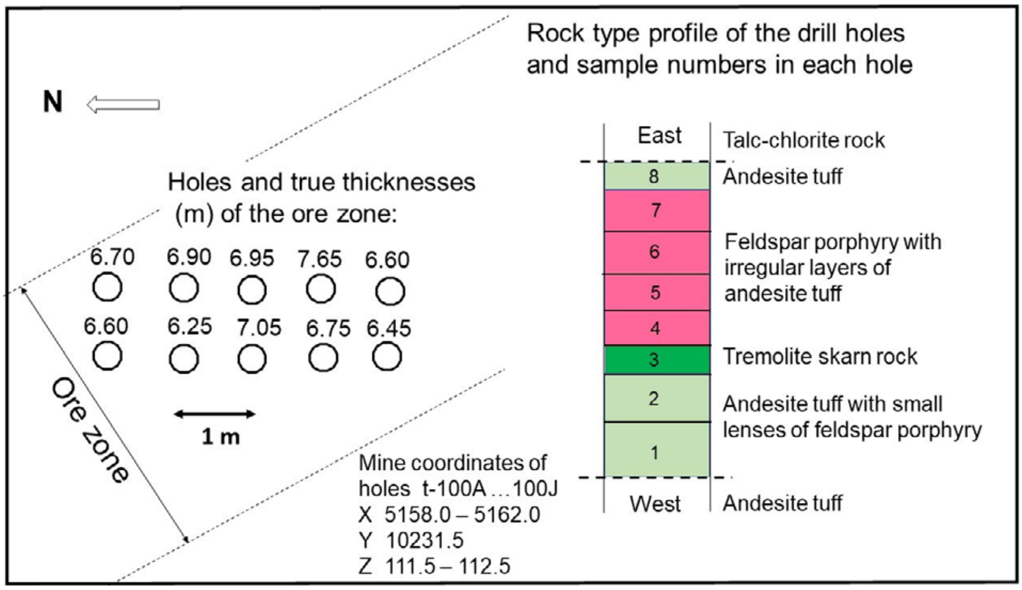



Fig. 19. Drill hole locations and the rock type profile of the test drilling at Pampalo in 1998. The test site was located at mine level 116 in the eastern ore shoot of the central (C) ore body. The holes were drilled from west to east, perpendicular to the ore zone, and the figure with holes is looking to the east.

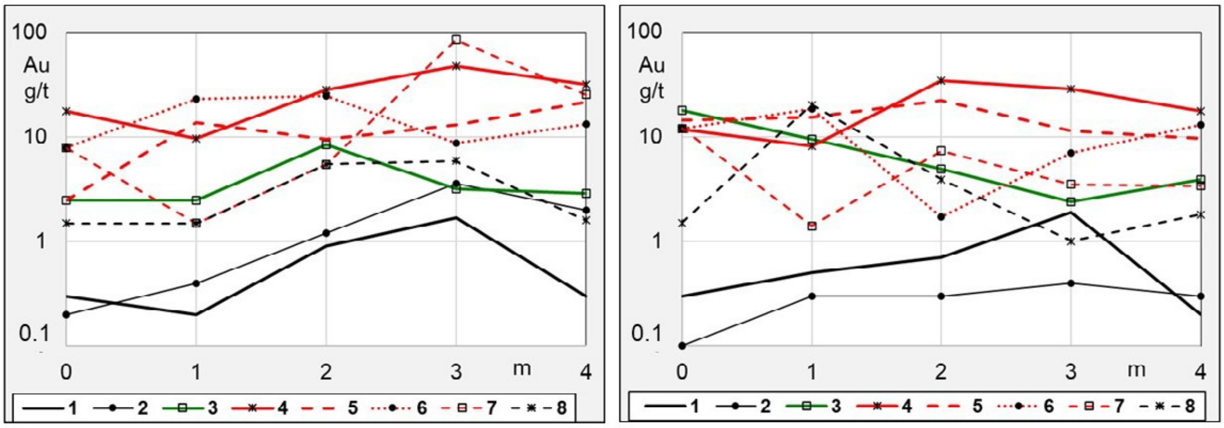



Fig. 20. Horizontal gold grade variation of rock types 1-8 from hole to hole in Figure 19.
*Left*: the upper drill hole line, from north to south as in Figure 19,
*Right*: lower line as in Figure 19.
The analytical method was fire assay with a gravimetric finish and the sample weight was 40 g (Code A5, Table 5).

The true thicknesses of the drill holes varied from 6.25 to 7.65 m being thickest in the centre of the ore zone, as could be expected. Although the intercepts appear macroscopically quite similar, the mean gold grades across the ore zone vary from 7.4 g/t to 30.4 g/t and individual gold grades from 0.1 g/t to 85 g/t. Figure 20 presents the horizontal variation in the drill hole lines of Figure 19. Gold grades of the neighbouring samples of the same rock type unit (1…8) of the ore zone are collected in a plot in Figure 21, (left figure). They are subdivided into four orientations: horizontal, vertical and inclined either to the north (plunge of the ore zone) or to the south (perpendicularly to the ore zone).

Correlation coefficients (r) of the sample sets are provided in Table 6. The number of sample pairs at the sample distances of three or four metres was too small for a reliable correlation estimate, but a correlation is also clear at these distances.

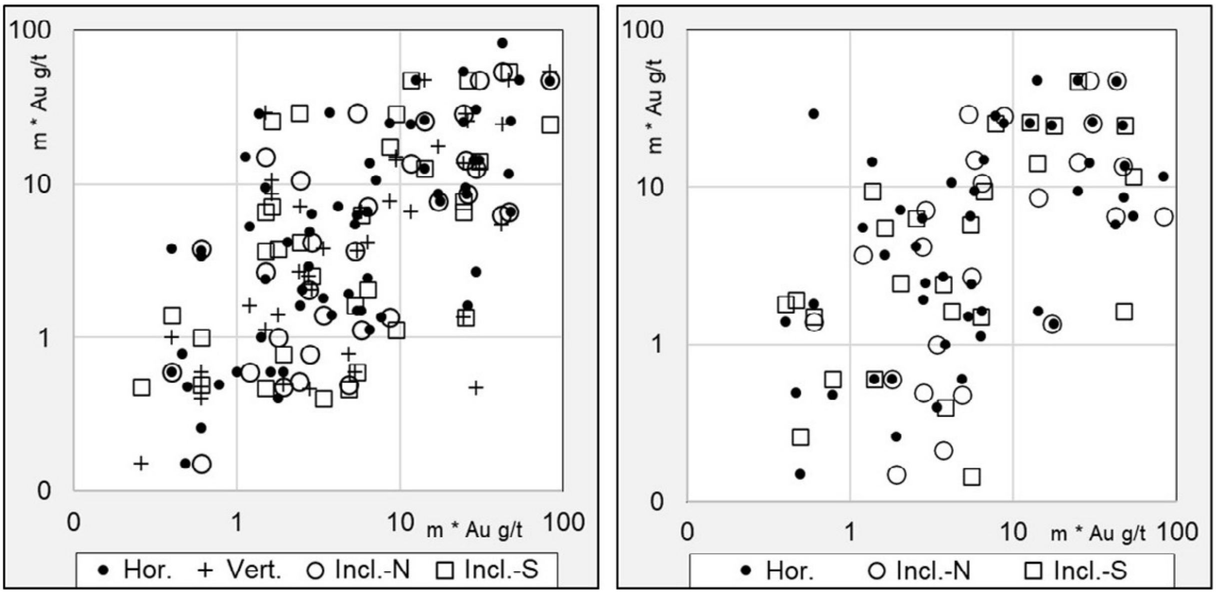



Fig. 21. Plots of normalized gold grades (core length x gold grade) of neighbouring samples at a sample distance of one metre (left figure) and two metres (right figure).
*Abbreviations:*
Hor. Horizontal position of the sample pairs,
Vert. Vertical position of the sample pairs,
Incl.-N Inclined position dipping to the north, dip 45°, real length 1.4 m (left plot) and dip 30° , length 2.2 m (right plot),
Incl.-S Inclined position dipping to the south, dip 45°, real length 1.4 m (left plot) and dip 30° , length 2.2 m (right plot).

Table 6. Correlation coefficients (r) of the sample sets of Figure 21.

| Sample position | Sample 1 m | distance 2 m |
|---|---|---|
| Horizontal | 0.474 | 0.214 |
| Vertical | 0.519 | |
| Inclined to North | 0.472 | 0.145 |
| Inclined to South | 0.291 | 0.416 |

The skarn horizon (number 3 in Figure 19) is the only clear lithological unit in the test. The rock type ratios of andesite tuff and feldspar porphyry were found to vary in the other lithological units.

Drill sludge sampling was started in Pampalo underground (UG) sampling in 2013, as suggested by the author (Sandberg 2012). Before that only grab sampling on the drift face had been carried out with varying results. In the sludge sampling, sand of the drilled drift run was collected evenly along the face bottom. The size of the sample was about 5 kg. The grab samples were picked out of the drift face as evenly as possible. The total sample weight was also about 5 kg. The two methods were used together until 2015, when grab sampling was ended, partly for safety reasons (Sandberg 2016). Sampling methods were further tested in 2016 by Endomines Oy (Eriksson 2016). It is generally accepted that grab sampling is the least preferred sampling method in underground mines (Spangenberg 2012, Clark & Dominy 2017). Grab sampling also has lower precision compared to hand cut or saw-cut channel sampling (Dominy et al. 2020).

Grab samples were collected from both sides of a separate drift run. Their mean gold grades were calculated by the author, and in Figure 22 they are compared with the gold grades of the drilling sludge, which represents the whole drift run. The correlation is good (r = 0.559) and slightly better than in the test drilling (Table 6). This is understandable because the large samples in this test should reduce local cluster effects.

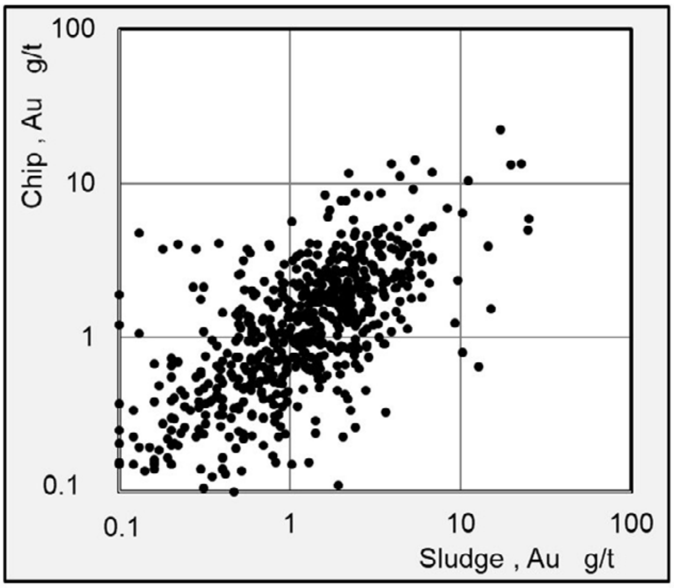



Fig. 22. Plot of chip and sludge sampling of drift runs in Pampalo mine. All the analyses were conducted in the laboratory of Endomines at Pampalo using the cyanide leaching PAL method (Code A13). The detection limit was 0.1 ppm and the values <0.1 g/t are marked as 0.05 g/t in the correlation estimation.

***Rämepuro***

At Rämepuro a grid drilling test was carried out in 2001. Four holes were drilled at the corners of a one-metre square. The holes were orientated in perpendicular with the quartz-tourmaline breccia ore body at an angle of 45 degrees. Additionally, one previous parallel hole exited at a distance of one metre. The location and hole layout are presented in Figure 23. The holes were logged and sampled using identical geological boundaries and lengths. The cores of the four holes were sawed into two halves, which were analysed separately. The results (Table 7) indicate significant variation. The lowest grade of a core half in the quartz-tourmaline breccia zone is 1.0 ppm and the highest grade of another half in the same core location is 50.6 g/t. The gold grades in an equal zone of the feldspar porphyry are 0.1 g/t and 74.9 g/t. The mineralogical reason for these differences and the cluster effect is probably randomly located minor folded quartz-tourmaline-sulphide veinlets enriched in gold (Sandberg 2001).

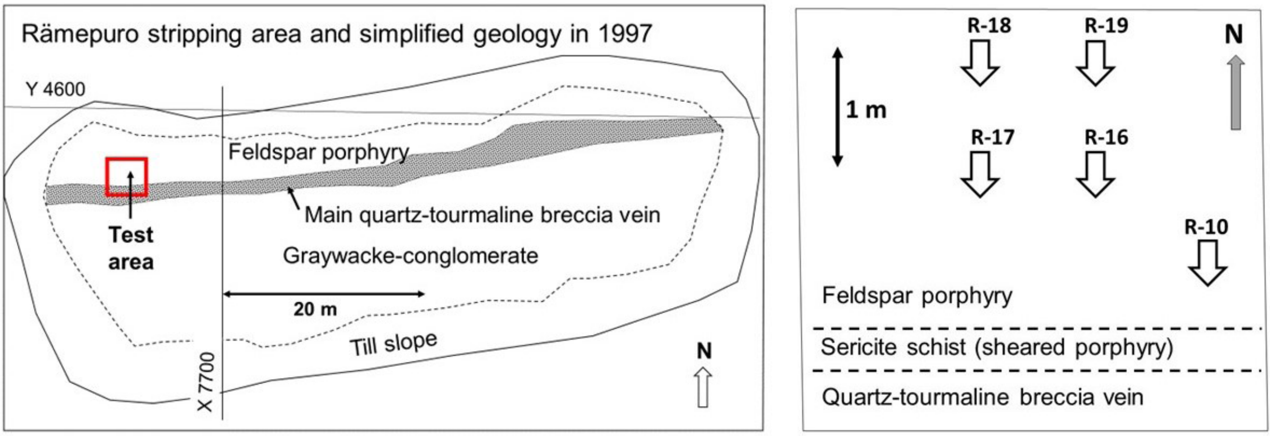



Fig. 23. Simplified geology after the first overburden stripping (left) and the drill hole locations of the test drilling (right) at Rämepuro. The core diameter of holes R-16 ... R-18 was 60 mm and that of hole R-10 was 42 mm. See also Figure 8.

Table 7. Gold grades (g/t) of the test drilling at Rämepuro. Core halves are marked as h1 and h2. The assay method by VTT-Outokumpu was the fire assay (FA) with a gravimetric finish (Code A5, Table 5). The unit is g/t.

| Rock type | Lenght m | R - h1 | 16 h2 | R - h1 | 17 h2 | R - h1 | 18 h2 | R - h1 | 19 h2 | R-10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Feldspar porph. | 1.80 | | | | | 0.1 | 0.3 | 0.2 | 0.2 | |
| Feldspar porph. | 1.80 | 0.9 | 0.7 | 0.1 | 0.2 | 0.3 | 0.3 | 2.1 | 0.0 | |
| Feldspar porph. | 1.80 | 0.1 | 0.3 | 0.1 | 0.4 | 0.1 | 0.1 | 0.2 | 0.2 | 74.9 |
| Feldspar porph. | 2.00 | 0.2 | 0.4 | 0.7 | 0.2 | 0.7 | 0.4 | 2.3 | 1.7 | 0.7 |
| Sericite schist | 1.00 | 0.6 | 0.4 | 0.5 | 1.3 | 0.5 | 0.2 | 0.3 | 0.5 | 1.1 |
| Q-tourm.-breccia | 1.40 | 2.2 | 0.2 | 0.7 | 0.9 | 0.3 | 0.3 | 2.9 | 4.8 | 0.5 |
| Q-tourm.-breccia | 1.40 | 1.0 | 1.0 | 1.2 | 1.0 | 29.5 | 50.6 | 5.9 | 3.4 | 1.1 |
| Q-tourm.-breccia | 1.40 | | | 1.0 | 0.5 | 3.0 | 2.3 | 15.8 | 3.8 | 2.9 |

Gold grades at a one-metre distance range from 0.1 to 75 g/t or from 1 to 51 g/t. These differences would have had a dramatical influence on the interpretation of the target potential in a case where only one hole was drilled.

*Replicate variation of half drill core samples*

***Pampalo***

The next step was to test the centimetre-scale variation using half-core replicates. In 1997-1999, this was examined in three separate tests. The drill core diameter was 42 mm and the core was cut using a saw and both halves were analysed separately. Various mineralisation types and gold grades were selected for the tests. The results are presented in Figure 24. The mean values differ because of a few high-grade samples resulting in higher grades in the primary halves than in the replicate halves.

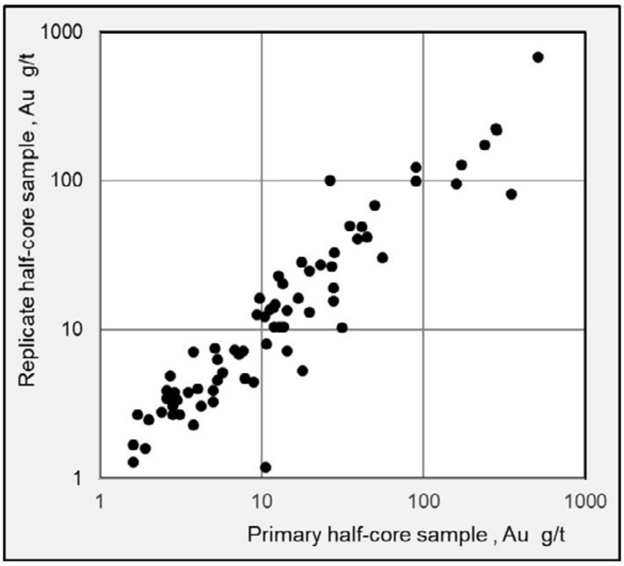



Fig. 24. Gold grade plot of half-core and opposite half-core samples from drilling programmes at Pampalo in 1997-1999. The number of sample pairs is 75. Mean grades are 40.3 / 36.6 g/t, median grades 10.7 / 10.4 g/t, r = 0.891 and CV% = 31.1. The samples were analysed at VTT / Outokumpu with the FA (Code A5).

#### *5.1.1.2 Kuusamo*

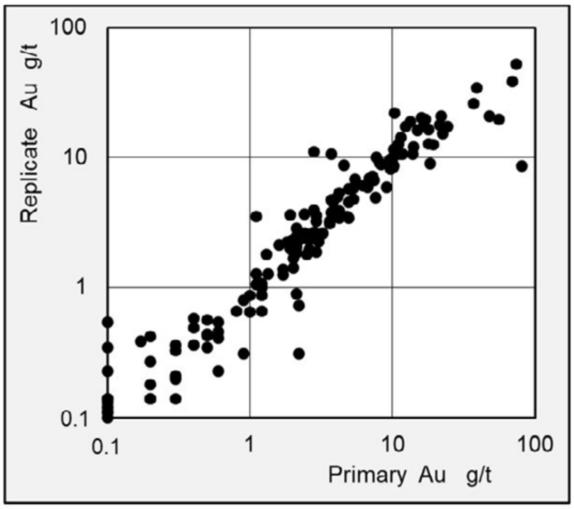
*Variography*

Geostatistics of the Juomasuo gold deposit were first investigated by the author in 1992 (Sandberg 1993), in connection with test mining operations. Data from diamond and sludge drilling were used as the estimation data. Ranges of variograms varied from three to ten metres, being longest in a vertical direction. The nugget value was small. The variography by Runge (2011) indicates the downhole range as 5 m and the longest subvertical range as 20 m for the first structure of the variogram. The nugget value is also small, being 5% of the sill value.

*Half core replicates*

Half core replicate tests were performed in two phases. The first phase (Sandberg 2007) included drill core samples from the drilling programmes of 1991-1992 by Outokumpu Mining Oy. Each core (diameter 42 mm) was cut using a core splitter ("guillotine") at that time and analysed by with the fire assay with a gravimetric finish using a sample weight of 40 g (Code A5). To determine the gold, uranium and other metal grades, a representative set of drill holes (13), containing significant gold intercepts was selected in 2006. The total number of samples was 148. The remaining half of the core was collected using primary sampling boundaries. The samples were assayed in Canada by Acme Analytical Ltd (Code A11). The results are plotted in Figure 25. The mean gold grade of the primary samples is 7.37 ppm and that of the replicate samples 6.05 ppm (correlation r = 0.821 with CV% as 30.3). The reason for the significant difference is the small number of high-grade samples in the primary sample set. In addition, some pieces of the high-grade core may have lost or sampled for mineralogy, or other testing, in 1991-1992.

Dragon Mining Oy started the Kuusamo project again in 2010 with intensive drilling. Accuracy and precision checks were systematically included in the sampling stream (Sandberg 2013b). Precision was tested using pulp duplicates, which only cover the splitting and analytical variation. Cores (diameter 50 mm) were cut using a saw. Systematic re-assaying was conducted on samples grading >3 ppm Au, and some samples yielded significantly different results in the re-analysis. These



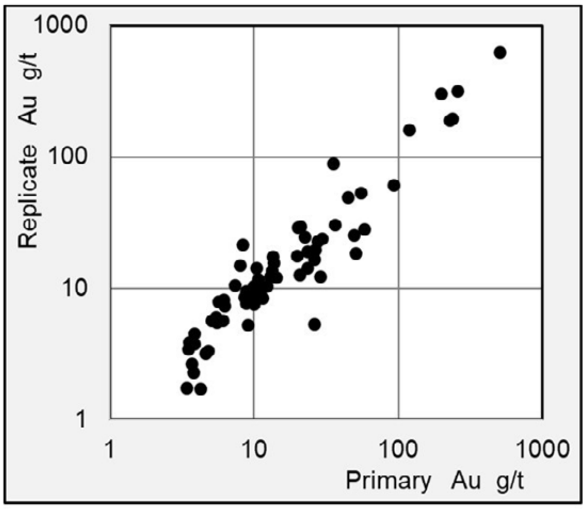




Fig. 25. Plots of half core replicate sampling in Juomasuo.
*Left*: Testing of primary grades from drilling in 1991-1992. The primary gold assays were conducted by VTT using the fire assay (Code A5). Replicate samples were analysed by Acme Analytical Ltd (Code A11).
*Right*: Replicate testing of problematic core samples drilled in 2011-2013. Both the primary and replicate samples were prepared by ALS Finland Oy and analysed using the ALS method Au-GRA22 (Code A9).

samples were considered as "problematic", indicating coarse-grained gold and the nugget effect. Half-core replicates were tested in a separate set by collecting these high-grade and problematic samples in the batch. The test included 68 samples. The remaining half core was cut in two and one quarter was used for replicate analysis. The results are presented in Figure 25, (right plot), indicating a much better correlation (r = 0.975, CV% 30.8) than in the earlier test (Fig. 25, left figure, r = 0.821). A good correlation of the high gold grades (>100 g/t) and the absence of low grades improved the correlation. The mean of the primary samples was 38.2 g/t and that of the replicate samples was 40.2 g/t.

Screen FA analysis was also checked for 13 samples. The cutting screen was 100 µm. The amount of coarse-grained gold (>100 µm) varied from 9 to 28% of the total gold and the mean was 17%. The total gold grade of screen FA analysis correlated perfectly with the total FA analysis. The means were 56.7 ppm (Screen) and 55.7 ppm (FA) and the correlation coefficient r = 0.998 (Sandberg 2013a).

### 5.1.2. Duplicate precision of crushed rock and pulp samples

#### *5.1.2.1 Ilomantsi*

In preparation, a half or whole core was crushed to −2 mm before pulverizing. Prior to 2003, no systematic duplicate testing was included in the logging and sampling procedure. Separate batches were analysed a few times to check the precision of both crushed rock and pulp analysis, partly using another laboratory or method. Figure 26 (left plot) presents the results from the analysis of duplicate aliquots, which were prepared by splitting and pulverizing the primary, crushed (-2 mm) sample. The correlation is good (r = 0.973) and the mean gold grades are almost the same (29.9 / 29.3 g/t).

The crushed material was also tested using larger sample weights (500 g) with cyanide leaching followed by ICP to identify the possible coarse gold nugget effect. However, the results were also almost identical (Fig. 26, right figure).

Endomines Oy conducted some tests in 2016 (Eriksson 2016) on crushed ore material before milling. One sample was collected every 10 minutes for two hours, each comprising two buckets of crushed ore (-25 mm) from the mill feed. Crushed ore was split for the first primary sample, mixed and split again for the first duplicate and once again for the second duplicate. Each sample was 500 g in weight. All the samples were analysed at the Endomines laboratory at Pampalo using cyanide leaching followed by AAS-analysis (Code A13). The results are presented in Figure 27 and the analytical means in Table 8.

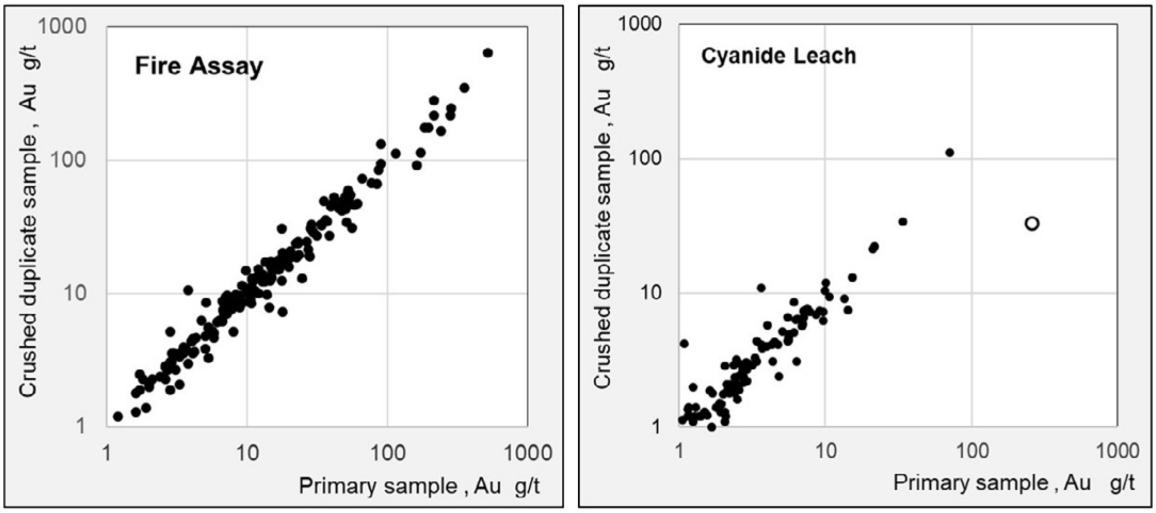



Fig. 26. Plot of primary gold grades compared to crushed rock duplicate gold grades at Pampalo, using a similar analytical method, the fire assay, and a sample weight of 40 g (Code A5, left figure) and large sample weight (500 g) and cyanide leaching (Code A4, right figure) (Sandberg 2009). The correlation coefficients (r) are 0.973 (left figure) and 0.512 (right figure). However, if one outlier (marked as o, with grades by FA 258 g/t and by CL 33 g/t) is excluded, the correlation rises to 0.966 and the means are 5.18 g/t (FA) and 5.21 g/t (CL).

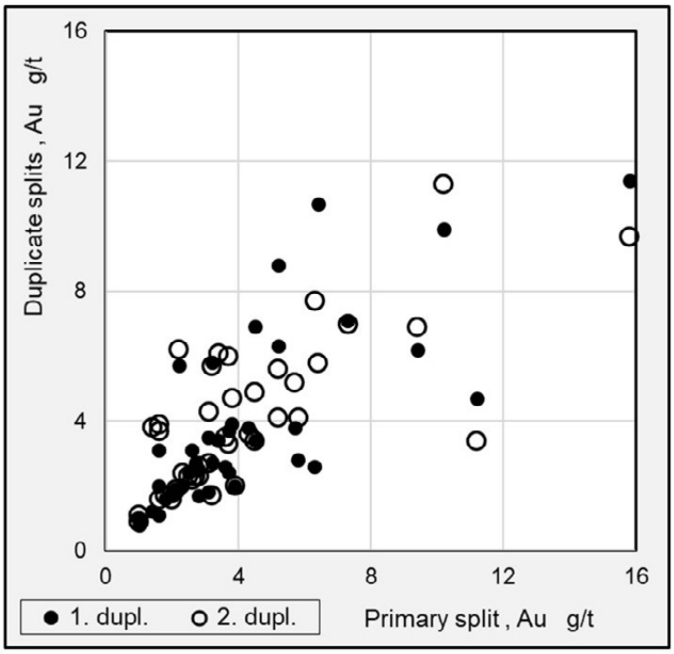



Fig. 27. Plots of the first and second duplicate splits (500 g) of the crushed ore (-25 mm) from the Pampalo mine.

Table 8. Mean gold grades of the coarse crushed duplicate test at Pampalo. the primary sample number is 40. The code "0/1" is the correlation coefficient (r) between the primary sample (0) and the first duplicate (1), "0/2" is the correlation between the primary sample (0) and the second duplicate (2) and "1/2" is the correlation between the first (1) and second (2) duplicate.

| | Primary (0) | 1 dupl. | 2 dupl |
|---|---|---|---|
| Mean , Au g/t | 4.2 | 3.9 | 4.1 |
| Median , Au g/t | 3.3 | 3.0 | 3.7 |
| Correlation , r | 0/1: 0.749 | 0/2: 0.723 | 1/2: 0.756 |

The correlation (r) is slightly better (from 0.723 to 0.756) compared with the drill sludge and face grab sample gold grades of the same drift run (r = 0.559, Fig. 22). However, the correlation and precision strongly improve when the grain size is reduced to two millimetres (r = 0.973, Fig. 26).

SRK Consulting carried out auditing in the laboratory of the Pampalo mine in 2016. The collected duplicate testing results for 173 samples in the Pampalo laboratory yielded quite similar results when comparing cyanide leaching and FA-analyses, including a few outliers. The samples were crushed to −2 mm (75%) and split by box splitter. A scatterplot of the results is presented in Figure 28 (SRK Consulting 2016).

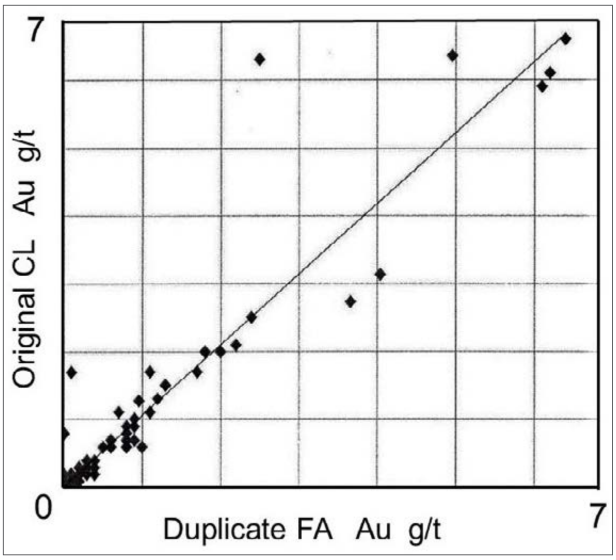



Fig. 28. Plot of primary and crushed duplicate testing results from the Pampalo laboratory using PAL 1000 cyanide leaching and FA analysis of gold for the duplicate samples (SRK Consulting 2016).

In 2004, the author planned a system to systematically test both accuracy and precision. Every tenth sample in the sampling stream was used either as a reference sample or a pulp duplicate. Since then, the system has been used in the projects of Polar/Dragon Mining and continued at Ilomantsi by Endomines Oy. Although the system is not statistically the best possible, it is easy to use in logging and core sampling.

The gold grades of the pulp duplicates from the drilling projects in 2007-2008 at Pampalo and in the surroundings are presented in Figure 29 (the left plot). High grade (>10 ppm) samples were also re-analysed, after the normal pulp duplicate analysis, by using the same sample weight (50 g), but a gravimetric finish for the FA-analysis. A few outlying points exist, but the correlation is generally reasonable (Fig. 29, right plot).

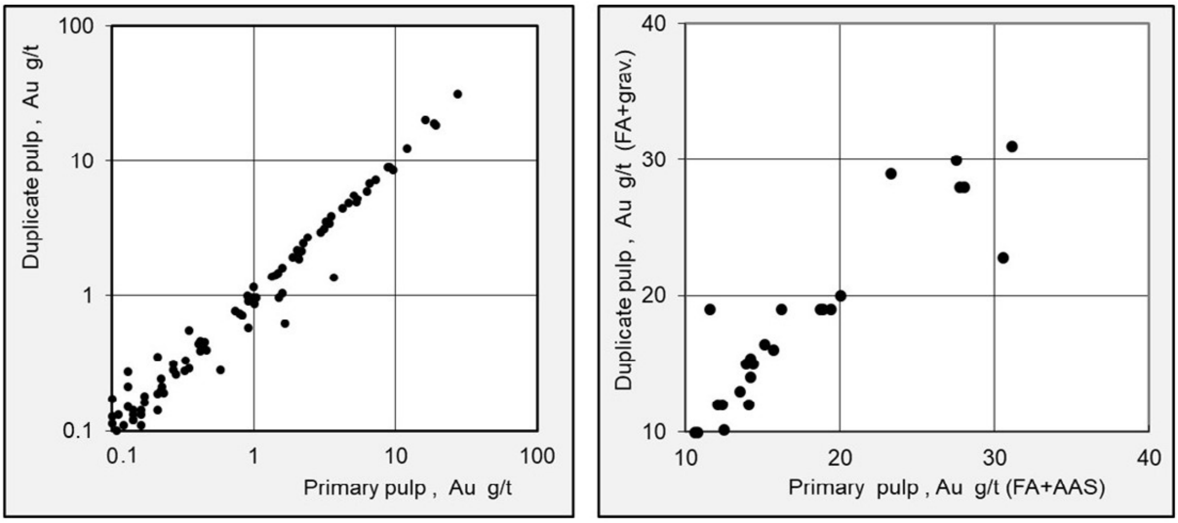



Fig. 29. Plot from a systematic pulp duplicate check of the Ilomantsi drilling in 2007-2008 (left figure). The number of the sample pairs is 321, the mean gold grades are 0.89 / 0.89 g/t and r = 0.993. The right figure presents the results of pulp re-assay using FA-analysis with a gravimetric finish (Code A8), instead of the normal AAS or ICP finish (Code A7, 50 g sample weight). The number of samples is 27, the mean grades 25.8 / 26.6 g/t and r = 0.998. One sample with a very high grade (241 / 255 g/t) is not included in the right plot. The sample weight in assays for both figures is 50 g. All the data are based on the report of Sandberg (2009).

#### 5.1.2.2 Kuusamo

When starting the Kuusamo project again in 2010, the old crushed sample relicts from the drilling programmes in 1991–1992 were pulverized and re-analysed to verify the quality of the old gold grades. A set of 95 samples was tested covering the whole grade range starting from 1 g/t. The old gold grades proved to be repeatable. The means were almost the same (10.1 and 10.2 g/t) and r = 0.963 (Table 9). Only a few outliers can be seen in the plot (Fig. 30).

Every 20th sample was systematically used as pulp duplicate (Sandberg 2013b). The duplicate was split from the same pulp as the primary sample and sent for analysis in the same sample batch by ALS Finland Oy at Outokumpu. The results were almost identical with only minor differences in mean the grades (Table 9 and Fig. 30). The grade variations were higher in the crushed duplicates than in pulverized duplicates, which should theoretically also be the case.

Table 9. General statistics for the duplicate testing of crushed (-3–4 mm) and pulp sample duplicates at Kuusamo. Au–p = primary analysis by Outokumpu (method FA with gravimetric finish and 40 g sample weight, Code A5), Au–d = duplicate analysis by ALS (method AA25, FA with an ICP finish and 30 g sample weight, Code A7). The pulp test covers the drilling programs in Kuusamo from 2011 to 2013 and pulp samples >0.1 g/t Au. Au-p is the primary sample and Au-d the pulp duplicate of the primary sample. Both sample sets were analysed by ALS using method AA25 (Code A7).

| | Crushed | Dupl. | Pulp | Dupl. |
|---|---|---|---|---|
| | Au-p | Au-d | Au-p | Au-d |
| Number | 95 | 95 | 50 | 50 |
| Min. g/t | 0.20 | 1.02 | 0.11 | 0.13 |
| Max. g/t | 90.9 | 77.1 | 19.9 | 21.0 |
| Mean g/t | 10.13 | 10.19 | 2.43 | 2.48 |
| Median g/t | 4.10 | 4.46 | 0.67 | 0.63 |
| Corr. r | | 0.963 | | 0.999 |

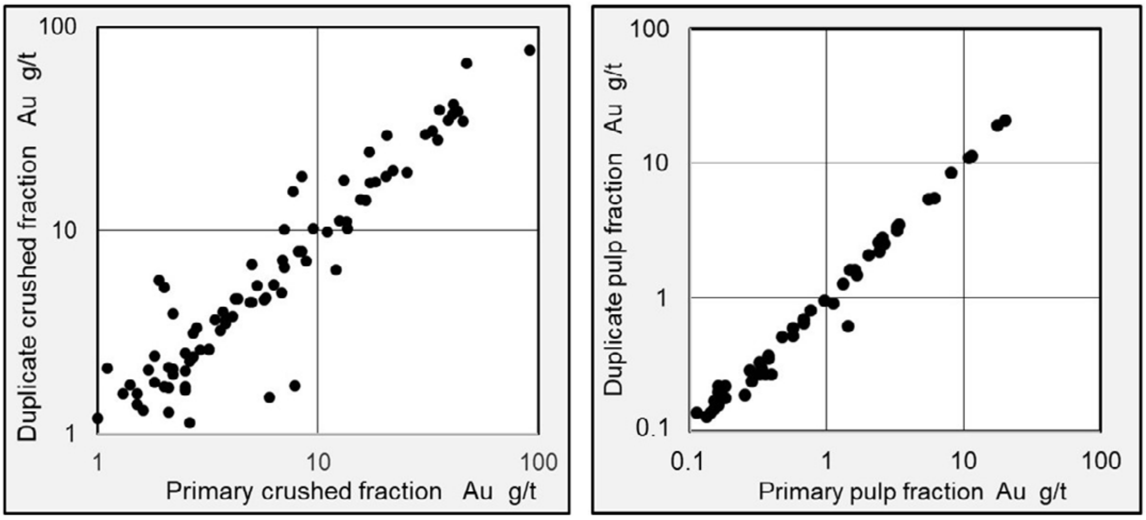



Fig. 30. Duplicate assay results for old crushed (-3 mm) samples from Juomasuo (the left plot). The primary aliquots were analysed at the OM laboratory by FA in 1991–1992 (Code A5). The duplicates were analysed by ALS (Code A7). The right plot presents the results of a systematic pulp duplicate check by ALS in 2011–2013 (Code A7).

All the samples grading >3 g/t analysed using ALS-method AA25 with a pulp sample weight of 30 g (Code A7) were systematically re-assayed using a sample weight of 50 g (method GRA22, Code A9). The aim was to confirm the grade and to detect possible nugget effects. The resulting variation was much higher for a few samples than in the basic pulp duplicate test (Table 10 and Fig. 31). This indicates a significant nugget effect for these few samples. One gold nugget with a diameter of 100 µm would produce a grade of 0.3 g/t in a sample of 30 g, but a nugget of 500 µm (0.5 mm) would result in a grade of 42 g/t. Nuggets >100 µm in diameter were found in the screen fire assay test and macroscopic gold was also observed many times in core logging. Typically, gold grains are flakes rather than spheres, which partly explains the floating of the gold flakes and low gold recoveries in gravity separation in the pilot testing by Outokumpu (Himmi 1993).

Why is the nugget effect evident in duplicate testing with a larger sample weight (Fig. 31) but not in the normal pulp duplicate testing (Fig. 30)? The primary reason is the nugget, effect dividing gold grains unevenly between samples in sample splitting. A second reason could be the weight difference (30 g versus 50 g), which increases the variation in the testing of high-grade samples. A third possible reason is errors in splitting or analysis.

Table 10. General statistics for the re-assayed gold grades >3 g/t. The primary method was AA25 by ALS (Code A7) and the re-assay method GRA22 by ALS (Code A8). The data are subdivided into two temporal sets, the years 2011-2012 and 2012-2013. Au-p = primary gold assay, Au-d = duplicate re-assay of gold.

| | 2011–2012 | | 2012–2013 | |
|---|---|---|---|---|
| | Au-p | Au-d | Au-p | Au-d |
| Number | 104 | 104 | 91 | 91 |
| Min. g/t | 3.02 | 2.94 | 3.02 | 1.60 |
| Max. g/t | 50.2 | 92.4 | 68.9 | 65.4 |
| Mean g/t | 9.66 | 10.23 | 9.69 | 9.36 |
| Median g/t | 6.38 | 6.63 | 5.96 | 6.03 |
| Corr. r | | 0.909 | | 0.966 |

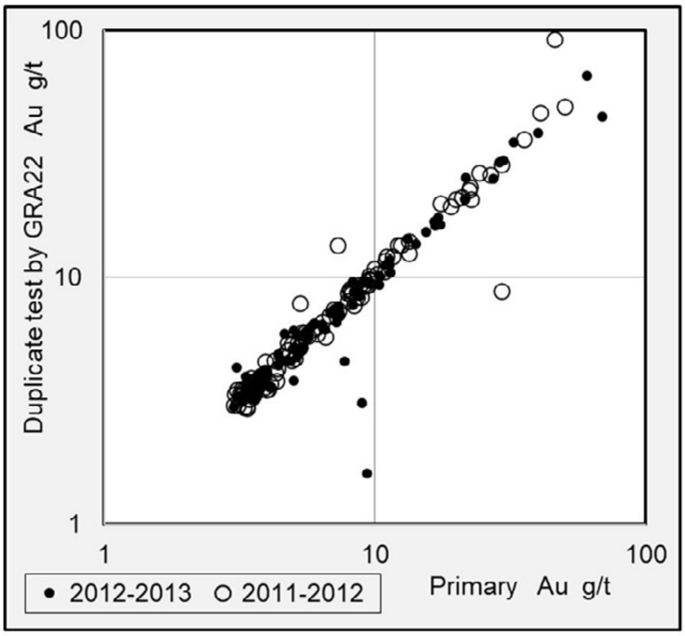



Fig. 31. Plot of gold grade in pulp duplicate checking by FA with a gravimetric finish and a sample weight of 50 g (ALS method GRA22). The primary method was AA25 (FA with an ICP finish and 30 g sample weight). The plot is divided into two time periods, from 2011 to June 2012 and from July 2012 to 2013.

#### 5.1.2.3 *Kittilä*

Limited data were available from the Suurikuusikko deposit, including all the duplicate assays analysed in 2018 (Välimaa 2019). All the previous gold grade duplicate tests indicate an excellent correlation in independent laboratory checks using a very similar fire assay method with a 30–50 g sample weight (Doucet et al. 2010) and in continuing QAQC tests (Välimaa 2017, personal communication). Even when comparing sample weights of 1 g and 50 g, the gold grades were found to be almost identical, although slightly lower using acid leaching tests with a 1 g sample weight than by FA with a sample weight of 50 g (Kontas & Niskavaara 1997).

The duplicate data from the Kittilä Mine in 2018 contains 333 crushed rock samples grading at minimum 0.10 ppm Au (the primary analysis) and 861 pulp samples in the same grade category. The crushing size was –2 mm. The assaying laboratories were Labtium Oy (Code A5, Table 5) and ALS (Code A13). General statistics are presented in Table 11 and gold grade plots in Figure 32. Precision is high for both sample types and laboratories. ALS achieved slightly higher precision than Labtium in assaying the two sample types. The results indicate a small nugget effect of gold and good laboratory quality.

Table 11.General statistics for the re-assayed gold grades ≥ 0.10 g/t of the duplicate test samples at the Kittilä mine in 2018, subdivided into crushed sample and pulp duplicates. Au-p = primary gold assay, Au-d = duplicate re-assay of gold.

| | Crushed samples | | Pulp samples | |
|---|---|---|---|---|
| | Au-p | Au-d | Au-p | Au-d |
| Number | 333 | 333 | 861 | 861 |
| Min. g/t | 0.10 | 0.02 | 0.10 | 0.03 |
| Max. g/t | 38.7 | 42.56 | 52.70 | 52.60 |
| Mean g/t | 2.82 | 2.86 | 2.97 | 2.96 |
| Median g/t | 1.12 | 1.07 | 1.47 | 1.49 |
| STD | 2.86 | 2.93 | 2.73 | 2.73 |
| Correlation r | | 0.998 | | 0.999 |

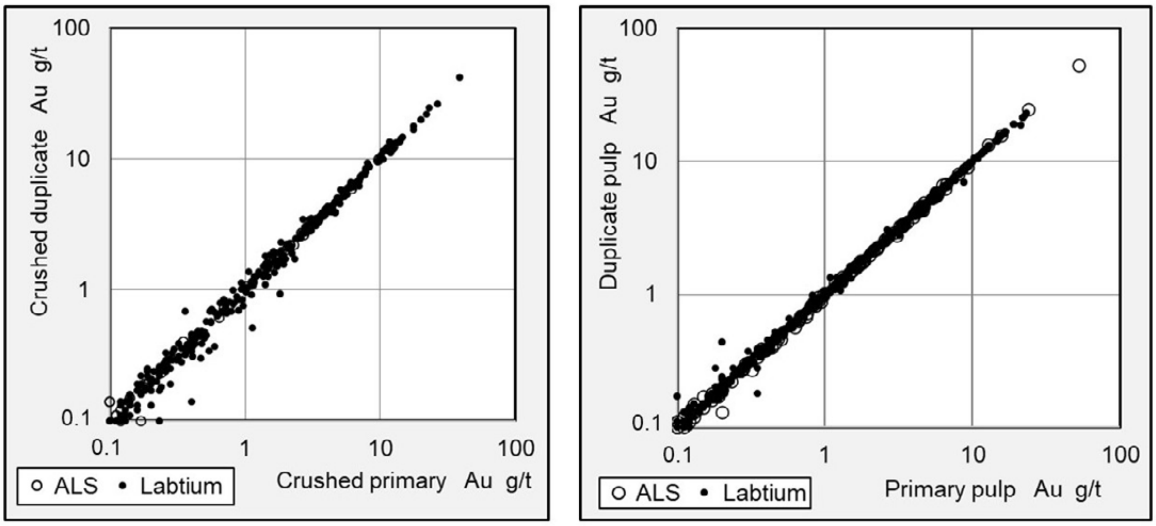



Fig. 32. Plots of results from duplicate sampling of crushed and pulp residue from the Kittilä mine in 2018.

## 5.2 Till samples

### 5.2.1 Test panels of till

Altogether, 36 aliquots were collected from each panel (Fig. 17). The total number of samples was 45, including 9 laboratory duplicate aliquots. The general data for the panels are divided here into three categories:

- means and precisions of the separate sample types (A … E) in a panel,
- means and precisions of the sample types inside the squares (1 … 9) in the panels,
- correlations of the sample types in a panel.

The following test pairs and correlations were estimated in each panel (Table 12):

Table 12. Sample pairs for estimating of correlations in the test panels of till.

| Pairs | Comparison |
|---|---|
| A-B | Small local aliquot (A) – adjacent small aliquot (B) |
| A-C | Small aliquot (A) – large aliquot of the whole 1 $m^2$ sampling square (C) |
| C-D | Large aliquot (C) – field duplicate of the large aliquot C (D) |
| D-E | Large aliquot (D) – sieved (-0.063 mm) fine fraction laboratory duplicate |
| A-A , B-B | Small aliquot ($A_1$, $B_1$) – small aliquot ($A_2$,$B_2$) in the adjacent sampling square |
| C-C | Large representative aliquot (C) – large aliquot (C) in the adjacent squares |

The purpose of the first pair (A-B) was to examine the differences between and correlation of a randomly located small till aliquot, from an area of 10 cm x10 cm x10 cm, with an adjacent aliquot of a similar size. The aliquots were small, but they are much larger in weight (1 kg) than samples used in normal till sampling by vibration or percussion drilling (0.1-0.2 kg). Despite the weight difference, the distance between the samples, about 10 cm in the vertical direction, is approximately the same as in mechanized sampling. Differences in the till structures and textures are greater in the vertical than in the horizontal direction. Thus, the possible cluster effect is almost the same in a drilled sample at the same location and depth.

The second pair, A-C, compared an aliquot from a small area (10 x 10 cm) with a “global”, representative aliquot covering the whole sampling square (100 x 100 cm). Sampling of the whole square is much more time consuming, as representative samples generally are. Would we obtain the same result simply by taking a small, randomly located sample? The cluster effect is now important, explaining possible differences.

The pair C-D tested the correlation between the primary aliquot from a sieved (-10 mm) and homogenized till heap and the field blind duplicate (Fig. 16) collected in the same way. This is basic duplicate testing of representative bulk samples, and the nugget effect is the dominant factor.

After sieving in the laboratory to -0.063 mm, the fine fraction was split into two (D and E) to test the precision of the fine fraction. This analytical precision is included in all the samples and caused by the nugget effect in sample splitting, as well as laboratory procedures.

The final pairs, combined $A_1$-$A_2$ and $B_1$-$B_2$, tested the correlation of small aliquots with similar small aliquots from neighbouring squares, both horizontally and vertically across the till panel. This test represents the minimum precision and can be compared with one-metre grid drilling in the rock sample section. Values of the sample pairs C-C in the adjacent sample squares were also calculated to test the precision of large aliquots and the smoothing effect.

#### *5.2.1.1 Ilomantsi*

***Pampalo***

The test panel was located on the south-eastern till slope of the open pit (Fig. 6). The till slope had a vertical height of 4.5 m, extending down to the bedrock surface. The inclined sampling panel was 3.9 m high and 3.0 m wide. The vertical height of the panel was 2.5 m and it ended 1.0 m vertically above the bedrock surface. The till is grey, typically sandy, and contained few boulders and pebbles (Fig. 33). A few small sandy lenses exist in the till.

Fig. 33. The face of the till panel at Pampalo after sampling.

The grade range of gold in the panel was quite large, from 1 to 34 ppb, whereas for the other elements it was smaller (Table 13). For this reason, the precision of gold grades, indicated by high CV values, was also much lower than for the other elements included. This can be seen in Table 14, in which the grades of gold and copper were calculated inside nine separate squares of the panel.

Table 13. Grade ranges (min-max), arithmetic means and precision (CV) of gold, copper, arsenic, manganese and the fine fraction percentage (-63 µm) in the Pampalo panel, subdivided by the sample types (A … E) and all together (All).

| | | Au ppb | Cu ppm | As ppm | Mn ppm | -63µm % |
|---|---|---|---|---|---|---|
| A | Range | 2-32 | 13.8-20.3 | 9.5-14.4 | 114-168 | 19.5-26.9 |
| | Mean | 8 | 16.6 | 11.4 | 132 | 23.4 |
| | CV | 0.88 | 0.13 | 0.09 | 0.13 | 0.07 |
| B | Range | 1-7 | 13.6-22.4 | 9.2-14.0 | 115-172 | 20.9-26.4 |
| | Mean | 4 | 17.2 | 11.1 | 132 | 23.9 |
| | CV | 0.28 | 0.16 | 0.07 | 0.13 | 0.06 |
| C | Range | 3-34 | 15.0-20.0 | 10.5-14.2 | 120-158 | 21.7-25.2 |
| | Mean | 10 | 17.6 | 12.2 | 133 | 23.4 |
| | CV | 0.62 | 0.07 | 0.10 | 0.07 | 0.04 |
| D | Range | 3-27 | 15.5-19.5 | 10.4-15.1 | 123-155 | 21.4-26.0 |
| | Mean | 9 | 17.7 | 11.9 | 134 | 24.0 |
| | CV | 0.55 | 0.05 | 0.09 | 0.06 | 0.07 |
| E | Range | 3-14 | 15.5-20.8 | 9.9-14.6 | 118-159 | |
| | Mean | 8 | 17.9 | 12.1 | 135 | |
| | CV | 0.44 | 0.07 | 0.10 | 0.07 | |
| All | Range | 1-34 | 13.6-22.4 | 9.2-15.1 | 114-172 | 19.5-26.9 |
| | Mean | 8 | 17.4 | 11.8 | 134 | 23.7 |
| | CV | 0.62 | 0.10 | 0.10 | 0.10 | 0.06 |

Table 14. Grade ranges, means and precision of gold and copper of the sample types (A … E) inside the nine squares (1 … 9) at Pampalo. The indication number (Fig. 16) of a square is marked in bold in the upper left corner of the square.

| | Au ppb | | | Cu ppm | | |
|---|---|---|---|---|---|---|
| Range | **1** 1-14 | **2** 3-13 | **3** 3-5 | 19.2-20.0 | 17.2-20.3 | 17.7-18.6 |
| Mean | 6 | 6 | 4 | 19.7 | 18.6 | 18.0 |
| CV | 0.58 | 0.47 | 0.17 | 0.02 | 0.06 | 0.02 |
| Range | **4** 2-8 | **5** 3-6 | **6** 2-12 | 13.9-15.5 | 13.6-17.2 | 3-12 |
| Mean | 6 | 5 | 7 | 14.8 | 15.6 | 7 |
| CV | 0.37 | 0.19 | 0.50 | 0.04 | 0.10 | 0.07 |
| Range | **7** 4-13 | **8** 3-34 | **9** 4-32 | 13.9-17.5 | 18.0-22.4 | 16.9-20.8 |
| Mean | 7 | 14 | 16 | 16.1 | 19.4 | 18.7 |
| CV | 0.34 | 0.60 | 0.64 | 0.09 | 0.06 | 0.06 |

Gold differed from the other elements, both in combined, separate sample types in the panel (Table 13), and inside the sampling squares combining all the sample types (Table 14).

Gold grades correlated between the sample types D and E, indicating only a weak nugget effect in the laboratory duplicates. However, the correlation was much higher for the other elements. In the other sample pairs, correlations for gold were poor or even weakly negative (Table 15), indicating a significant cluster effect. Correlations for copper, arsenic and manganese were mainly good between the sample types, as can also be seen for copper in Figure 34. Exceptions were samples from adjacent squares, both for small aliquots (AA+BB) and for large aliquots (CC). The effect of a single outlier sample in such a small sample set can be seen in the copper plot of CC-samples (Fig. 34). The reason for the poor correlation, for example for the fine fraction (-63 µm), is the small weight variation from 20% to 26%, which means that small random differences also have a significant influence on the correlation coefficient (Table 15).

Table 15. Correlation coefficients (r) of gold, copper, arsenic, manganese and the fine fraction percentage (-63 µm) in the sample type sets at Pampalo.

| | Au | Cu | As | Mn | -63 µm |
|---|---|---|---|---|---|
| AB | -0.118 | 0.888 | 0.062 | 0.951 | 0.428 |
| AC | -0.217 | 0.747 | 0.197 | 0.821 | -0.083 |
| CD | -0.006 | 0.940 | 0.875 | 0.855 | 0.691 |
| DE | 0.696 | 0.963 | 0.924 | 0.868 | |
| AA+BB | -0.014 | -0.011 | -0.064 | 0.460 | 0.197 |
| CC | -0.293 | -0.117 | 0.723 | 0.185 | -0.169 |

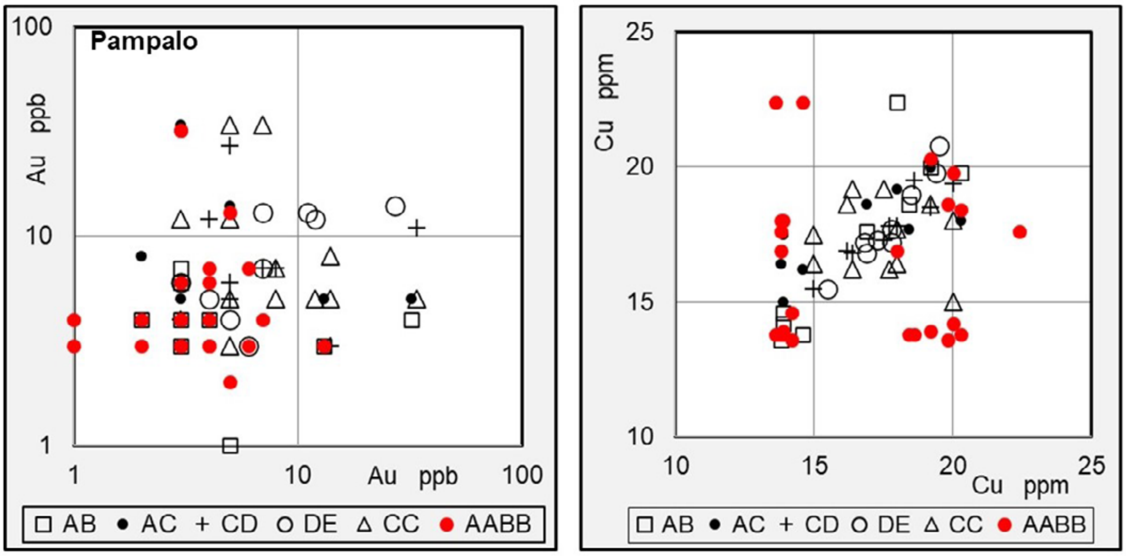



Fig. 34. Plots of gold and copper in the studied test sample pairs from the Pampalo till panel. Sample pairs are as in Table 15.

To test the vertical homogeneity, the means of the C+D-samples in the three horizontal layers of the sampling squares (square indication numbers 1-3, 4-6 and 7-9) were calculated. The gold grades varied, being highest in the bottom square layer, but the other elements and the fine fraction percentage were almost the same, indicating minor vertical variation in till quality (Table 16).

Table 16. Mean grades and median grades of Au of the C+D-samples according to depth in the Pampalo test panel. Surface = sample squares 1-3, Middle = squares 4-6, Bottom = squares 7-9 (Fig. 17). $Au_1$ = arithmetic mean, $Au_2$ = median.

| | $Au_1$ ppb | $Au_2$ ppb | Cu ppm | As ppm | Mn ppm | -63µm % |
|---|---|---|---|---|---|---|
| **Surface** | 6 | 5 | 18.4 | 10.7 | 146 | 24.9 |
| **Middle** | 8 | 8 | 16.1 | 11.8 | 123 | 23.0 |
| **Bottom** | 15 | 9 | 18.4 | 13.7 | 130 | 23.2 |

*Rämepuro*

The two test panels were located on the north-eastern (2015) and northern (2017) wall of the Rämepuro open pit (Fig. 35). Both panels started from the top of the C-horizon of till and extended vertically downwards to 0.3 m above the bedrock surface. The till was sandy, brownish grey in color and with relatively few boulders and pebbles (Fig. 36).

The variation in gold grades was also large at Rämepuro, from 2 to 152 ppb, whereas for the other elements it was small. The precision for gold was generally ten times lower than for the other elements (Table 17). The difference was even larger when comparing gold and copper grades of the sample types inside the individual squares in the till panel (Table 18).

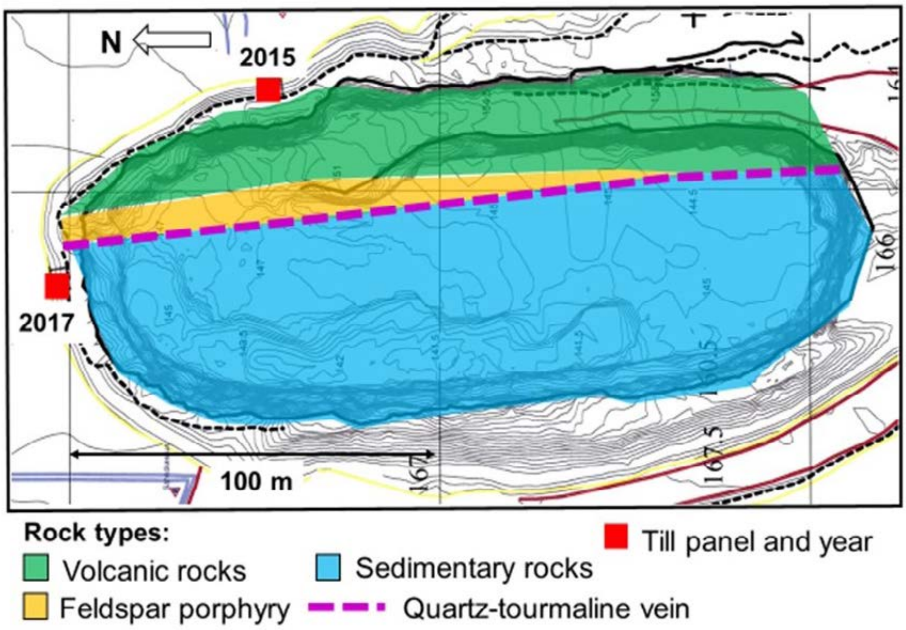



Fig. 35. Locations of the two till panels in the sampling years 2015 and 2017 at Rämepuro with the surface rock types indicated (Sandberg 2001). The open pit surveys were executed and drawn by Endomines Oy.


Fig. 36. The till panels with sampling squares at Rämepuro, the left panel was sampled in 2015 and the right one in 2017.

Table 17. Grade ranges (min-max), arithmetic means and precision (CV) of gold, copper, arsenic, manganese and the fine fraction percentage (-63 µm) in the Rämepuro sample sets.

| | | Au ppb | Cu ppm | As ppm | Mn ppm | -63µm % |
|---|---|---|---|---|---|---|
| A | Range | 5-42 | 15.2-19.7 | 10.7-13.6 | 114-137 | 31.5-43.0 |
| | Mean | 17 | 18.3 | 12.0 | 125 | 36.0 |
| | CV | 0.60 | 0.05 | 0.05 | 0.05 | 0.06 |
| B | Range | 7-50 | 15.2-19.5 | 10.7-14.3 | 112-138 | 34.7-39.8 |
| | Mean | 24 | 17.8 | 12.2 | 126 | 37.2 |
| | CV | 0.46 | 0.06 | 0.08 | 0.05 | 0.03 |
| C | Range | 6-17 | 18.2-22.0 | 9.9-15.1 | 112-145 | 31.6-37.3 |
| | Mean | 10 | 19.4 | 11.9 | 133 | 35.3 |
| | CV | 0.34 | 0.05 | 0.12 | 0.06 | 0.04 |
| D | Range | 7-152 | 18.3-21.0 | 10.7-15.2 | 124-151 | 31.9-38.5 |
| | Mean | 26 | 19.7 | 12.1 | 136 | 36.1 |
| | CV | 1.09 | 0.04 | 0.09 | 0.07 | 0.04 |
| E | Range | 5-52 | 18.2-21.1 | 10.4-15.4 | 120-152 | |
| | Mean | 14 | 19.6 | 12.1 | 136 | |
| | CV | 0.60 | 0.03 | 0.10 | 0.06 | |
| All | Range | 5-152 | 15.2-22.0 | 9.9-15.4 | 112-152 | 31.5-43.0 |
| | Mean | 18 | 19.0 | 12.1 | 131 | 36.1 |
| | CV | 0.71 | 0.05 | 0.09 | 0.07 | 0.04 |

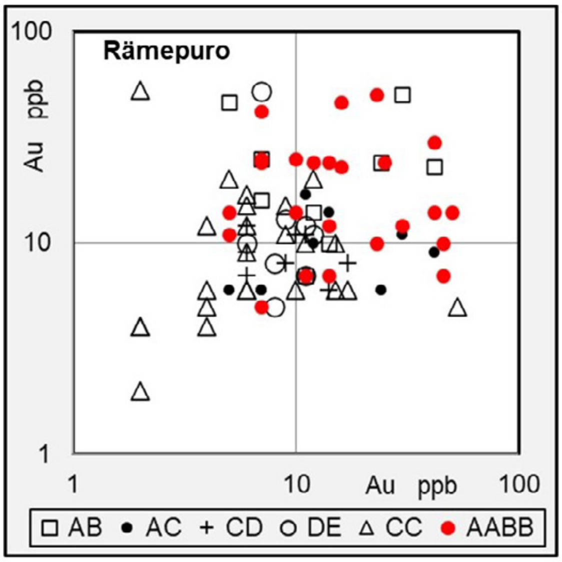
Table 18. Grade ranges, means and precision (CV) of gold and copper of the sample types (A ... E) inside the nine squares (1 ... 9) at Rämepuro. The indication number (Fig. 17) of a square is marked in the upper left corner of the square.

| | Au ppb | | | | | | Cu ppm | | |
|---|---|---|---|---|---|---|---|---|---|
| Range | **1** | 6-52 | **2** | 5-42 | **3** | 11-50 | 16.8-18.9 | 18.5-20.4 | 16.2-19.2 |
| Mean | | 18 | | 17 | | 23 | 18.2 | 19.5 | 18.0 |
| CV | | 0.78 | | 0.69 | | 0.60 | 0.04 | 0.03 | 0.06 |
| Range | **4** | 5-152 | **5** | 6-15 | **6** | 7-14 | 16.6-19.8 | 17.9-22.0 | 15.2-19.3 |
| Mean | | 44 | | 12 | | 11 | 18.9 | 20.1 | 18.1 |
| CV | | 0.99 | | 0.26 | | 0.17 | 0.05 | 0.06 | 0.06 |
| Range | **7** | 7-17 | **8** | 6-25 | **9** | 6-24 | 19.1-20.7 | 18.6-21.1 | 18.2-18.9 |
| Mean | | 10 | | 12 | | 15 | 19.7 | 19.9 | 18.4 |
| CV | | 0.30 | | 0.42 | | 0.46 | 0.02 | 0.04 | 0.01 |

Gold displayed no correlation between the sample types (Table 19), and only the closest sample pair AB had a weak correlation. Moreover, copper correlated only weakly between the small sample pairs (AB) and all the elements between small sample and large sample (AC). The correlation was better between the small samples (A and B) than between the small and local samples (A) and the large, representative samples (C). Dispersion was significant, although the grade variations of other elements than gold were small (Fig. 37).

Table 19. Correlation coefficients (r) of gold, copper, arsenic, manganese and the fine fraction (-63 µm) between the sample types at Rämepuro.

| | Au | Cu | As | Mn | -63 µm |
|---|---|---|---|---|---|
| AB | 0.207 | 0.186 | 0.686 | 0.549 | 0.642 |
| AC | 0.083 | 0.077 | 0.234 | 0.385 | 0.412 |
| CD | -0.335 | 0.777 | 0.909 | 0.807 | 0.892 |
| DE | -0.078 | 0.806 | 0.939 | 0.857 | |
| AA+BB | -0.140 | -0.234 | -0.282 | 0.032 | 0.149 |
| CC | -0.164 | 0.763 | 0.513 | 0.641 | 0.074 |



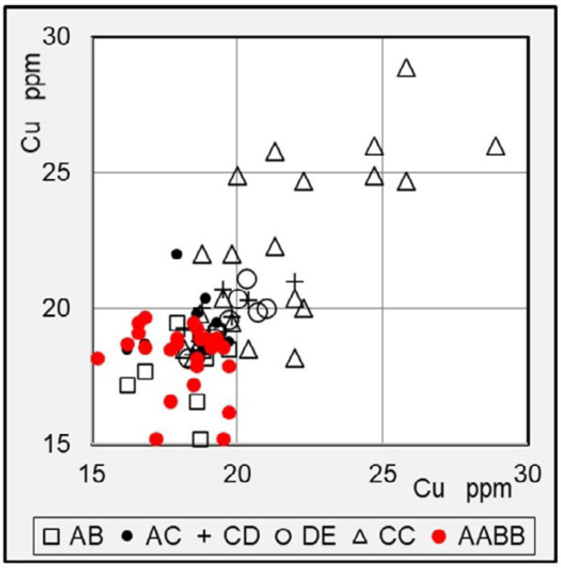




Fig. 37. Plots of gold and copper of the test sample pairs at Rämepuro. The figures include the two till panels in the sample set of CC.

Vertical differences in the test panels were quite small (Table 20). Both gold and arsenic grades were highest at the bottom.

Table 20. Mean grades and median grades of Au of the C+D-samples according to depth in the Rämepuro test panels. Surface = sample squares 1–3, Middle = squares 4–6, Bottom = squares 7–9 (Fig. 17). $Au_1$ = arithmetic mean, $Au_2$ = median.

| | $Au_1$ ppb | $Au_2$ ppb | Cu ppm | As ppm | Mn ppm | -63µm % |
|---|---|---|---|---|---|---|
| Surface | 7 | 4 | 21.1 | 10.8 | 128 | 28.9 |
| Middle | 7 | 5 | 21.4 | 12.9 | 125 | 27.6 |
| Bottom | 10 | 7 | 21.4 | 14.6 | 128 | 29.7 |

The distributions and mean grades of gold and copper were quite similar in the combined data of Pampalo and Rämepuro when combining small samples (A and B) and larger, more representative samples (C, D and E, Fig. 38). The sampling of many small local samples yielded the same mean as the sampling of many representative global samples. The population distributions were not identical, and the small number of samples did not justify detailed and reliable interpretation.

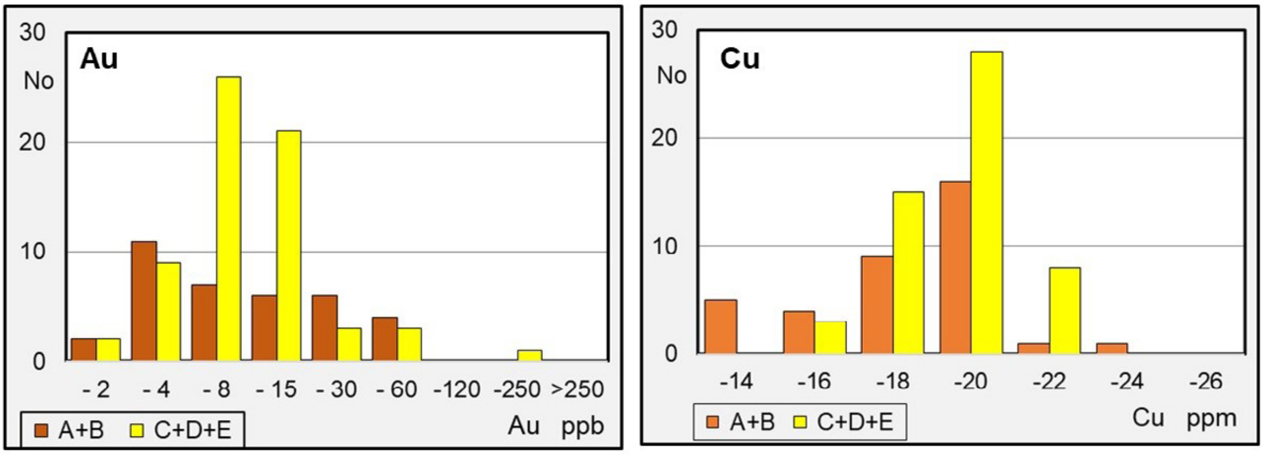



Fig. 38. Distribution of gold and copper grades in small samples (A+B) and large samples (C+D+E) in the combined Pampalo and Rämepuro test data. The average values of the sample sets AB / CDE for gold are 13/13 ppb (means), 7/8 ppb (medians) and for copper 17.5/18.7 ppm (means), 18.1/18.8 ppm (medians). The total number of samples for the set of A+B is 36 and for the set of C+D+E it is 65.

The mean gold grade of the small aliquots was found to be the same as for the large aliquots, but the laboratory precision was low and no correlation existed in this small aliquot set. For copper the correlation was good (Fig. 39). The analytical sample weight was 25 g and despite this, a nugget effect for gold was evident, including in the laboratory duplicates. In the Pampalo DE-samples, the correlation was clear (r = 0.696, Table 15) indicating a higher nugget effect in the Rämepuro samples without a correlation (r = -0.078, Table 19).

GTK re-analysed a large sample set of Ilomantsi till samples using a sample weight of 1 g (Hartikainen & Nurmi 1993). The correlation between the primary fine fraction samples and duplicate samples analysed by the same method, but in separate laboratories of GTK, was almost non-existent (r = 0.131, Fig. 40). The nugget effect has an important role in the interpretation of gold results for the fine till fraction in the Ilomantsi area. The small analysed sample size highlighted the nugget effect in this test.

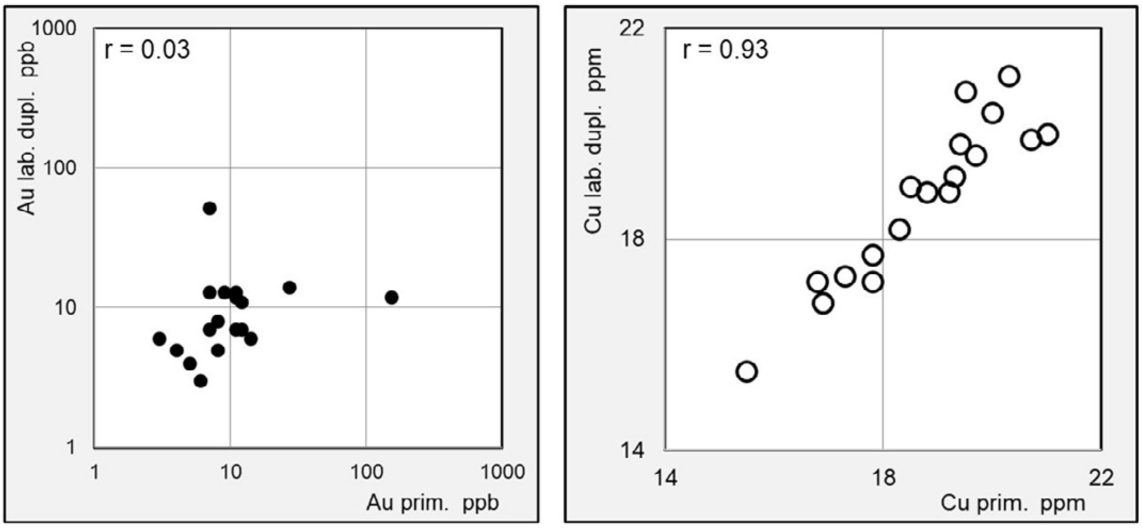



Fig. 39. Plot of laboratory duplicate grades of gold and copper (sample pair set of DE, 18 sample pairs) in the combined Pampalo and Rämepuro data.

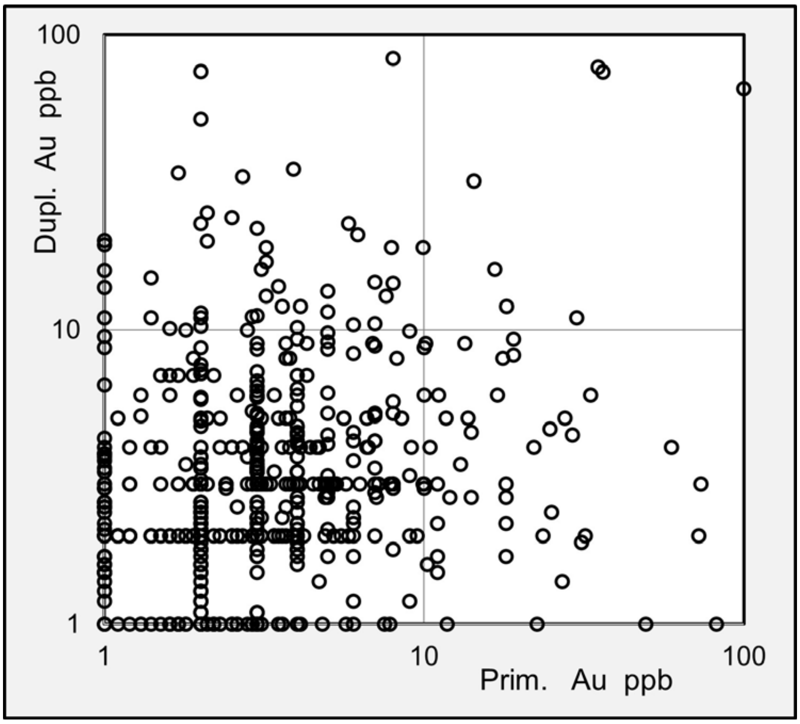



Fig. 40. Comparison of duplicate gold grades from the fine till fraction analysed by GTK laboratories in Kuopio (primary samples) and Rovaniemi (duplicate samples). The analytical sample weight was 1 g and the analytical method code A1 (Table 5). The figure is modified by the author from Hartikainen and Nurmi 1993.

#### 5.2.1.2 *Kuusamo*

The till thickness around the Juomasuo stripping area varies from five metres at the northern end to ten metres at the southern end. The till is homogeneous and no separate till beds or large glaciofluvial layers were observed. The till panel was located at the southern end of the stripping area (Fig. 11). The till thickness at the site was ten metres and the till sampling panel was from two to five metres vertically above the bedrock surface (Fig. 41). The till was grey in colour and sandy with only a few pebbles and boulders (Fig. 42). All the aliquots were visually similar with identical field sieving properties.

At Hangaslampi the till panel was located on the northern face of the small stripped pit (Fig. 12). The till thickness was 4,5 metres and the panel extended vertically from 0.5 m to 3.5 m above the bedrock surface (Fig. 43). The bottom layer of till was avoided to prevent contamination by weathered bedrock. As at Juomasuo, all the samples were visually identical with similar field sieving properties. Here, the till was also grey in colour and sandy with few pebbles or boulders.


Fig. 41. Location of the till panel at the southern end of the Juomasuo stripping area.

Fig. 42. The till panel at Juomasuo after sampling.

Fig. 43. The till panel in at Hangaslampi after sampling.

The data from Juomasuo and Hangaslampi were partly combined because of their similar till type and close location. The gold grades in both test panels were low, close to the detection limit of 1 ppb, which weakens the reliability of the results. The grade ranges, means and precision according to the sample type are presented in Table 21 for Juomasuo and Table 23 for Hangaslampi. The same values for gold and copper inside the sampling squares (1...9) are presented in Table 22 for Juomasuo and Table 24 for Hangaslampi.

Table 21. Grade ranges (min-max), arithmetic means and precision (CV) of gold, copper, cobalt, manganese and the fine fraction percentage (-63 µm) in the Juomasuo sample sets.

| | | Au ppb | Cu ppm | Co ppm | Mn ppm | -63µm % |
|---|---|---|---|---|---|---|
| A | Range | 1-29 | 15.3-23.4 | 5.3-6.7 | 94-117 | 12.6-22.2 |
| | Mean | 5 | 18.5 | 5.8 | 107 | 14.4 |
| | CV | 1.19 | 0.09 | 0.07 | 0.06 | 0.12 |
| B | Range | 1-3 | 15.9-34.3 | 5.4-7.0 | 99-122 | 12.0-15.1 |
| | Mean | 2 | 20.4 | 6.1 | 109 | 13.5 |
| | CV | 0.40 | 0.21 | 0.05 | 0.05 | 0.05 |
| C | Range | 1-51 | 13.4-24.8 | 4.7-8.1 | 86-127 | 14.0-21.9 |
| | Mean | 10 | 16.7 | 6.0 | 102 | 16.9 |
| | CV | 1.17 | 0.14 | 0.15 | 0.13 | 0.19 |
| D | Range | 1-12 | 13.8-24.4 | 5.5-7.0 | 97-124 | 13.1-21.7 |
| | Mean | 3 | 17.8 | 6.2 | 110 | 16.7 |
| | CV | 0.74 | 0.11 | 0.06 | 0.07 | 0.18 |
| E | Range | 1-118 | 14.0-24.7 | 5.5-7.5 | 100-128 | |
| | Mean | 17 | 17.8 | 6.4 | 111 | |
| | CV | 1.33 | 0.10 | 0.06 | 0.06 | |
| All | Range | 1-118 | 13.4-34.3 | 4.7-8.1 | 86-128 | 12.0-22.2 |
| | Mean | 7 | 18.2 | 6.1 | 108 | 15.3 |
| | CV | 1.27 | 0.13 | 0.08 | 0.04 | 0.16 |

Table 22. Grade ranges, means and precision (CV) of gold and copper of the sample types (A ... E) inside the nine squares (1 ... 9) at Juomasuo. The indication number (Fig. 17) of a square is marked in the upper left upper of the square.

| | Au ppb | | | | | | Cu ppm | | |
|---|---|---|---|---|---|---|---|---|---|
| Range | 1 | 1-6 | 2 | 1-4 | 3 | 1-118 | 16.5-19.7 | 15.7-18.5 | 19.1-25.5 |
| Mean | | 2 | | 3 | | 37 | 18.4 | 17.2 | 23.7 |
| CV | | 0.80 | | 0.34 | | 1.05 | 0.05 | 0.06 | 0.08 |
| Range | 4 | 1-18 | 5 | 2-3 | 6 | 1-29 | 14.2-19.1 | 14.3-34.3 | 13.4-17.7 |
| Mean | | 5 | | 2 | | 12 | 17.0 | 21.2 | 16.4 |
| CV | | 1.10 | | 0.20 | | 0.92 | 0.09 | 0.29 | 0.07 |
| Range | 7 | 1-2 | 8 | 1-3 | 9 | 1-2 | 17.4-18.8 | 13.8-15.9 | 16.8-18.5 |
| Mean | | 1 | | 2 | | 2 | 18.2 | 14.8 | 17.4 |
| CV | | 0.34 | | 0.45 | | 0.18 | 0.03 | 0.05 | 0.03 |

Table 23. Grade ranges (min-max), arithmetic means and precision (CV) of gold, copper, cobalt, manganese and the fine fraction percentage (-63 µm) in the Hangaslampi sample sets.

| | | Au ppb | Cu ppm | Co ppm | Mn ppm | -63µm % |
|---|---|---|---|---|---|---|
| A | Range | 1-6 | 20.1-27.4 | 4.1-6.1 | 77-166 | 19.7-28.3 |
| | Mean | 2 | 29.8 | 5.0 | 98 | 25.2 |
| | CV | 0.41 | 0.10 | 0.10 | 0.17 | 0.07 |
| B | Range | 2-3 | 18.8-28.8 | 4.4-5.7 | 82-114 | 18.5-27.7 |
| | Mean | 2 | 23.2 | 5.1 | 92 | 25.5 |
| | CV | 0.16 | 0.10 | 0.06 | 0.07 | 0.09 |
| C | Range | 1-42 | 19.3-25.9 | 4.4-5.5 | 77-99 | 18.7-27.0 |
| | Mean | 8 | 21.6 | 4.9 | 83 | 22.5 |
| D | CV | 1.13 | 0.10 | 0.05 | 0.06 | 0.11 |
| | Range | 1-4 | 18.0-25.3 | 4.3-5.3 | 74-92 | 20.3-24.3 |
| | Mean | 2 | 21.8 | 4.8 | 83 | 22.0 |
| | CV | 0.49 | 0.09 | 0.06 | 0.04 | 0.06 |
| E | Range | 1-5 | 18.7-25.7 | 4.7-5.5 | 74-95 | |
| | Mean | 2 | 21.8 | 4.9 | 83 | |
| | CV | 0.53 | 0.10 | 0.03 | 0.04 | |
| All | Range | 1-42 | 18.0-28.8 | 4.1-6.1 | 74-166 | 18.5-28.3 |
| | Mean | 3 | 22.5 | 5.0 | 88 | 23.8 |
| | CV | 0.80 | 0.10 | 0.07 | 0.09 | 0.11 |

Table 24. Grade ranges, means and precision (CV) of gold and copper of the sample types (A ... E) inside the nine squares (1 ... 9) at Hangaslampi. The indication number (Fig. 17) of a square is marked in the upper left corner of the square.

| | Au ppb | | | | | | Cu ppm | | |
|---|---|---|---|---|---|---|---|---|---|
| Range | **1** | 2-5 | **2** | 1-14 | **3** | 1-2 | 22.5-25.9 | 20.9-26.8 | 23.2-27.4 |
| Mean | | 3 | | 4 | | 1 | 24.8 | 22.4 | 24.6 |
| CV | | 0.34 | | 1.00 | | 0.27 | 0.04 | 0.08 | 0.05 |
| Range | **4** | 1-6 | **5** | 1-3 | **6** | 1-3 | 20.6-25.6 | 18.8-20.8 | 19.4-26.5 |
| Mean | | 3 | | 2 | | 2 | 22.0 | 20.0 | 21.8 |
| CV | | 0.49 | | 0.45 | | 0.36 | 0.07 | 0.04 | 0.12 |
| Range | **7** | 1-4 | **8** | 2-42 | **9** | 1-2 | 20.0-28.8 | 23.9-25.2 | 18.0-22.0 |
| Mean | | 2 | | 10 | | 1 | 22.1 | 24.7 | 19.5 |
| CV | | 0.33 | | 1.22 | | 0.34 | 0.12 | 0.02 | 0.05 |

The CV-values for gold were about ten times higher than for the other elements, both for sample types (A...E) and sample squares (1...9), indicating much lower precision.

The nugget effect of gold appears not to have been significant at Juomasuo because of the high correlation coefficients of aliquot pairs CD and DE. No or a weak correlation of Cu, Mn and the fine fraction percentage was detected between the small and large aliquots (AC) and sample squares (CC) indicating some inhomogeneity in the till panel, which was not macroscopically visible (Table 25). Furthermore, the left plot in Figure 44 displays no or a very low correlation of gold grades between the aliquot pairs in the combined data of Juomasuo and Hangaslampi. The pair data were combined because of the small number of aliquots and quite similar correlations.

Table 25. Correlation coefficients r of gold, copper, cobalt, manganese and the fine fraction percentage (-63 µm) between the sample types in the test panels of Juomasuo and Hangaslampi.

| | Juomasuo | | | | | Hangaslampi | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Au | Cu | Co | Mn | -63 µm | Au | Cu | Co | Mn | -63 µm |
| AB | -0.295 | 0.842 | 0.01 | 0.716 | -0.588 | -0.225 | -0.012 | 0.68 | 0.918 | 0.496 |
| AC | 0.227 | 0.020 | -0.63 | -0.056 | 0.763 | -0.036 | 0.420 | 0.66 | -0.024 | -0.541 |
| CD | 0.881 | 0.830 | 0.61 | 0.793 | 0.976 | 0.672 | 0.949 | 0.74 | 0.783 | 0.611 |
| DE | 0.937 | 0.989 | 0.55 | 0.952 | | 0.202 | 0.987 | 0.51 | 0.646 | |
| AA+BB | -0.057 | -0.275 | 0.059 | 0.104 | -0.057 | -0.079 | 0.065 | 0.142 | -0.013 | 0.214 |
| CC | 0.168 | -0.269 | -0.055 | -0.154 | 0.958 | -0.220 | -0.298 | 0.228 | 0.350 | 0.062 |

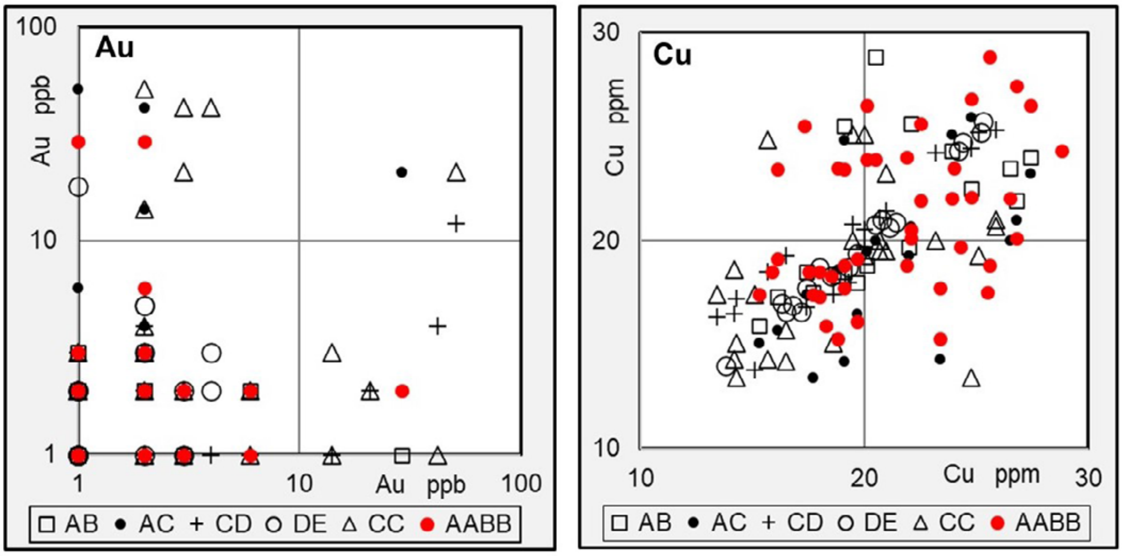



Fig. 44. Plot of the gold and copper grades of the test pair samples from the combined data of Juomasuo and Hangaslampi.

In the till panel the gold mean grades were highest in the top squares decreasing downwards. For the other elements and the fine till fraction, the differences in grade were small (Table 26).

Table 26. Arithmetic mean grades and median grades of Au in the C-samples according to depth in the Juomasuo and Hangaslampi test panels. Surface = aliquots in squares 1-3, Middle = squares 4-6, Bottom = squares 7-9. Square numbers as in Table 26 or Figure 17. $Au_1$ = arithmetic mean, $Au_2$ = median.

| | Juomasuo | | | | | | Hangaslampi | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $Au_1$ ppb | $Au_2$ ppb | Cu ppm | Co ppm | Mn ppm | -63µm % | $Au_1$ ppb | $Au_2$ ppb | Cu ppm | Co ppm | Mn ppm | -63µm % |
| Surface | 13 | 5 | 19.9 | 6.4 | 110 | 21.4 | 3.5 | 1.5 | 23.5 | 5.1 | 88 | 23.7 |
| Middle | 5 | 2 | 15.3 | 5.6 | 95 | 14.4 | 2.2 | 2.0 | 20.3 | 4.7 | 82 | 20.7 |
| Bottom | 2 | 2 | 16.5 | 6.4 | 112 | 14.5 | 8.8 | 2.5 | 21.4 | 4.8 | 79 | 22.3 |

### 5.2.1.3 *Kittilä*

The test panel sampling was carried out on 11 July 2017. The only available till face was around the southern open pit ("Etelä Pit"). The face was selected on the south-eastern corner of the pit (Fig. 45). The face was cleaned with an excavator and more thoroughly with a mine hoe. The sampling grid was measured and marked (Fig. 46) and samples were collected and sieved with the assistance of Tarmo Hannula.

The total thickness of overburden was about 4.5 m. The soil profile started with a narrow peat layer of about 0.5 m in thickness. This was followed by grey silt-rich till, and partly layered silt with only a few pebbles. Under the silty layer was light brown till with a few pebbles and some silty lenses. This upper till included sample squares 1-3 (Fig. 46) and probably corresponded to the upper till of Peltoniemi-Taivalkoski and Sarala (2009). Gradually changing light brown till under this upper till contained more stones (sample squares 4-9). The vertical distance from the bottom of sampling to the volcanic bedrock surface was 0.40 m of which only the lowermost 0.1 m contained some weathered bedrock. The horizontal distance to the weakly mineralized north-south-orientated ore zone was only 20-40 m.

The gold grades were exceptionally low considering the closeness of the outcropping ore deposit and the thin till cover. The gold grades varied from 3 to 36 ppb and the mean of all samples was 5 ppb (Table 27). The variation in gold grades was smaller than for the other study targets. The CV-values were about five times higher than for the other elements (Tables 27 and 28). Only a few gold grains were found in the till samples by Auger (2015) at the southern end of the Etelä Pit. Furthermore, relatively few gold grains were discovered in till close to some gold occurrences in central Lapland (Al-Ani et al. 2008).

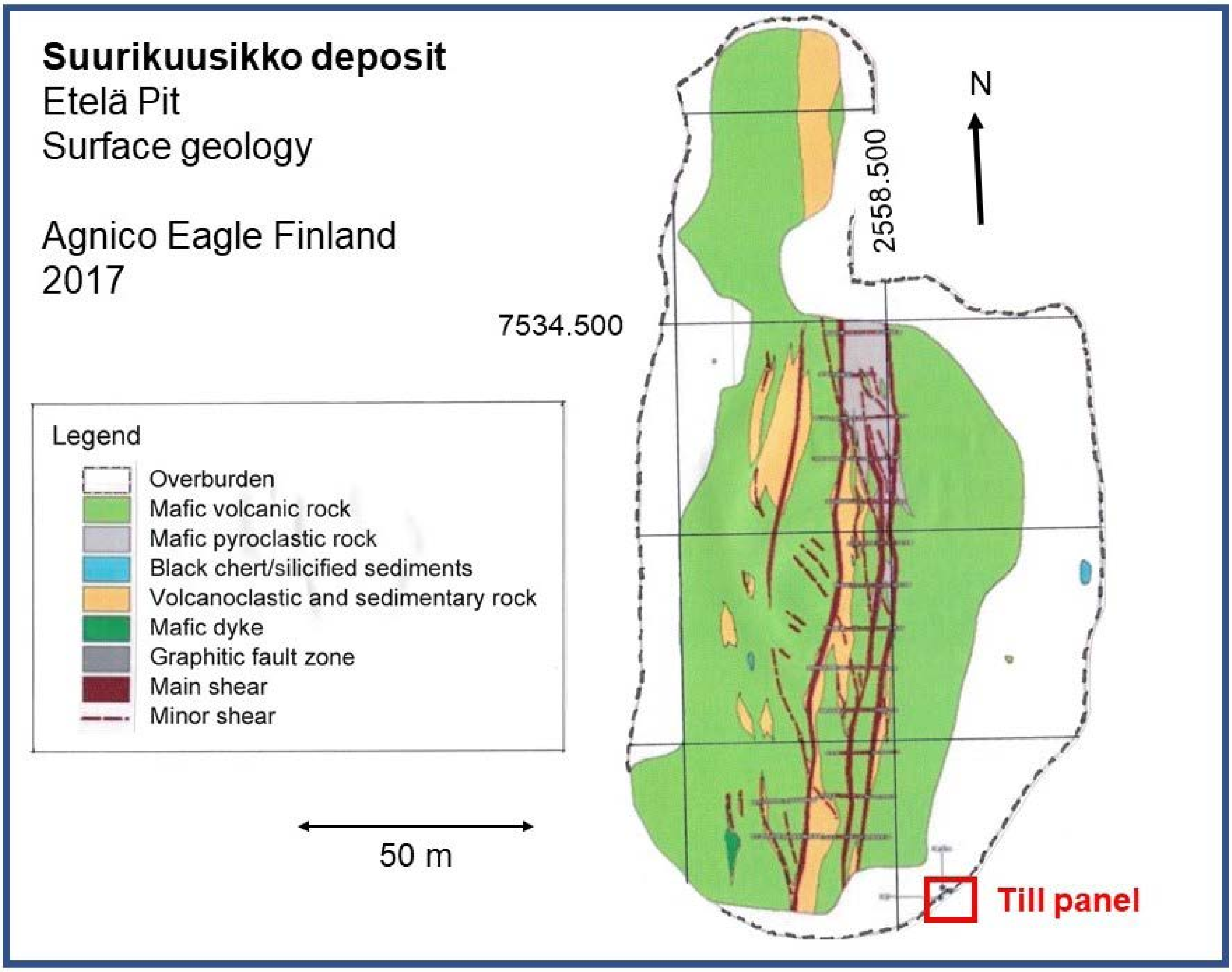



Fig. 45. The till panel located in the south-eastern till face of the Etelä Pit. Geological map prepared by Agnico Eagle Finland in 2017.

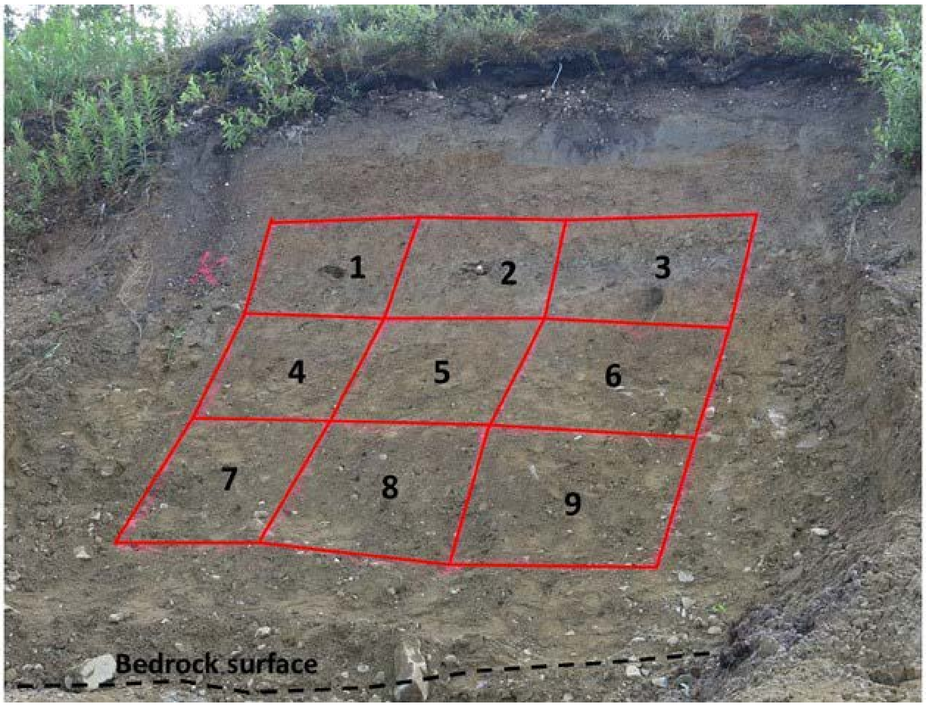



Fig. 46. Till panel of the "Etelä Pit" looking to the east. The bedrock surface is visible at the bottom. The weathered layer on the bedrock was very thin, but the lowermost 40 cm of till was unsampled to prevent any contamination by weathered bedrock. The width and depth of the sampling area (numbered 1–9) was 3.2 m and the true vertical depth 2.4 m.

Table 27. Grade ranges (min–max), arithmetic means and precision (CV) of gold, copper, arsenic, manganese and the fine fraction percentage (-63 µm) in the Kittilä sample sets (A...E).

| | | Au ppb | Cu ppm | As ppm | Mn ppm | -63µm % |
|---|---|---|---|---|---|---|
| A | Range | 3-20 | 47.1-63.6 | 6.6-15.1 | 224-534 | 13.6-30.7 |
| | Mean | 6 | 53.6 | 8.7 | 365 | 19.9 |
| | CV | 0.56 | 0.08 | 0.21 | 0.19 | 0.17 |
| B | Range | 3-7 | 47.8-61.9 | 6.4-14.8 | 219-575 | 14.7-31.0 |
| | Mean | 4 | 54.8 | 8.9 | 361 | 19.7 |
| | CV | 0.22 | 0.07 | 0.19 | 0.22 | 0.17 |
| C | Range | 3-10 | 42.3-56.3 | 6.8-9.0 | 220-500 | 13.1-19.1 |
| | Mean | 5 | 51.4 | 7.8 | 374 | 15.9 |
| | CV | 0.25 | 0.09 | 0.08 | 0.23 | 0.08 |
| D | Range | 3-36 | 38.5-55.4 | 5.9-9.5 | 231-480 | 11.0-19.3 |
| | Mean | 8 | 49.9 | 7.9 | 368 | 16.2 |
| | CV | 0.76 | 0.10 | 0.12 | 0.22 | 0.12 |
| E | Range | 3-8 | 39.6-56.2 | 6.5-9.4 | 222-499 | |
| | Mean | 5 | 49.7 | 7.9 | 366 | |
| | CV | 0.28 | 0.11 | 0.09 | 0.23 | |
| All | Range | 3-36 | 38.5-63.6 | 4.1-6.1 | 74-166 | 18.5-28.3 |
| | Mean | 5 | 51.9 | 5.0 | 88 | 23.8 |
| | CV | 0.47 | 0.08 | 0.07 | 0.09 | 0.11 |

Table 28. Grade ranges, means and precision (CV) of gold and copper of the sample types (A ... E) inside the nine squares (1 ... 9) at Kittilä. The indication number (Fig. 17) of a square is marked in the upper left corner of the square.

| | Au ppb | | | | | | Cu ppm | | |
|---|---|---|---|---|---|---|---|---|---|
| Range | 1 | 3-6 | 2 | 3-4 | 3 | 3-36 | 38.5-47.8 | 40.8-52.1 | 44.8-51.9 |
| Mean | | 5 | | 3 | | 10 | 43.1 | 45.5 | 48.4 |
| CV | | 0.22 | | 0.10 | | 1.04 | 0.08 | 0.08 | 0.05 |
| Range | 4 | 3-20 | 5 | 3-5 | 6 | 3-10 | 52.2-58.5 | 51.9-56.3 | 51.1-55.2 |
| Mean | | 7 | | 4 | | 5 | 54.6 | 53.6 | 53.4 |
| CV | | 0.68 | | 0.20 | | 0.40 | 0.03 | 0.03 | 0.03 |
| Range | 7 | 4-7 | 8 | 4-5 | 9 | 3-8 | 50.0-58.1 | 53.8-63.6 | 55.4-59.9 |
| Mean | | 5 | | 5 | | 5 | 53.8 | 57.8 | 56.9 |
| CV | | 0.16 | | 0.10 | | 0.39 | 0.06 | 0.07 | 0.02 |

No positive correlation of the gold grades existed between the aliquot types (Table 29). The copper grades varied from 38 to 64 ppm and the aliquot types correlated well with each other. In addition, arsenic, grading from 6-15 ppm and manganese correlated between the aliquot types (Table 29 and Fig. 47). A variable or non-existent correlation between the sample squares (C-C) and the fine fraction percentage (-63 µm) indicates some inhomogeneity probably originating from silty lenses in the till. Vertically the mean grades did not differ much (Table 30). Manganese grades increase downwards due to probable co-precipitation with iron (correlation coefficient r = 0.68), caused by the flow of groundwater.

Table 29. Correlation coefficients r of gold, copper, arsenic, manganese and the fine fraction percentage (-63 µm) between the sample types at Kittilä.

| | Au | Cu | As | Mn | -63 µm |
|---|---|---|---|---|---|
| AB | 0.104 | 0.868 | 0.905 | 0.832 | 0.883 |
| AC | 0.048 | 0.678 | 0.448 | 0.874 | -0.330 |
| CD | -0.419 | 0.947 | 0.697 | 0.984 | 0.428 |
| DE | -0.025 | 0.973 | 0.731 | 0.996 | |
| AA+BB | -0.037 | 0.523 | 0.038 | 0.352 | -0.066 |
| CC | -0.168 | 0.507 | 0.132 | 0.651 | -0.079 |

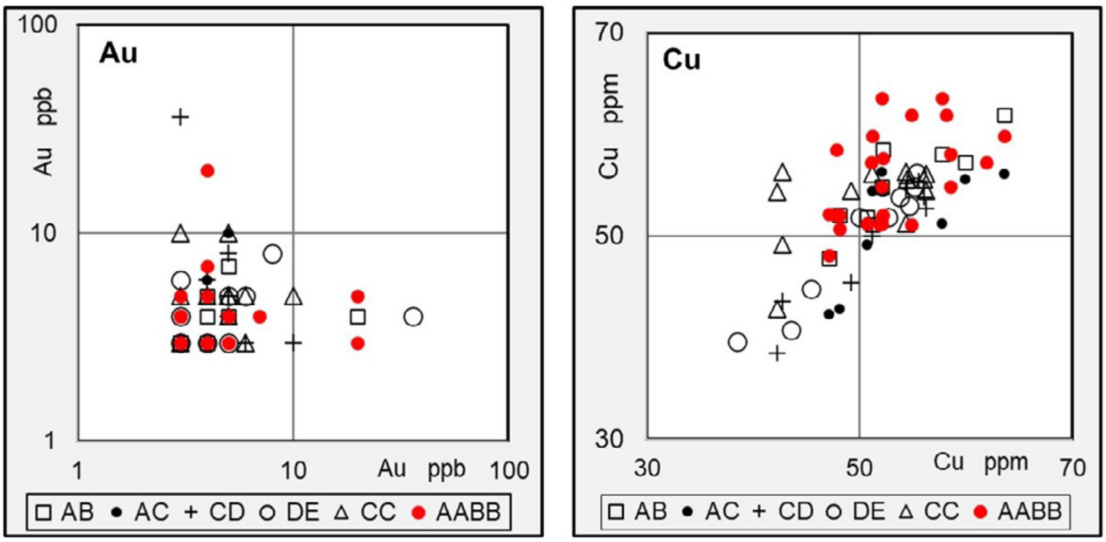



Fig. 47. Plots of the gold and copper grades in the test pair samples from the Kittilä test panel.

Table 30. Mean arithmetic grades and medians of Au in the C-samples according to depth in the Kittilä test panel. Surface = samples in squares 1-3, Middle = samples 4-6, Bottom = samples 7-9 (Fig. 17). $Au_1$ = arithmetic mean, $Au_2$ = median.

| | $Au_1$ ppb | $Au_2$ ppb | Cu ppm | As ppm | Mn ppm | -63µm % |
|---|---|---|---|---|---|---|
| **Surface** | 9 | 3 | 43.7 | 8.7 | 245 | 16.6 |
| **Middle** | 5 | 5 | 54.6 | 8.3 | 395 | 15.6 |
| **Bottom** | 6 | 5 | 53.7 | 6.5 | 473 | 15.9 |

### 5.2.2 Regional geochemistry of the fine fraction of till and comparison with the test panels

#### *5.2.2.1 Ilomantsi*

No correlation existed between the primary and re-analysed till samples from the regional till data of GTK using 1.0 g assay weights, as noted earlier (Hartikainen & Nurmi 1993, Fig. 40). The following data sets are from pits excavated by GTK (GTK-1, Huhta 1993) and by Outokumpu / the author (EAS), as explained in chapter 4.2.3. Replicate aliquot plots of gold in both the GTK and Outokumpu data sets are presented in Figure 48. The correlation is poor in both sample sets. A few duplicate aliquots are also included in the OM data, but their correlation is not better.

Copper grades were found to correlate, but not so strongly as could be expected (Fig. 49). The copper grades were generally low and the distribution narrow, and the analytical precision can thus be relatively significant.

Bismuth, antimony and tellurium are widely used pathfinder elements for gold and similar cluster behavior could be expected. However, replicate grades correlate strongly with primary grades for all these elements (Fig. 49). The cluster effect appears not to be an important factor for the dispersion of these elements in till. If gold grades correlated with these or some of these pathfinder elements, then these could be used as “real” pathfinders. Unfortunately, this is not the case: gold grades were not found to correlate clearly with any of these elements (Fig. 50). A weak correlation existed only between gold and tellurium grades.

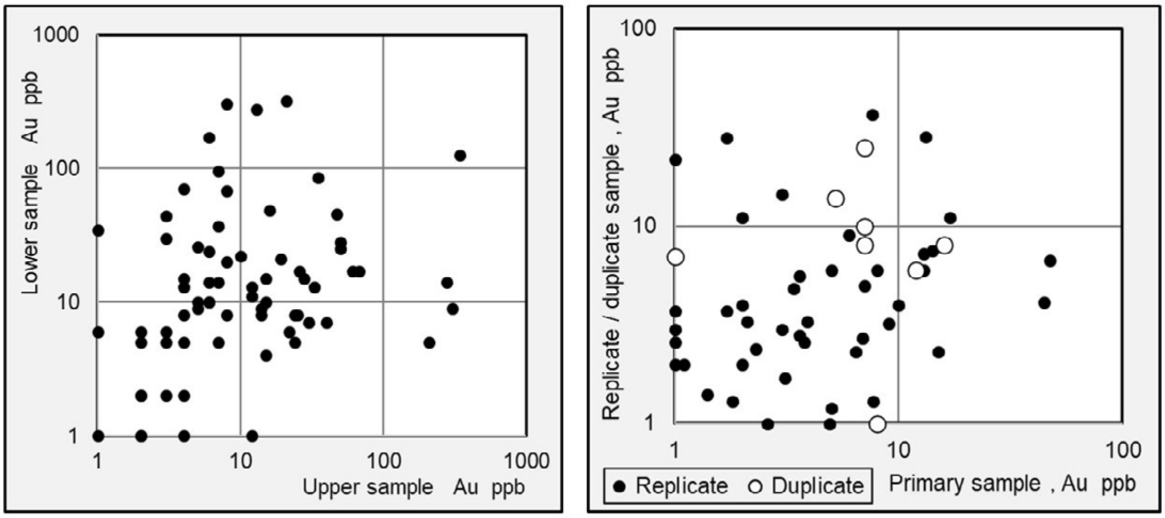



Fig. 48. Replicate aliquot plot of gold grades in the fine fraction of till. GTK data (left) and OM data (right). Correlation coefficients (r) are 0.061 for the GTK data and 0.156 (replicate samples) and -0.074 (duplicate samples) for the OM data.

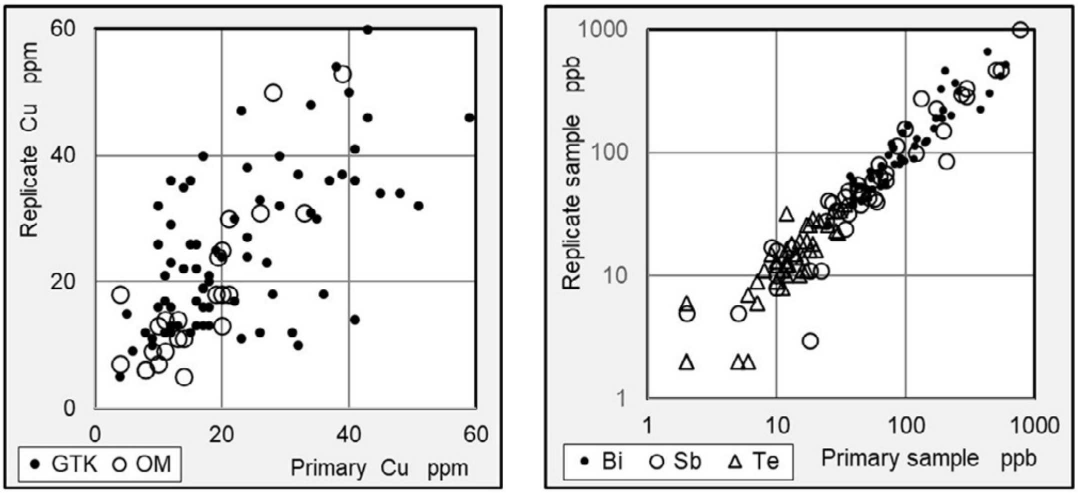



Fig. 49. Replicate sample plot of Cu grades in the fine fraction of till in the combined GTK and OM data (left). Correlation coefficients (r) are 0.543 for the GTK data and 0.855 for the OM data. The right plot contains Bi, Sb and Te grades of the primary and replicate sample in the OM data. Correlation coefficients are 0.869 (Bi), 0.964 (Sb) and 0.835 (Te).

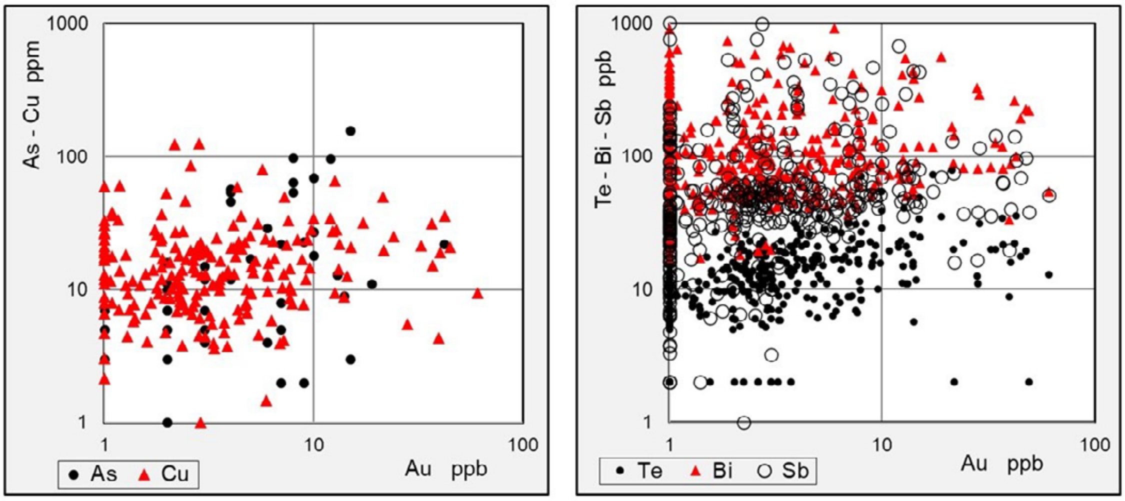



Fig. 50. Plots of gold grades of the fine fraction compared to the common pathfinder elements in the OM till data from 1997-2004. Correlation coefficients of gold with these elements are: As 0.111, Cu 0.046, Te 0.197, Bi -0.031 and Sb 0.012.

***Effect of sampling depth on the correlation between replicate and duplicate samples***

The sampling depth may have some effect on the correlation between replicate or duplicate samples. In theory some depth levels could have a strong positive correlation and other levels a negative correlation. Combining data from these levels could therefore totally remove indications of a correlation. This was tested using percussion drilling duplicate data of GTK (Fig. 40) and by grouping the data in intervals of one or two metres. The results are presented in Table 31. The arithmetic mean and correlation coefficient were found to be strongly influenced by one or a few abnormally high gold grades. This effect was calculated by excluding sample pairs with a high gold grade (Au >100 ppb).

Table 31. Correlation between primary and duplicate samples as a function of the sampling depth. Data of GTK from percussion drilling campaigns at Ilomantsi. No = number of primary-duplicate sample pairs. Results after excluding very high gold grades (>100 ppb) are marked in bold numbers.

| | All data | | | | | | Au >100 ppb excluded | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Depth interval** | **No** | **Median** | | **Mean** | | **r** | **No** | **Mean** | | **r** |
| **m** | | **Prim.** | **Dupl.** | **Prim.** | **Dupl.** | | | **Prim.** | **Dupl.** | |
| **–1.0** | 52 | 2.0 | 2.0 | 8.3 | 4.6 | 0.963 | **51** | **3.8** | **2.8** | **0.042** |
| **1.1–2.0** | 173 | 3.0 | 3.0 | 5.1 | 6.6 | 0.807 | 172 | 4.4 | 5.6 | 0.312 |
| **2.1–3.0** | 64 | 3.1 | 3.0 | 6.9 | 39.7 | 0.054 | **60** | **5.4** | **4.6** | **-0.122** |
| **3.1–4.0** | 49 | 3.4 | 2.3 | 5.4 | 6.4 | 0.022 | 49 | 5.4 | 6.4 | 0.022 |
| **4.1–6.0** | 62 | 3.9 | 3.0 | 6.3 | 6.1 | 0.277 | 62 | 6.3 | 6.1 | 0.277 |
| **6.1–8.0** | 51 | 3.0 | 2.9 | 7.1 | 6.7 | 0.529 | **50** | **5.9** | **5.9** | **0.016** |
| **8.1–10.0** | 37 | 3.4 | 3.0 | 7.4 | 5.0 | -0.111 | 37 | 7.4 | 5.0 | -0.111 |
| **10.1–12.0** | 25 | 2.6 | 2.6 | 9.0 | 6.0 | 0.871 | **24** | **3.0** | **4.3** | **-0.240** |
| **12.1–** | 23 | 1.8 | 3.0 | 8.7 | 3.6 | -0.232 | 23 | 1.8 | 3.6 | -0.232 |

No trends were visible in either mean or median grades, or in correlations. After excluding very high gold grades, the correlation was found to be weak or non-existent without any trend. A weak positive correlation was seen in the upper and central levels and a negative correlation in the deeper levels. The combined correlation coefficient was 0.131.

***Comparison of test panels and regional geochemistry***

Comparing the variation in the distribution between the test panels and regional geochemistry could reveal the importance of test panel precision in the regional interpretation of the results. If the distributions are almost similar, the classical interpretation of a regional anomaly can be misleading. On the other hand, if the test panel distribution is much narrower than the regional distribution, then the interpretation is much more reliable. Although the panels were close to the outcropping gold deposits, the mean gold grade of the panels were close to the regional gold grade mean. At Ilomantsi the mean gold grade of panel was 16 ppb while in regional data it was 6-19 ppb (Table 32). It is therefore relevant to compare the data sets.

The till data from the pits excavated by GTK (GTK-1, Huhta 1993) and OM (Sandberg 2002) were used for the test. The grade distribution within the two data sets was almost similar, as illustrated in Figure 51, thus allowing the two data sets to be combined. To clarify the comparison, the number of samples in each class was transformed to percentages for the test panels and the OM+GTK sample sets. The number of test panel samples was 63 (including C, D and E samples) and the number of OM+GTK samples was 690 (468+222). Arsenic was not included in this data set of GTK (GTK-1). Instead, the regional percussion drilling (flow through drill bit) data of GTK were used for arsenic (GTK-2). Gold of the set GTK-2 was also utilized for comparison with the data of Huhta (GTK-1).

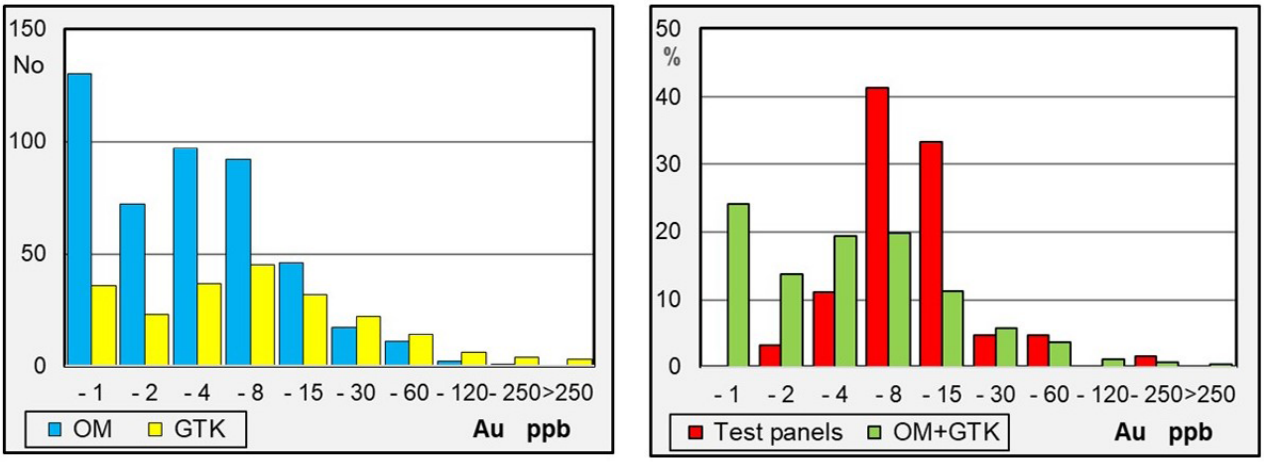



Fig. 51. Gold grade distribution of the fine fraction of till (-0.06 mm) in the Hattu Schist Belt according to the data of Outokumpu Mining (OM) and the Geological Survey of Finland (GTK) (left) and the combined distribution of OM+GTK compared to the test panel distribution (right). In the right figure the grade classes are transformed to percentages.

The gold grades of the test panels cover the whole distribution of the regional samples (OM+GTK-1, Fig. 51 right). This indicates problems in interpreting regional results. A high gold grade is a significant indication of anomalous gold, but low grades can mask a real gold anomaly. The test panels were located close to the existing deposits and possibly for this reason there were fewer low gold grades (<4 ppb) than in the regional gold distribution.

Copper and arsenic distributions were identical but differed from the distributions of gold. The test panel grade distributions of Cu and As were narrow and no high grades were found (Fig. 52). The regional anomalies are thus objective.

Calculated relative variances ($\sigma^2$) indicate numerical differences in grade distributions and are used to compare different data sets. Variances of the panels / regional sampling are presented in Table 32. The variances of gold differed significantly from those of copper and arsenic. The grades in the GTK data, especially the gold grades in GTK-1, were found to be higher than in the OM data, also increasing the variances. The excavation pits of Huhta (GTK-1) were located in or close to anomalous areas with higher gold grades than the more regionally located till samples of OM and GTK-2. Variances of gold in the OM and GTK-2 data were close to each other and to the variance of the till panels. Variances of gold in the OM and GTK-2 data sets were only twice as high as the variances of the panels, but the variances of copper and arsenic were tens of times higher. The relative variances confirmed the results observed in the distribution histograms.

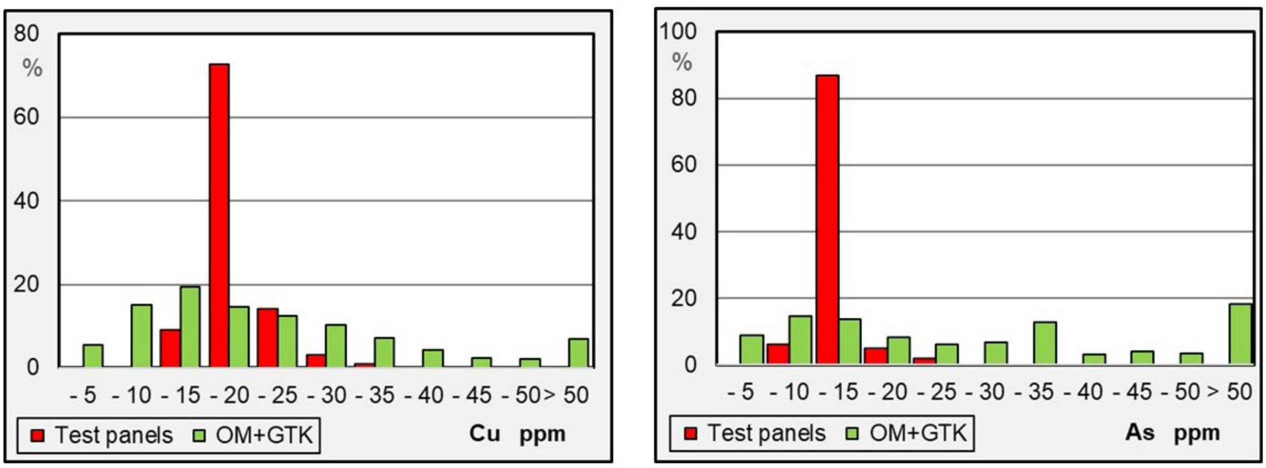



Fig. 52. Distribution of copper (left) and arsenic (right) grades in the test panels and in the combined data of OM and GTK-1 (Cu) and GTK-2 (As) in the Hattu Schist Belt. The grade classes have been transformed to percentages.

Table 32. Relative variances ($\sigma^2$) of gold (ppb), copper (ppm) and arsenic (ppm) in Ilomantsi in the regional samples of Outokumpu Mining (OM) and the Geological Survey (GTK) subdivided into the samples of Huhta (GTK-1) and the regional samples of GTK (GTK-2). The variance ratio of the panel data (within site) and regional data (between sites) is marked as $\sigma^2_p / \sigma^2_R$ (F-factor).

| | Au | | | | Cu | | | As | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Panel | OM | GTK-1 | GTK-2 | Panel | OM | GTK-1 | Panel | OM | GTK-2 |
| No | 99 | 468 | 222 | 544 | 99 | 46 | 222 | 99 | 210 | 310 |
| Mean | 16,3 | 6,1 | 19,2 | 6,4 | 31 | 18 | 28 | 12,5 | 24 | 33 |
| $\sigma^2$ | 0,32 | 0,79 | 6,92 | 0,87 | 0,01 | 0,33 | 0,62 | 0,01 | 0,84 | 1,56 |
| $\sigma^2_R / \sigma^2_P$ | | 2,46 | 21,62 | 2,72 | | 33 | 62 | | 84 | 156 |

#### 5.2.2.2 *Kuusamo*

The Juomasuo-Hangaslampi area is covered by surface till sampling by GTK, at one sample / 4 km², as well as the whole of Finland (Salminen 1995). The median gold grade is 1 ppb, but in the southern Juomasuo area it is generally over 6 ppb. The median Cu grade of the Salla map sheet is 22 ppm (Pulkkinen 1996).

GTK sampled till around the Juomasuo-Hangaslampi deposits over an area of about 25 km² in the 1980s. The sampling grid was 250 x 250 m in the regional sampling campaign and 50 x 50 m in detailed till sampling, while in the more detailed profile sampling the sampling distance was 10 m along the sampling lines (Vanhanen 1992). The till data of GTK were compiled by GTK (E. Lampio) for the author´s use. All the samples with the material quality marked as "till" were compiled by the author in a database containing 2273 Au, 2276 Cu and 1849 Co analyses. The sample weight for gold was usually 1 g in the 1980s and gold values below the detection limit (1 ppb) were not included in the data. Arsenic grades in the test panels were mainly under or close to the detection limit (0.5 ppm). Cobalt is an important element in the ore type and it was selected instead of arsenic for comparison purposes.

The distribution of the gold grades in the till panels was almost similar at Juomasuo and Hangaslampi (Fig. 53). Some differences exist, but both histograms have both low and high gold grades. Thus, the data from the panels were combined for comparison with the regional GTK gold data. Both the panel and the GTK grades in the grade categories were recalculated to percentages. The gold grade distributions were almost similar in the combined test panel data and the regional data by GTK (Fig. 53).

The distributions of copper and cobalt grades in the test panels were much tighter than in the regional data (Fig. 54). The median grades of copper are quite close to each other, but the cobalt grades of GTK are much higher than in the test panels. There might have been some changes in laboratory methods

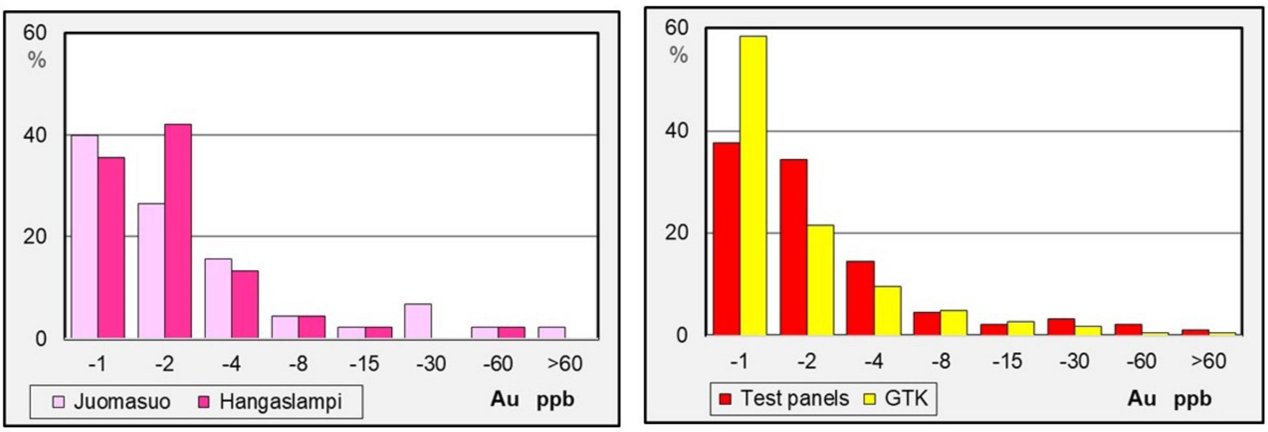



Fig. 53. Distributions of the gold grades in the Juomasuo and Hangaslampi test panels (left figure) and combined test panel data compared to the regional distribution of gold grades in the GTK data. Numbers of samples in the grade classes have been transformed to percentages.

over the 30 years between the analytical sets. However, no anomalous grades of copper or cobalt were recorded in the test panels, although the panels were located close to the deposits. However, the panels were not located in the bottommost basal till.

The numerical relative variance ($\sigma^2$) of the GTK gold data is close to the panel data (Table 33). In addition, the mean grades are close to each other. Variances again confirm what can be visually seen in the distribution histograms.

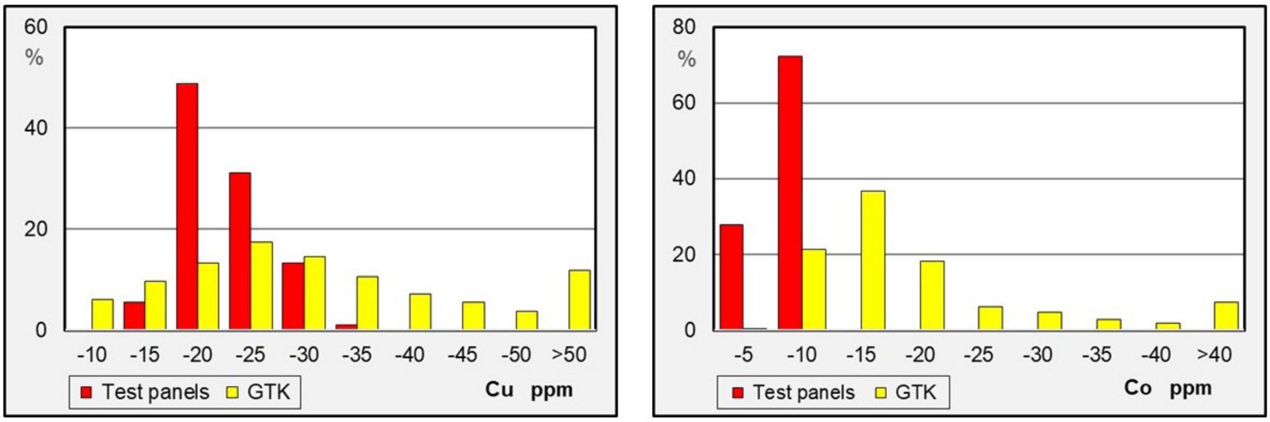



Fig. 54. Distribution of the copper (left figure) and cobalt grades (right figure) in the combined test panels and GTK samples. The grade classes have been transformed to percentages.

Table 33. Mean grades and relative variances ($\sigma^2$) of gold (ppb) and copper (ppm) of the test panels of Juomasuo and Hangaslampi and the regional till data of GTK. The variance ratio of the panel (within site) and regional data (between sites) is marked as $\sigma^2_P / \sigma^2_R$ (F-factor).

| | Au | | Cu | |
|---|---|---|---|---|
| | Panels | GTK | Panels | GTK |
| No | 90 | 2273 | 90 | 1848 |
| Mean | 5.2 | 4.3 | 22 | 40 |
| $\sigma^2$ | 1.30 | 1.71 | 0.02 | 0.45 |
| $\sigma^2_R / \sigma^2_P$ | 1.32 | | 23 | |

#### 5.2.2.3 *Kittilä*

The geochemical sampling of GTK covered the Kiistala map sheet (KKJ 2743, 1:100 000) (Äyräs 1979). At that time, gold was not analysed, but GTK has subsequently carried out intensive sampling of till and weathered bedrock in the map sheet area by percussion drilling. In addition, the old samples have later been analysed for gold (Härkönen 1997). The Kittilä Mine and the test panel are located almost in the centre of the KKJ map sheet 274305. The till sampling data were compiled by GTK (E. Lampio) for the authors use in 2018. Most of the samples on this map sheet were from weathered bedrock. Data for these samples were excluded and only identified till samples were included in this data prepared by the author. Samples of gold grades below the detection limit (1 ppb) were excluded. The sampling depths of the 1020 selected till samples varied from 0.5 m to 19.9 m. The mean/median depths were 3.1 / 2.3 m, corresponding to the depths of the till panel.

The gold grade distributions of the test panel and the regional GTK data are illustrated in Figure 55. Although the GTK data contain numerous gold grades of 1–2 ppb the mean grades are almost the same, being 5 ppb in the test panel samples and 4 ppb in the GTK samples. The lowest test panel gold grade is 3 ppb. The high-grade distributions are quite similar compared to each other.

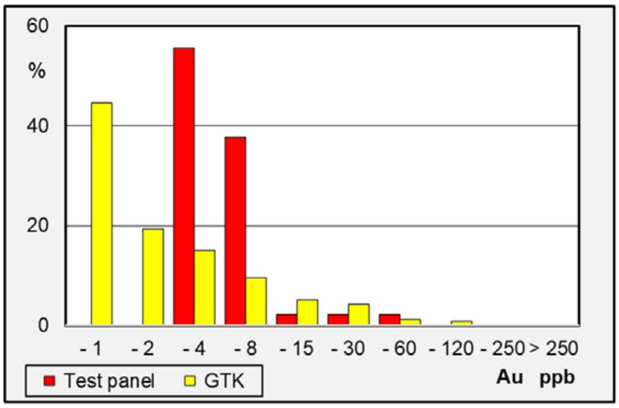



Fig. 55. Distribution of gold in the till panel samples (45 in number) and till samples (1020) in the area of KKJ map sheet 274305 by GTK. The numbers of samples in the grade classes have been transformed to percentages.

The histogram distributions of the two pathfinder elements copper and arsenic are presented in Figure 56. The distributions of the test panel data are narrow, and no high grades exist. Because of high grades in the regional GTK data the mean grades are much higher, being 114 ppm (Cu) and 46 ppm (As), whereas in the test panel they are 52 ppm (Cu) and 8 ppm (As).

The numerical relative variance ($\sigma^2$) of the GTK gold data is higher than that of the panel data (Table 34). The mean grades are close to each other. The variance of the till panel data is lower than at Ilomantsi and Kuusamo and the difference compared to the regional GTK data is greater, indicating a more homogeneous occurrence of gold in the panel.

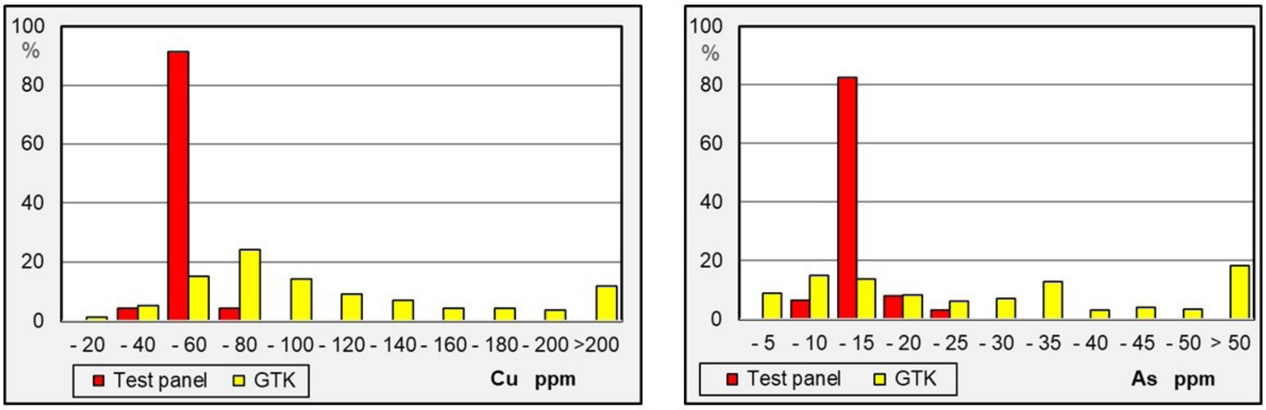



Fig. 56. Distribution of copper and arsenic in the till panel samples (45) and till samples (1020) in the area of map sheet 274305 by GTK. The grade classes have been transformed to percentages.

Table 34. Relative variances ($\sigma^2$) and mean grades of gold (ppb), copper (ppm) and arsenic (ppm) at Kittilä. The variance ratio of the regional GTK data (between sites) and the panel (within site) is marked as $\sigma^2_R / \sigma^2_P$ (F-factor).

| | Au | | Cu | | As | |
|---|---|---|---|---|---|---|
| | Panel | GTK | Panel | GTK | Panel | GTK |
| No | 45 | 1020 | 45 | 526 | 45 | 100 |
| Mean | 5.5 | 3.7 | 52 | 114 | 8.2 | 119 |
| $\sigma^2$ | 0.22 | 1.24 | 0.01 | 0.27 | 0.02 | 0.74 |
| $\sigma^2_R / \sigma^2_P$ | 5.65 | | 27 | | 37 | |

### 5.2.3 Heavy mineral geochemistry, Ilomantsi

Gold in the heavy mineral fractions of till in the Hattu Schist Belt has been investigated in many phases by GTK (Salminen & Hartikainen 1986, Nikkarinen 1991, Huhta 1993) and by OM (Ojalainen 1998, Sandberg 2002). Commonly the transport distances of gold are interpreted as short and gold anomalies as local. However, as stated by Huhta (1993): "*No statistically significant correlations were obtained between any of the three fractions (fine fraction, heavy mineral fraction and calculated value based on gold grains) in any of the subareas, nor within the background region*". This is depressing, but quite a typical result for gold. To test this further, the panels were also sampled for heavy minerals in Pampalo and Rämepuro.

Heavy mineral samples from the test panels were collected from Pampalo and Rämepuro in 2015 (four samples from each) and from the second test panel in Rämepuro in 2017 (the whole panel, 9 samples). The total number of panel samples for heavy mineral testing from Ilomantsi was 17. They were wet-sieved and panned by the author using the same procedure as earlier (section 4.2.3). The grade range of gold was found to be wide, from 15 to 2160 ppb, in analysis by Labtium Oy using aqua regia dissolution followed by graphite furnace AAS (method A6, Table 3).

The distribution of gold grades is illustrated in Figure 57 with a test for a possible lateral or vertical correlation of the gold grades. The number of samples is small, but no positive correlation is visible in the plot.

A correlation of gold grades between the heavy mineral fraction and the fine fraction (-63 µm) of the duplicate samples is evident, but not strong (Fig. 58, left). Correlation coefficients were not calculated because of a small number of samples and the strong influence of one sample pair on the results. The two pathfinder elements bismuth and tellurium did not correlate with gold in these samples (Fig. 58, right).

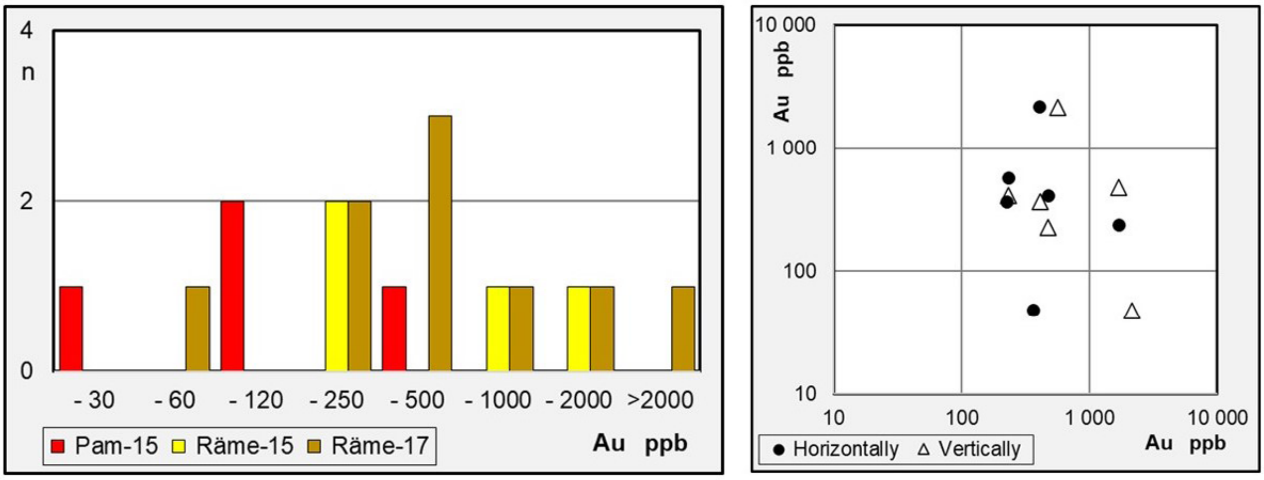



Fig. 57. Distribution of gold grades in the heavy mineral fraction of till, subdivided by sampling phases (left) and the possible correlation of the heavy mineral fractions with the adjacent samples either horizontally or vertically in the Rämepuro second test panel R-17 (right). Abbreviations: Pam-15 = samples from Pampalo in 2015, Räme-15 = samples from Rämepuro in 2015, Räme-17 = samples from Rämepuro in 2017.

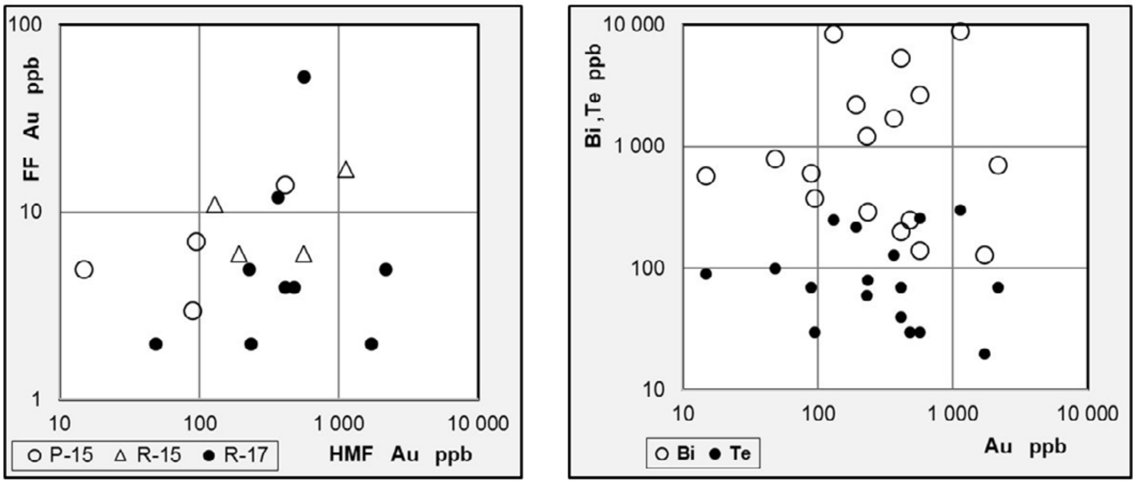



Fig. 58. Plot of gold grades of heavy mineral and fine fraction till samples subdivided by sampling sites (left) and the correlation of gold with bismuth and tellurium in the heavy mineral samples (right) on the test panels. Abbreviations: FF = fine fraction (-63 µm), HMF = panned heavy mineral fraction (-1 mm). P-15 = samples from Pampalo in 2015, R-15 = samples from Rämepuro in 2015, R-17 = samples from Rämepuro in 2017.

In the data of GTK (Huhta 1993), compiled by the author, no clear correlation was detected between upper and lower samples (Fig. 59, left). The lower samples from the same excavated pits were not true replicates because of the depth differences, usually 1–1.5 m. Till quality can change vertically, affecting the interpretations. Microscopically visible gold grains were removed from the analysed samples reducing the true gold grade and the analysed sample weight was only 1 g. These factors also affected to the results.

Replicates of the bulk till samples collected by Outokumpu are more representative, because the samples were taken close to each other and they consisted of macroscopically identical till material. In addition, the primary excavated sample size of 100–200 litres, of which 20–30 litres were sieved, reduces the possibility of methodological errors. Moreover, the analytical weight was 5 g instead of 1 g by GTK. The correlation should be better for these reasons. Despite this, no or only a weak correlation was detected and this was not dependent on the concentrating methods used (Fig. 59, right). The test with a Knelson concentrator revealed a weak correlation.

Similar tests to those applied to GTK data were carried out using data from heavy mineral exploration using reverse circulation drilling in Ontario, Canada (Averill and Graham 1988). Altogether, 103 holes were drilled into the bedrock with a mean overburden thickness of 17.6 m. The till mainly consisted of Late Wisconsinan Albany till. Usually three or more till samples, commonly 1.5 m in length, were collected above the bedrock surface. The second (*Lower*) sample and third (*Upper*) sample above the bedrock were selected for this test by the author, all representing homogenous Albany till. The lowermost till sample was not used because of possible bedrock contamination. The primary bulk sample was 8–10 kg. The sample was wet sieved, concentrated on a shaking table (Mitchell et al. 1997) and after heavy liquid separation (SG 3.3) and magnetic separation it was assayed for gold using fire assay with an AAS finish. In addition, arsenic, copper and zinc were analysed (Averill & Graham 1988). A plot of gold grades in this test, carried out by the author, is presented in Figure 60.

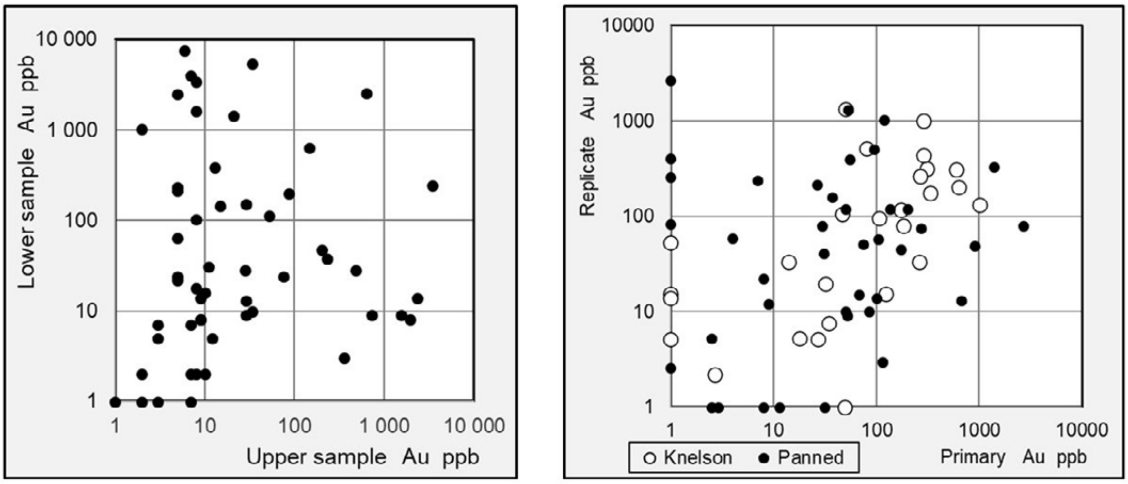



Fig. 59. Replicate sample plot of gold grades in the heavy mineral fraction of till. GTK data (left) and Outokumpu data (right). Correlation coefficients (r) are -0.029 for the GTK data and 0.156 (Knelson) and -0.061 (panned) for the Outokumpu data.

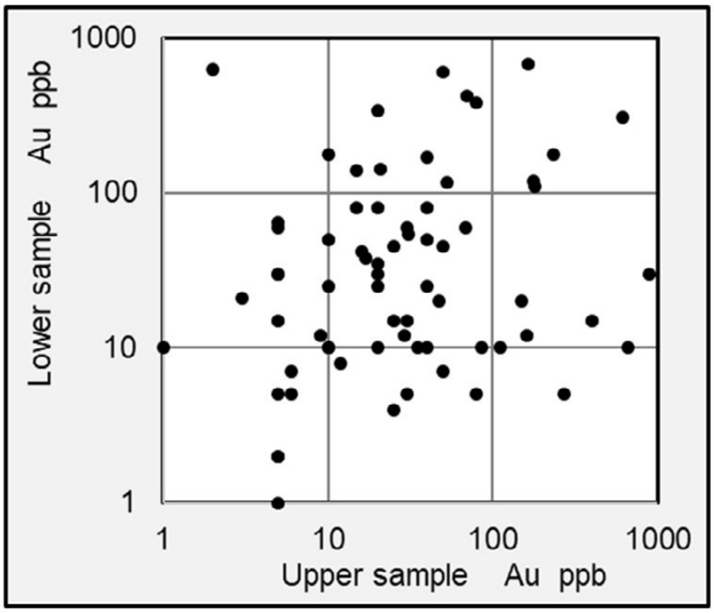



Fig. 60. Plot of gold grades of the heavy mineral fraction of till in the data of the Firstloon Lake Property of Kerr Addison Mines LTD (Averill & Graham 1988). The lower sample is the second till sample and upper sample the third sample above the bedrock surface.

Gold grades of the upper (U) and lower arsenic it is 0.551 and copper 0.622. Gold correlates very weakly or not at all with arsenic (r = -0.022 in the U-samples and 0.056 in the L-samples) or with copper (r = -0.079 (U) and 0.185 (L)).

Duplicate samples from the till samples of OM from Ilomantsi were also tested using the Knelson laboratory concentrator to verify the reliability of the panning method, which was the standard method in heavy mineral exploration. The samples were collected from the same sample heap as panned samples. The correlation was found to be weak, but the mean grades were almost the same (Knelson 81 ppb and panned 94 ppb). The concentrate weights by panning were generally slightly lower (25–50 g) than with the Knelson concentrator (about 50 g), theoretically increasing the concentration. The tellurium grades of the two concentrating methods were found to correlate much better than gold (Fig. 61).

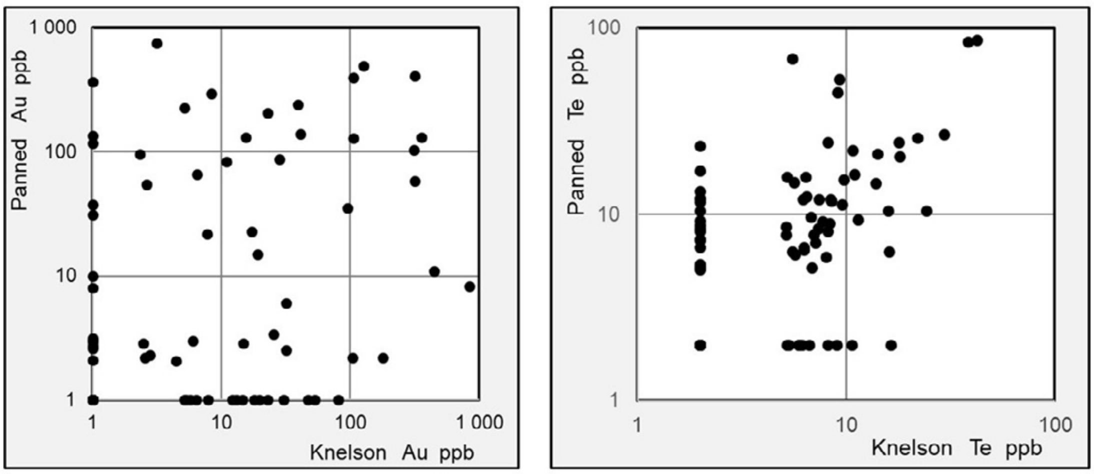



Fig. 61. Plot of duplicate sample results of gold (left) and tellurium (right), concentrated using the laboratory Knelson concentrator and by panning (86 test samples). The correlation coefficients (r) are 0.281 for Au and 0.801 for Te 0.801. The detection limits are 1 ppb for Au and 2 ppb for Te 2 ppb.

The gold grade distributions in the GTK and OM heavy mineral data differ in the maximum column heights of the histograms (Fig. 62), but the amounts of the high gold grade classes are similar. They both cover the Hattu Schist Belt varying in their detailed sampling locations. The panel test sample distribution of Pampalo and Rämepuro and the distribution of the large OK+GTK data set differ for low grades (Fig. 62). No very low grades (<10 ppb) exist in the test panels and the grades are commonly a few hundred ppb. This is understandable because the test locations were in anomalous areas, close to the gold deposits. The same phenomena was also found in the fine till fraction analysis (Fig. 51). Gold grades of the test panels cover the grade distribution of the regional sampling, except the very low grades. In a sparse sampling programme a gold deposit can remain undiscovered because of this statistical gold distribution at a single point, if a low grade in the gold grade distribution happens to be the result.

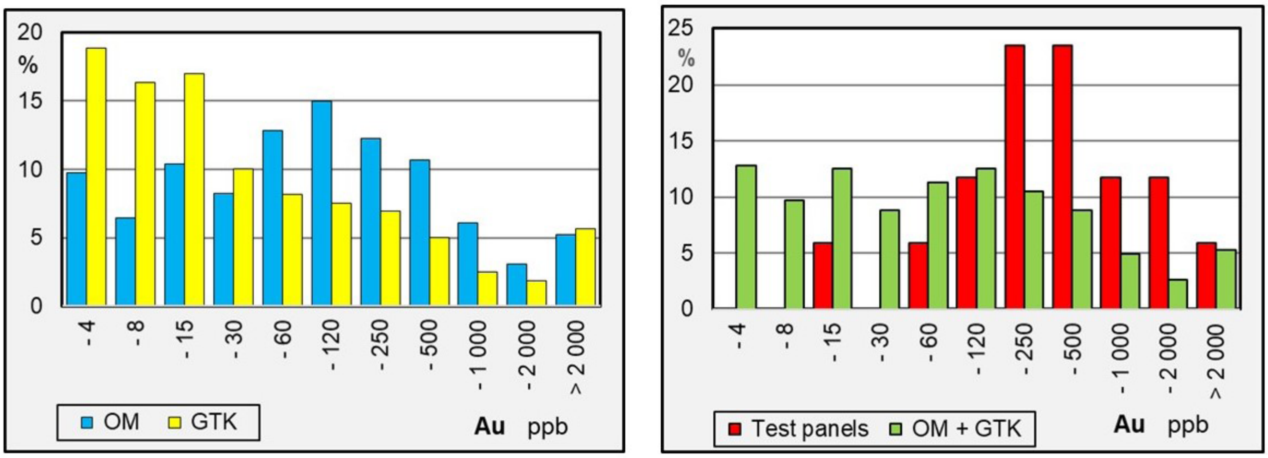



Fig. 62. Gold grade distribution of the heavy mineral fraction in the data of Outokumpu (OM) and GTK (GTK-1 data, left) and the distribution of the test profiles compared to the combined OM+GTK data in the Hattu Belt (right). The class values have been transformed to percentages to normalize the difference in sample numbers (test 17 samples, OM+GTK 635 (410+225) samples).

The numerical relative variances of gold differ significantly between OM and GTK heavy mineral data, although the means are close to each other (Table 35). The main reason is probably the methodological differences, and for this reason, the OM results can best be compared with the panel results. The OM and panel samples were concentrated by panning (keeping gold in the primary sample) and the GTK samples with the Goldhound (taking gold out of the sample). The GTK sample sites were concentrated in anomalous areas leading to a few very high gold grades and most grades were low. The mean grade is thus close to the mean of OM, but the variance is much higher. This is also seen as high gold variance for the fine till fraction in GTK-1 data in Table 32. A few abnormally high gold grades in the GTK data have a strong influence on both the mean and variance. Excluding the two highest gold grades would reduce the mean to 180 ppb and the relative variance to 15.4 in Table 35. The relative variance of the regional OM data is three times higher than in the panels and the reason for this is the lack of very low gold grades in the panels. The most important fact is the equal number of high gold grades (as %) in the local test panel as well as in the regional GTK and OM samples.

Copper and arsenic were not found to significantly concentrate in the heavy mineral fraction, probably because of the absence of chalcopyrite and arsenopyrite in the samples. The results are more or less random.

Table 35. Relative variances ($\sigma^2$) of gold (ppb), copper (ppm) and arsenic (ppm) of the till panel heavy mineral data from Ilomantsi compared to the regional data of Outokumpu Mining (OM) and the Geological Survey of Finland (GTK, data set GTK-1). The variance ratio of the regional data (between sites) and the panel data (within site) is marked as $\sigma^2_R$ / $\sigma^2_P$ (F-factor).

| | Au | | | Cu | | | As | | |
|---|---|---|---|---|---|---|---|---|---|
| | Panel | OM | GTK | Panel | OM | GTK | Panel | OM | GTK |
| No | 17 | 410 | 320 | 17 | 211 | 311 | 17 | 46 | 311 |
| Mean | 518 | 290 | 367 | 47 | 14 | 60 | 240 | 331 | 114 |
| $\sigma^2$ | 0.64 | 1.85 | 51.2 | 0.57 | 0.12 | 10.47 | 1.04 | 2.84 | 12.77 |
| $\sigma^2_R / \sigma^2_P$ | | 2.89 | 80.00 | | 0.21 | 18.37 | | 2.73 | 12.28 |

# 6 DISCUSSION

## 6.1 Bedrock

### 6.1.1 Comparison between the datasets

Systematic precision tests in QAQC are commonly first applied when resources are to be estimated. Material for testing can consist of previous crushed rejects or pulps, the remaining half or quarter of a core or sometimes new holes drilled close to an old one (twinned holes). In this study, all these rock materials were utilized.

***Connection of geostatistics and replicate sampling in estimating the nugget value in variography***

The link between geostatistics and the theory of sampling (TOS) is based on the influence of TOS to the nugget value, especially with inadequate sampling followed by a significant sampling error (Francois-Bongarcon 2017).

At Pampalo, the nugget values, as a percentage of the sill value in the modelled variograms, varies from 13% to 36% (Payne 2004, WAI 2007, SRK 2016). This is compared to the drill core replicate data (half drill core–half core). In these replicate data, the precision (CV%) is 31% (Fig. 24), which can be compared with the variography results.

In the Juomasuo drilling data, the nugget values of variograms are lower than at Pampalo, about 5% (Sandberg 1993, Runge 2011). The replicate (half drill core–half or quarter core) precision as CV% is about 30%, both in the old data from 2006 and in the new data from 2010-2012, Fig. 25). These figures are higher than the variography results, corresponding to the CV% values of Pampalo. However, the results indicate that replicate testing (half core-half core) could be widely used in variography to compare and confirm the extrapolated nugget values estimated from drilling or other sampling data.

***Effects of sampling procedures***

Precision has a strong influence on sampling and drilling methods, sample weights and 3D sampling grids. Problems commonly arise in greenfield exploration because the local precision is not known in advance. Geological, mineralogical and structural data that are as good as possible are needed to estimate precision, especially the cluster effect in primary sampling and the nugget effect in the preparation and analytical phases. Later, increased sampling data with replicates and duplicates, together with geostatistics, allows a better estimation of precision and optimization of sampling.

Traditionally the term "sampling error" has been used to describe the combination of precision and accuracy. Abzalov (2011) divided the total sampling error into three groups, simplified as the sampling protocol, sampling practice, and analytical procedure.

The sampling protocol includes the planning of sampling, the sampling equipment, and the sample location, type and sample size related to the heterogeneity of the material. Precision in this phase is known as fundamental sampling error (Gy 1982). Principally, this is a natural phenomenon when sampling untouched geological material, depending on the primary characteristics of the material. When sampling loose and transported material (e.g., blasted or crushed rock), natural qualities will change, and new technical factors will arise to affect the precision of this stage.

Principally, the phase of sampling practice (from sampling to laboratory samples) should not add precision if everything is done 100% perfectly and theoretical precision is included in the sampling protocol. Unfortunately, this is never realistic, and many types of errors can occur, such as instrument problems, human carelessness, unprofessional work practices, rush, contamination and sample mixing. Basically, these are human errors, but they can have a significant impact on the total precision. Errors in this phase can add both precision and accuracy in the following analytical phase, for example due to incorrect sieving or pulverizing practices.

The third group, analysis, has a combination of precision and accuracy. Generally, precision in this group is smaller than in the first two groups. However, precision can be significant if too coarse-grained or small sample size in relation to the material type is used or if the analytical method or instrument is not suitable for the sample type.

### *Influences in preparation and analytical procedures*

Knowledge of precision and the grain size of gold are the key factors when selecting the optimal crushing and pulverizing methods and the necessary sample weights in each step to keep nugget and cluster effects at an acceptable level (Gy 1982). The nugget effect of pulverized samples in coarse-grained gold occurrences cannot be entirely avoided because of the small sample weights used for gold analysis. In pulverization, soft and unbroken gold nuggets do not grind in the same way as normal rock minerals but remain as flexible flakes in the pulp. The first preparation line used (Pre-1, Fig. 14) did not fulfil the theoretical requirements, but the results appear to be good enough for precision testing.

### *Precision chain*

The total precision decreases from primary sampling to analysis and the ratio of nugget to cluster effects accordingly increases. Finally, the pulp fraction (-75 µm) contains only the nugget effect.

The results for the relative precision (CV%) in separate phases from the Ilomantsi, Kuusamo and Kittilä data are presented in Table 36 and in Figure 63.

Table 36. Mean relative precision of the different sample types from Ilomantsi, Kuusamo and Kittilä.

*Abbreviations:*
No: Number of sample pairs, CV%: Mean relative precision,
Juo old: Old sample set (2006) from Juomasuo also including Hangaslampi,
Juo new: New sample sets (2010-2012) from Juomasuo and Hangaslampi.

| | Pampalo | | Rämepuro | | Juo. old | | Juo. new | | Suurikuusikko | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No | CV% | No | CV% | No | CV% | No | CV% | No | CV% |
| Grid drilling of 1 m | 65 | 62.1 | 25 | 83.0 | | | | | | |
| Half core replicates | 75 | 31.1 | 29 | 54.1 | 148 | 30.3 | 68 | 30.8 | | |
| Crushed duplicates | 197 | 24.0 | | | 95 | 38.2 | | | 333 | 12.7 |
| Pulp duplicates | 217 | 17.6 | | | | | 50 | 11.8 | 861 | 6.3 |

The relative precision of the pulp duplicates varies from 6% (Suurikuusikko) to 18% (Pampalo). This represents the “constant nugget effect”, which is also included in coarse duplicates and replicates. This constant nugget effect includes splitting and analytical variances of pulp samples together with analytical accuracy, if this changes. In half-core replicates, the precision is twice as high and thus the nugget and cluster effects are similar in size. In one-metre grid drilling, the precision is again doubled and the cluster effect forms ¾ of the total precision. The increasing trend of CV% is clear. The old Juomasuo half-core and crushed sample analyses were conducted by different laboratories and using slightly different methods, which probably influenced the results. Variation at Rämepuro is systematically higher than at Pampalo. The CV% values are close to or within the acceptable practice limits in gold mining projects. The best practice limits in a coarse to medium-grained gold deposit for coarse rejects is 20% and for pulp 10% (Abzalov 2008). The constant nugget effect is 18% in Pampalo, 12% in Juomasuo and 6% in Suurikuusikko as CV% values (Fig. 63).

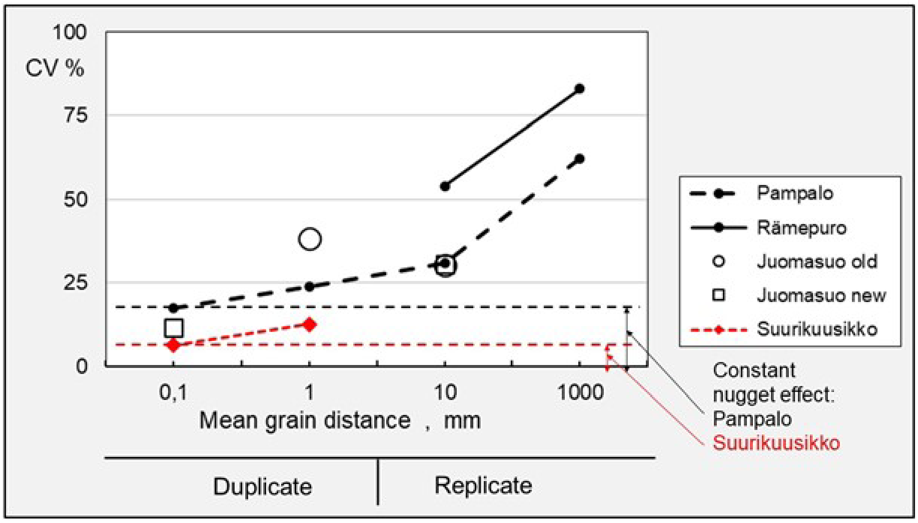



Fig. 63. Mean relative precision (CV%) related to the mean distance between gold grains in samples.
0.01 mm = pulverized pulp samples (<0.075 mm),
1 mm = crushed sample duplicates (<2 mm),
10 mm = half core or quarter core replicates,
1000 mm = grid drilling replicates, distance one meter.

The splitting tests by Endomines Oy using the –25 mm cone crusher product (Eriksson 2016) yielded a CV% value of 29%, which agrees well with the half-core replicate results. The drift run comparison of sludge sand and drift face grab sampling (Eriksson 2016) had a higher CV% reaching up to 50.5%, but it cannot be directly compared with the one-metre grid drilling because of the different methods.

Correlation coefficients (r) change similarly to CV%. No significant differences were found in half-core replicates or crushed and pulp duplicates between the targets. In the grid drilling, the correlation was weak at Pampalo and non-existent at Rämepuro (Table 37).

Table 37. Replicate-duplicate correlation coefficient (r) related to the distance between gold grain, as in Figure 63, at Pampalo, Rämepuro, Juomasuo and Suurikuusikko.

| Replicate-duplicate | Grain dist. (mm) | Pampalo r | Rämepuro r | Juomasuo r | Suurikuusikko r |
|---|---|---|---|---|---|
| Grid drilling of 1 m | 1000 | 0.291–0.519 | -0.059 | | |
| Half core replicate | 10 | 0.891 | 0.903 | 0.821–0.975 | |
| Crushed duplicate | 1 | 0.973 | | 0.963 | 0.998 |
| Pulp duplicate | 0.01 | 0.998 | | 0.999 | 0.999 |

Pulp duplicates are commonly used in QAQC programmes together with reference samples. In Ontario, duplicate testing of 1629 samples (Tetlock et al. 2016) resulted in correlation coefficients of 0.998 for both split pulp samples and internal laboratory duplicate analysis. Further examples are collected in section 6.1.2.

***Variances of the procedure chain of sampling – preparation – analysis***

Precision in each step must be calculated as variances to estimate the "weakest" point of the procedure chain of sampling–preparation–analysis. The sampling here includes primary drilling (grid drilling) and preparation with all operations from core cutting to pulverization. The total, overall variance is the sum of variances of the procedure chain (Pitard 1993):

OE = FE + PE + AE and then also FE = OE − PE − AE, where

OE = overall, total variance,
FE = sampling variance (fundamental sampling error),
PE = preparation variance and
AE = analytical variance.

The preparation variance (PE) can be subdivided into two steps.
– variance of the half core replicates (HR),
– variance of the crushed duplicates (CD).

Relative variances ($\sigma^2$) of OE, HR, CD and AE were estimated using existing data by calculating CV% values for $\sigma^2$ values, and FE was calcuted based on these variances. OE is the variance of the grid drilling at Pampalo and Rämepuro. At Pampalo UG (underground) it is the variance of face chip sampling and sludge sampling, which is notated as OE. The duplicate test of crushed ore (Fig. 27) is defined as CD. These UG variance tests cannot be directly compared with drilling tests and the variances are presented in parentheses. Estimated variances in each step and percentages are provided in Table 38.

Table 38. Relative variances (upper table) and percentage distribution (lower table) of the gold grades in the procedure chain of grid drilling–preparation–analysis.

FE = sampling precision,
PE = preparation variance,
AE = analytical variance,
OE = overall, total variance.

| **Target** | **FE** $\sigma^2$ **FE** $\times 10^{-4}$ | **PE+AE** $\sigma^2$ **HR** $\times 10^{-4}$ | $\sigma^2$ **CD** $\times 10^{-4}$ | **HR** $\sigma^2$ **HR-CD** $\times 10^{-4}$ | **CD** $\sigma^2$ **CD-AE** $\times 10^{-4}$ | **PE** $\sigma^2$ **HR-AE** $\times 10^{-4}$ | **AE** $\sigma^2$ **AE** $\times 10^{-4}$ | **OE** $\sigma^2$ **CC** $\times 10^{-4}$ |
|---|---|---|---|---|---|---|---|---|
| **Pampalo, drill** | 2889 | 967 | 576 | 701 | 266 | 657 | 310 | 3856 |
| **Pampalo, UG** | (1703) | | (847) | | | | | (2550) |
| **Rämepuro, drill** | 3963 | 2927 | | | | | | 6890 |
| **Kuusamo, drill** | | 949 | | | | 810 | 139 | |
| **Kittilä** | | | | | | 161 | 40 | |

| **Target** | **FE** $\sigma^2$ **FE** % | **PE+AE** $\sigma^2$ **HR** % | $\sigma^2$ **CD** % | **HR** $\sigma^2$ **HR-CD** % | **CD** $\sigma^2$ **CD-AE** % | **PE** $\sigma^2$ **HR-AE** % | **AE** $\sigma^2$ **AE** % | **OE** $\sigma^2$ **CC** % |
|---|---|---|---|---|---|---|---|---|
| **Pampalo, drill** | 75.0 | 25.0 | 14.9 | 18.1 | 6.9 | 17.0 | 8.0 | 100 |
| **Pampalo, UG** | (66.8) | | (33.2) | | | | | (100) |
| **Rämepuro, drill** | 57.5 | 42.5 | | | | | | 100 |

Of the total variance the sampling variance (FE, fundamental sampling error) is >50% and the analytical variance is <10%. The variance in core cutting (HR, 18.1%) is higher than in crushing (CD, 6.9%) in the drilling test at Pampalo. Variances are then in the size order:
– sampling > preparation > analysis

Sampling in the grid drilling with the one-metre distances has understandably higher variances than more closely located replicate samples and dominates the total variance. The phases of core-cutting and crushing-pulverization have almost the same variances as the analytical operation.

#### *Effects on anomaly interpretation and target selection*

Precision can have a major influence in target selection after the first sampling phases as shown in the example from Rämepuro (section 5.1.1.1.). Despite the similar macroscopic rock type, mineralogy and alteration, the gold grade can vary from 1 ppm to 51 ppm within a distance of one metre (Table 7). Two main solutions exist to avoid misinterpretations: larger samples and understanding and utilization of geology. The sample size is based on statistics, i.e., how large the sample should be to include a desired number of gold nuggets or clusters (Gy 1982)? However, a large sample size does not help if the sampling site is not representative. Geology, gold indications in alteration, mineralogy and structures are the most important factors in target and sampling site selection. The poor "natural" precision of gold should always be remembered. If the gold grade is lower or higher than expected based on geological indications, replicate analysis should at minimum be performed.

#### *Effects in practical mining*

High nugget and cluster effects create problems in estimating the grade, cut-off grades, and top cutting. The practical and daily decision in mines is: "ore" or "waste". Often, the macroscopic appearance and analysed gold grade do not agree or acceptable and local gold grade data are entirely lacking. The question arises whether to believe the macroscopic appearance of the ore or the assayed gold grade, which can have a huge nugget and/or cluster effect. The best solution is to know the mineralogy, alteration or textural-structural indications of the ore. For example, the author used three features to indicate gold ore in the Pampalo ore deposit:

- pyrite and scheelite as mineralogical indications,
- alteration, potassic or silicic depending on the host rock type and
- small-scale textural heterogeneity, tiny or small folds, faults, etc.

These gold indications should be identified and understood for every gold ore, because they are individual to each gold deposit and type. In the QAQC procedure special attention should be focused on primary sampling, instead of on pulp re-assaying and laboratory testing (Carswell 2016).

### 6.1.2 Reference data from other gold deposits

Mining companies generally have only limited publicly available data. Technical reports, mainly based on the Canadian NI 43-101 instructions, were the main information source in this study. The reports include plots of duplicate samples, often without numerical data. Pulverized samples are usually also analysed in another laboratory. These results were not suitable for this study, because of the different assay methods or procedures applied. Often, the grade variation of pulp duplicates assayed in another laboratory, is larger than when assaying coarse duplicates in the primary laboratory. The assaying laboratory and method must be the same to determine the real precision without laboratory differences. Absolute distributions of the gold grain size are usually lacking, and estimation of the grain size must be interpreted by mineralogy, possible gravity concentration tests and variography. Public information on about 200 gold companies or deposits was reviewed and 75 deposits were found to have relevant data, most of them operated by Canadian companies. The following data were collected from the reports:

- general grain size of gold in the deposit,
- sampling type in duplicate testing,
- analytical sample size,
- classified number of samples in the replicate-duplicate testing,
- replicate-duplicate test results either as correlation coefficient (r), and/or half absolute relative difference (HARD) of field replicate and crushed reject and/or pulp duplicates.

The grain size of gold in a deposit was estimated based on geological and mineralogical studies, duplicate data, and possible gravity concentration results. Five classes are used, based on the weighed mean grain size of gold. The weighed mean size is defined as the size in which 50% of gold is smaller in size and 50% larger, by weight. The classes, with numbers of reference deposits in each class, are as follows:

- **f** fine grained, median grain size <10 µm, 13 deposits,
- **m** medium grained, size 10–50 µm, 29 deposits,
- **c** coarse grained, size >50 µm, 8 deposits,
- **mf** between m and f, 20 deposits,
- **mc** between m and c, 5 deposits.

Correlation results are collected in Table 39, as Pearson correlation coefficients, and/or as the half absolute percent relative difference (HARD), together with general nugget values in variography and recoveries by gravity methods, if available. Duplicate test results with this base data help to estimate the amount of coarse gold and mutual correlation of various factors. Duplicate tests are classified into field, crushed reject and pulp duplicates. In diamond core drilling a "field duplicate" is the other half or quarter of a core. This is defined by the author and also in some of the referrence studies as a "field replicate". No details of laboratories or methods are included, but all the duplicate samples were analysed in the same laboratory as the primary samples to eliminate precision between laboratories. A brief description of the Finnish gold deposits and a few example deposits are included in the text. The names of the rest of 75 reference deposits are summarized in Table 39, with references. The number in parentheses refers to the number in Table 40 with the data.

#### *Finnish deposits*

The Hirsikangas Gold Project (1) is located within the Svecofennian area in western Finland. The bedrock consists of mica schist, mafic and ultramafic volcanic rocks and felsic schist, the main host rock of the gold mineralization. These rocks are in places intruded by late-stage granite porphyry dykes and pegmatites (Wolfe 2018a). The deposit is orogenic, hydrothermal in origin and is principally hosted within deformed felsic schist. Within the felsic schist, randomly disseminated blebs of sulphides can account for up to 10% of the rock, although more typically they account for 1-2% combined sulphides, arsenopyrite, pyrite and pyrrhotite. Gold is sometimes visible (Kontoniemi & Mursu 2006, Wolfe 2018a). The precision of the tested replicates and duplicates is good, indicating a low nugget effect.

The Jokisivu Gold Mine (2) is a Paleoproterozoic orogenic gold deposit within the Vammala Migmatite Belt. The two deposits comprise auriferous and deformed quartz veins in hosting diorite. The mostly free gold grains in quartz veins are locally related to arsenopyrite, loellingite, pyrrhotite and scheelite (RPM Global 2019) The mine systematically tests pulp duplicates, both as own duplicates and laboratory duplicates. Gold grades higher than 5 g/t are re-assayed by FA and a gravimetric finish. Macroscopic gold grains are commonly seen in core logging. The precision of the pulp duplicates is quite poor, indicating a significant nugget effect.

The epigenetic, Paleoproterozoic Osikonmäki gold deposit (3) is situated within the Ladoga-Bothnian Bay Zone in eastern Finland. The bedrock of the area predominantly consists of metaturbidites, intruded by a variety of granitoids. The primary mineralization is controlled by an east-west orientated shear zone. The gold is found within a tonalite intrusive. The major sulphide minerals associated with the gold deposits are pyrrhotite, arsenopyrite, löllingite and chalcopyrite. Gold and electrum, together with a number of Bi-Te-Sb minerals, occur both as inclusions and at grain boundaries and between arsenopyrite and silicate grains (Kontoniemi 1998). Geological control on the gold grade is still relatively poorly understood (Wolfe 2018b)

The Pahtavaara gold mine/deposit (4) is located in the Central Lapland Greenstone Belt and was discovered and investigated by GTK (Pulkkinen et al. 1986, Korkeakoski 1992). Mineralization is hosted by amphibolitised komatiites. The mineralized structural corridor identified in the Pahtavaara Project is characterised by hydrothermal alteration and mineralization within komatiites. Gold occurs mostly as free and quite coarse-grained, and a smaller proportion is associated with magnetite (Wolfe 2018c). The replicate-duplicate results do not indicate poor precision, despite the coarse grain size of gold and presumably significant nugget effect.

The Rajapalot Property in Ylitornio explored by Mawson Resources (AMC Consultants 2018) resembles the Kuusamo deposits in geology, mineralogy and the grain size of gold. A systematic QAQC study indicates a good correlation between original versus duplicate samples in both crushed and pulp duplicates. The correlation of the pulp duplicates is better than of the crushed duplicates, as usual. The analyses were conducted by the CRS Laboratory in Kempele Finland using the PAL1000 method with a flame AAS finish. The sample weight was 1 kg (AMC Consultants 2018). The results can be compared with those from Pampalo and Juomasuo.

#### *Example deposits*

The Goldboro Property (5) is underlain by folded sedimentary rocks of the Cambro-Ordovician Goldenville Formation of the Meguna Group, Nova Scotia, Canada. The formation consists of interbedded greywacke, arenite, and argillite. The Goldboro Deposit contains three type of quartz veins, but is also characterized by mineralization within the host argillite units. This deposit class is identified as a member of the category "Turbidite-hosted, quartz-carbonate vein deposit (Bendigo Type)". Gold mineralization occurs in both quartz veins and within the argillite that hosts the veins, and to a lesser extent, greywacke. Disseminated, euhedral arsenopyrite is associated with gold mineralization. Other sulphides associated with the mineralized quartz veins are pyrrhotite, chalcopyrite and pyrite. Native gold is nuggety in nature, and grains range from microscopic up to several centimetres in size. Gold is present in quartz and within arsenopyrite grains, along grain boundaries and internal fractures, and is non-refractory in nature (McCracken & Raponi 2019). Quite poor precision is natural for this type of deposit with a significant nugget effect, and high gravity recovery. However, the estimated nugget value in variography is abnormally low.

The Meadowbank mine (6) and Amaruq satellite mine (7) properties are underlined by Archean-age volcanic and sedimentary rocks of the Woodburn Lake Group in the northern Canadian Shield. Since 2010, three of the known gold deposits have already been exploited. At Meadowbank the Goose and Portage deposits are hosted within deformed iron-formation rocks and gold is mainly associated with pyrite and pyrrhotite, and rarely with chalcopyrite or arsenopyrite. In the third deposit, Vault, pyrite is the principal gold-bearing sulphide (Bilodeau et al. 2018). The Ameruq Mineral Deposit is divided into three sectors: Whale Tail, IVR and Mammoth. Three contrasting mineralization styles coexist in these sectors. In all these styles, gold is found associated with pyrrhotite and/or arsenopyrite as 25-50 µm inclusions or grains along fractures, or simply as free grains in a quartz-rich gangue. Gravity concentrating is used in the plant without detailed recovery figures, but based on a few tests, it is expected to be 10-20%. The nugget value in the Amaruq variograms varies from 25% to 76% (Bilodeau et al. 2018). All the indicative factors in Meadowbank, namely the general grain size of gold, the gravity recovery, the nugget value of variography and duplicate correlation, and both r and HARD-values, are not far from the factors at Pampalo and Juomasuo.

The Mediadine gold project (8) is located in the Archean Rankin Inlet Greenstone Belt in the northern Canadian Shield, including seven identified gold deposits. Gold mineralization in these deposits is mostly mesothermal quartz-vein-dominated gold systems in strongly sheared and folded host rocks of turbidites, iron formation and volcanic rocks. Sulphide mineralogy varies between deposits, but commonly visible gold in quartz-ankerite-veins is connected to pyrrhotite and coarse arsenopyrite (Larouche et al. 2015). The gravity recovery in tests varied from 22% to 76% with an average recovery of 45%. The nugget effect in variograms generally varies from 20% to 40% (Larouche et al. 2015) It is lower than could be expected based on coarse gold, pointing to a less important cluster effect in the distribution of gold. The precision of all the duplicate sample types is lower than at Pampalo and Juomasuo, both as r and HARD values.

The Massawa gold project (9) in Senegal is located in Paleoproterozoic Kedougou-Kenieba inlier, mainly containing volcanic, volcano-clastic and sedimentary rocks. The deposits are strongly controlled by structures. The two main deposits, Central (CZ) and Northern Zone (NZ), differ strongly in gold mineralogy (Quick et al. 2019). Extensive QAQC testing has been carried out connected to the feasibility study. In the Central Zone gold is mainly free with a bimodal size distribution with peaks between 10 µm to 30 µm and 50-70 µm. The distribution of gold grain sizes can be compared with the Ilomantsi deposits. The Northern Zone has no evidence of free coarse gold. Gold is refractory within the crystal lattice of arsenopyrite and, to a lesser extent, arsenian pyrite (Quick et al. 2019), having close to the same style of occurrence as at Suurikuusikko. To test the existing diamond core drilling holes (DD, HQ or NQ in diameter) a twin hole programme was drilled in both deposits with RC drilling (RC, 140 mm in diameter), comprising 54 holes in CZ and 7 in NZ. The half-core samples of the DD campaigns were analysed in West African laboratories by FA using a 50 g sample weight. RC-samples in this programme were assayed by cyanide leaching (LeachWELL) followed by tail FA determination. The sample weight was 1 kg. The analytical intervals in DD and RC drilling are not exactly same. The gold grades are generally higher in RC drilling in the CZ deposit, but in the NZ deposit the differences are smaller and not systematic (Quick et al. 2019). The precision of gold grades between the DD and RC drilling, as CV% values, is 56.1% for CZ and 9.2% for NZ, calculated by the author. The values of CZ are similar to the grid drilling at Pampalo (CV% = 62) with an almost identical gold grain size distribution. Analogously, the much lower CV% value at NZ indicates similarity with the Suurikuusikko deposit. The field duplicate tests in RC drilling indicated a good correlation (Table 40). In variography, the nugget value varies from 20% in NZ to 40%-50% in CZ

Table 39. List of gold deposits and projects included in Table 40. In total, 75 deposits subdivided into Finnish deposits, example deposits and other depositssubdivided according to the continents.

***Deposit (D) references:***

***Finland***

P Pampalo (including Rämepuro),
J Juomasuo (including Hangaslampi),
S Suurikuusikko,
1 Hirsikangas Gold Project, Wolfe 2018a.
2 Jokisivu Gold Mine, RPM Global 2019,
3 Osikonmäki Gold Project, Wolfe 2018b
4 Pahtavaara Project, Wolfe 2018c,

***Example deposits outside of Finland, with a short text explanation:***

5 Goldboro Gold Project, Canada, McCracken & Raponi 2019,
6 Meadowbank, Canada, Meadowbank mine; Bilodeau et al. 2018,
7 Meadowbank, Canada, Amaruq project; Bilodeau et al. 2018,
8 Mediadine Gold Project, Canada, Larouche et al. 2015,
9 Massawa Gold Project, Senegal, Quick et al. 2019,

***Deposits with suitable duplicate data subdivided according to the continents and with references:***

***Africa***

10 Natougou Gold Deposit Project, Burkina Faso, Lincoln et al. 2016,
11 Kibali Gold Mine, Doko deposit, Congo, Quick et al. 2018b,
12 Kibali Gold Mine, Mwanza deposit, Congo, Cardenas et al. 2018a,
13 Asmara Project, Eritrea, Senior et al. 2014,
14 Bogoso/Prestea Gold Mine, Ghana, Raffield & Wasel 2017,
15 Wassa Gold Mine, Ghana, Raffield et al. 2019,
16 Yaoure Gold Project, Ivory Coast, Rossi et al. 2014,
17 Gounkoto Gold Mine, Mali, Quick et al. 2018b,
18 Loulu Gold Mine, Gara deposit, Mali, Quick et al. 2018a,
19 Loulo Gold Mine, Yalea deposit, Mali, Quick et al. 2018a,
20 Nampala Gold Deposit, Mali, Wolfe 2007, Baril et al. 2011,
21 Blanket Mine, Zimbabwe, Roets et al. 2018,

***America, Central-South***

22 Don Mario Mine, Bolivia, Zandonai 2017,
23 Castello de Sonhos Gold Project, Brazil, Viana et al. 2018,
24 Coringa Project, Brazil, Gunesch et al. 2019,
25 Jacobina Mine Complex, Brazil, Ladd et al. 2019,
26 Posse Deposit, Brazil, Whitehouse 2016,
27 Turmalina Mine Complex, Brazil, Sepp et al. 2019,
28 Volta Grande Project, Brazil, Chubb et al. 2015,
29 El Peñón Mine, Chile, Krutzelmann et al. 2018,
30 Volcan Gold Project, Chile, Pressacco et al. 2009,
31 Marmato Project, Colombia, Parsons et al. 2019a,
32 Segovia Project, Colombia, Parsons et al. 2019a,
33 Romero Gold Project, Dominican Republic, Macdonald et al. 2016
34 Pueblo Viejo Mine, Dominican Republic, Cardenas et al. 2018, year 2016,
35 Nivré Gold Deposit, French Guiana, Sirois & Purchase 2019,
36 Cerro Jumil Project, Mexico, Bond et al. 2011,
37 El Castillo Complex, Mexico, Lechner et al. 2018,
38 La India Gold Project, Mexico, Doucet et al. 2012,
39 Mercedes Gold-Silver Mine, Mexico, Altman et al. 2018,
40 Morelos Gold Project, Mexico, Neff et al. 2012,
41 Pico Machay Gold Project, Peru, Fox & Roy 2011,

***America, North***

42 Back River Gold Property, Canada, Kent et al. 2014,
43 Barry and Gladiator Deposits, Canada, Armitage & Vadnais-Leblanc 2019,
44 Canadian Malartic Project, Canadian Malartic deposit, Canada, Belzile & Gignac 2010,
45 Canadian Malartic Project, South Barnat deposit, Canada, Belzile & Gignac 2010,
46 Eskay Creek Au-Ag Project, Canada, Ulansky et al. 2019,
47 Garrison, Canada, Hennessey 2019,
48 Green Bay Property, Canada, McCracken et al. 2017,
49 Hammond Reef Gold Property, Canada, Cukor et al. 2011,
50 Island Gold Mine, Canada, Adam et al. 2017,
51 Kena Property, Canada, Giroux & Park 2013,
52 Kiena Mine Complex, Canada, Beausoleil et al. 2019,
53 Marban Block Property, Canada, Belzile 2016,
54 Martiniére Property, Canada, Voordouw & Perk 2015,
55 Moss Lake Project, Canada, Poirier et al. 2013,
56 O´Brien Project, Canada, Williamson 2019,
57 Orenada Project, Canada, Savard et al. 2018,

58 Premier Gold Project, Canada, Bird & Meintjes 2020,
59 Val-d´Or East Project, Canada, Beauregard et al. 2019,
60 Valentine Lake Gold Project, Canada, Lincoln et al. 2018,
61 Stibnite Gold Project, USA, Becker et al. 2019,
62 Talapoosa Project, USA, McCracken & Kanhai 2013,

***Asia***
63 Amulsar Project, Armenia, Sheykholeslami et al. 2019,
64 Oyadao Gold Project, Cambodia, Meyer 2011,
65 Uzboy Gold Deposit, Kazakhstan, Hogg et al. 2008,
66 Efemçukuru Gold Mine, Turkey, Sutherland et al. 2019a,
67 Kişladaĝ Gold Mine, Turkey, Sutherland et al. 2020,
68 Cöpler Sulfide Expansion Project, Turkey, Bohling et al. 2015,

***Australia***
69 Burnakura Project, Western Australia, Slater 2018,
70 Mt Todd Gold Project, Northern Territory, Bryan et al. 2019,
Europe, outside of Finland
71 Olympias Mine, Greece, Sutherland et al. 2019b,
72 Skouries Project, Greece, Alexander et al. 2018,
73 Omagh Gold Project, Northern Ireland, Phelps et al. 2104,
74 Certej Project, Romania, Forward et al. 2009, Alexander et al. 2014,
75 El Valle Boinás-Carlés Operation, Spain, Cox et al. 2014.

Table 40. Data table of the gold deposits.

***Abbreviations:***
D = deposit indication number, P Pampalo, J Juomasuo, S Suurikuusikko
GS = estimated grain size of gold, c = coarse, m = medium, f = fine,
ST = sampling type, dd = diamond drilling, rc = reverse circulation, rd = combination of dd and rc, cs = channel or other sampling
SS = analytical sample size for gold analysis,
NV = estimated mean nugget value in variography,
GR = tested mean gravity recovery as a % of the total recovery,
n = number of duplicate pairs, A <100, B 100-500, C 501-2 000, D 2 001-10 000, E >10 000,
r = Pearson correlation coefficient,
HARD = half absolute relative percent difference of gold at 90% cumulative confidence limit

| D | GS | ST | SS g | NV % | GR % | Field repl./dupl. | | | Coarse dupl. | | | Pulp dupl. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | n | r | HARD | n | r | HARD | n | r | HARD |
| **P** | m | dd | 40 | 30 | 20 | A | 0.891 | 29 | B | 0.973 | 22 | B | 0.993 | 12 |
| **J** | m | dd | 40 | 5 | 7 | A | 0.975 | 34 | | | | A | 0.999 | 12 |
| **S** | f | dd | 25 | | | | | | B | 0.998 | 11 | C | 0.999 | 3 |
| **1** | m | dd | 30 | | | A | 0.980 | | A | 0.999 | | A | 0.999 | |
| **2** | mc | dd | 50 | | | | | | | | | C | 0.912 | 34 |
| **3** | m | dd | 30 | 42 | | | | | | | | C | 0.970 | |
| **4** | c | dd | 50 | 43 | 70 | B | 0.840 | 33 | C | 0.990 | 31 | B | 0.990 | 30 |
| **5** | c | dd | 50 | 20 | 60 | B | 0.766 | | C | 0.850 | | B | 0.918 | |
| **6** | m | dd | 50 | 72 | 20 | | | | D | 0.991 | 26 | C | 0.996 | 20 |
| **7** | m | dd | 50 | 53 | | D | | 49 | D | | 25 | C | | 17 |
| **8** | c | dd | 50 | 35 | 45 | D | 0.775 | 87 | D | 0.995 | 71 | E | 0.994 | 36 |
| **9** | m | rc | 50 | 45 | 40 | D | 0.950 | 54 | | | | | | |
| **10** | c | dd | 50 | 45 | 50 | B | | 80 | | | | | | |
| **11** | m | rc | 50 | 22 | | D | 0.996 | | D | 0.997 | | | | |
| **12** | m | rc | 50 | | | | | | D | 0.999 | | | | |

Table 40. Cont.

| D | GS | ST | SS g | NV % | GR % | Field repl./dupl. | | | Coarse dupl. | | | Pulp dupl. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | n | r | HARD | n | r | HARD | n | r | HARD |
| **13** | f | rd | 50 | | | | | | B | | 20 | B | | 14 |
| **14** | m | dd | 50 | 20 | 70 | A | | 50 | B | | 62 | B | 0.843 | 35 |
| **15** | m | rd | 50 | 20 | 15 | | | | D | | 26 | | | |
| **16** | m | dd | 50 | | 34 | C | 0.819 | 115 | C | 0.984 | 63 | B | 0.976 | 22 |
| **17** | mf | rc | 50 | | | C | 0.987 | 58 | | | | | | |
| **18** | mf | rc | 50 | 25 | | | | | B | 0.943 | 56 | | | |
| **19** | mf | rc | 50 | 20 | | | | | B | 0.985 | 57 | | | |
| **20** | mf | dd | 30 | | 18 | B | 0.630 | 37 | | | | C | 0.920 | 17 |
| **21** | m | dd | 50 | | | | | | A | 0.977 | | | | |
| **22** | m | dd | 30 | | | A | 0.902 | | | | | | | |
| **23** | c | dd | 50 | 55 | 75 | A | 0.970 | | | | | | | |
| **24** | mf | dd | 30 | 38 | 60 | A | 0.493 | | | | | A | 0.992 | |
| **25** | m | dd | 50 | 50 | | C | 0.857 | | D | 0.979 | | | | |
| **26** | m | dd | 30 | 35 | | | | | C | 0.838 | | | | |
| **27** | mf | dd | 50 | 30 | 10 | | | | | | | C | 0.999 | |
| **28** | m | rd | 50 | 20 | 50 | A | 0.977 | 24 | | | | B | 0.995 | |
| **29** | m | rd | 50 | 40 | | | | | | | | B | 0.999 | |
| **30** | f | rc | 50 | 10 | | A | 0.913 | | A | 0.999 | | A | 0.999 | |
| **31** | mf | dd | 30 | 35 | 55 | B | 0.679 | | B | 0.992 | | B | 0.995 | |
| **32** | m | dd | 50 | 50 | 30 | B | 0.935 | | | | | | | |
| **33** | f | dd | 30 | 25 | 12 | A | 0.955 | | | | | A | 0.999 | |
| **34** | f | rc | 15 | 35 | | D | 0.890 | | | | | | | |
| **35** | f | dd | 50 | 30 | | A | 0.850 | | A | 0.999 | | A | 0.999 | |
| **36** | f | rd | 30 | 20 | | C | 0.948 | 24 | A | 0.975 | | A | 0.999 | 12 |
| **37** | mf | rc | 30 | 20 | | B | 0.981 | | | | | | | |
| **38** | mf | rc | 50 | 30 | | C | | 19 | C | | 10 | C | | 7 |
| **39** | mf | dd | 30 | 25 | | B | 0.830 | | | | | B | 0.980 | |
| **40** | mf | dd | 30 | | 7 | C | | 48 | | | | C | | 38 |
| **41** | f | rc | 30 | 34 | | | | | B | 0.940 | | | | |
| **42** | mf | dd | 58 | | 44 | | | | D | | 12 | D | | 9 |
| **43** | c | dd | 30 | | 72 | C | 0.331 | | | | | A | 0.911 | |
| **44** | mf | dd | 50 | 20 | 19 | | | | | | | D | 0.963 | |
| **45** | mc | dd | 50 | | 53 | | | | | | | D | 0.862 | |
| **46** | mf | dd | 50 | 17 | | B | 0.968 | | B | 0.997 | | B | 0.998 | |
| **47** | m | dd | 30 | 32 | | | | | D | 0.928 | | | | |
| **48** | mf | dd | 30 | 18 | 13 | | | | B | 0.980 | | | | |
| **49** | m | dd | 30 | 30 | | C | 0.856 | | D | 0.977 | | | | |
| **50** | m | dd | 30 | 40 | 55 | C | 0.933 | | | | | C | 0.995 | |
| **51** | mf | dd | 30 | 40 | 40 | A | 0.967 | | B | 0.997 | | A | 0.990 | |
| **52** | m | dd | 30 | 27 | | | | | | | | B | 0.912 | |

Table 40. Cont.

| D | GS | ST | SS g | NV % | GR % | Field repl./dupl. | | | Coarse dupl. | | | Pulp dupl. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | n | r | HARD | n | r | HARD | n | r | HARD |
| **53** | mc | dd | 50 | 40 | 50 | | | | | | | B | 0.985 | |
| **54** | m | dd | 30 | | | C | | 35 | C | | 15 | C | | 9 |
| **55** | m | dd | 30 | | | A | 0.838 | | | | | | | |
| **56** | mc | dd | 30 | | 47 | | | | | | | A | 0.993 | |
| **57** | m | dd | 50 | 29 | 9 | C | 0.779 | | | | | B | 0.994 | 28 |
| **58** | m | dd | 30 | | 42 | C | 0.594 | 43 | | | | | | |
| **59** | c | dd | 50 | | 50 | C | 0.721 | | | | | C | 0.942 | |
| **60** | c | dd | 30 | 50 | 52 | | | | | | | A | 0.947 | |
| **61** | f | dd | 30 | 22 | | C | 0.940 | | | | | D | 0.985 | |
| **62** | mf | dd | 50 | 10 | | A | 0.860 | | | | | | | |
| **63** | mf | dd | 30 | 24 | | C | 0.920 | | | | | | | |
| **64** | m | dd | 30 | | | | | | | | | B | 0.984 | 26 |
| **65** | mc | dd | 200 | 40 | | | | | | | | C | 0.972 | |
| **66** | mf | dd | 30 | 16 | | | | | C | | 6 | | | |
| **67** | f | dd | 30 | 25 | | | | | C | | 7 | C | | 4 |
| **68** | f | dd | 30 | 6 | | | | 27 | | | | | | |
| **69** | m | rc | 30 | 48 | | C | 0.988 | 35 | | | | C | 0.998 | |
| **70** | m | dd | 50 | 40 | | | | | | | | D | 0.996 | |
| **71** | f | dd | 30 | | | | | | C | | 6 | C | | 5 |
| **72** | m | dd | 30 | 25 | | | | | C | | 17 | | | |
| **73** | f | dd | 30 | 15 | | A | 0.930 | | | | | A | 0.994 | |
| **74** | f | rd | 30 | 28 | | B | 0.997 | | B | 0.996 | | A | 1.000 | |
| **75** | mf | dd | 30 | 21 | 10 | | | | | | | B | 0.999 | |

Differences between the deposits are significant. Best practice QAQC for a gold grade sampling programme producing a sound resource estimate (Dominy et al. 2020) is met by 65% of field replicates, 71% of crushed duplicates but only 39% of pulp duplicates. The Finnish study deposits are not included in those figures. The pulp duplicates are the weakest link in the process chain pointing to the influence of the nugget effect. All three Finnish study deposits are included in the best practice category, if Pampalo-Rämepuro and Juomasuo-Hangaslampi are defined as coarse-grained and Suurikuusikko as a fine-grained gold deposit.

The distributions of the correlation coefficients (r) and HARD values according to the three replicate-duplicate classes are displayed in Figures 64 to 66, with the Finnish study deposits presented for comparison. The median correlation coefficients are included in Table 41. In the medium and coarse grain-size classes, the correlation is better in the crushed duplicate than in the pulp duplicate class, in which the nugget effect could be a dominant factor. This is an exception in the general tendency for an increasing correlation with an increasing reduction in the sample grain size.

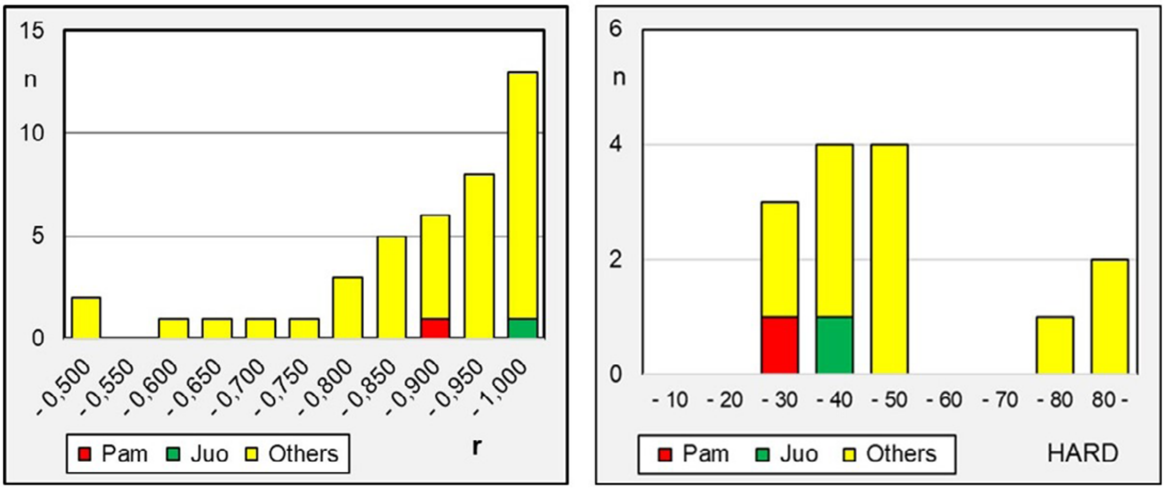



Fig. 64. The correlation distribution of field replicates according to the correlation coefficient (r) and half absolute relative difference (HARD) at the 90% cumulative confidence limit. All deposits with diamond drill core replicates (half or quarter core as replicate) are included with Pampalo (Pam) and Juomasuo (Juo) presented for comparison.

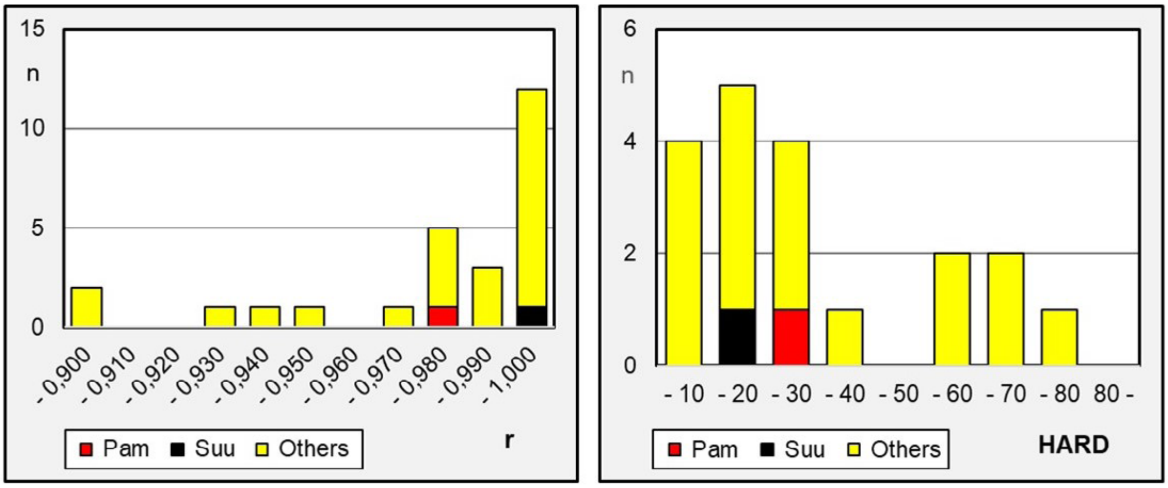



Fig. 65. The correlation distribution of coarse reject (crushed) duplicates according to the correlation coefficient (r) and half absolute relative difference (HARD) at the 90% cumulative confidence limit. All deposits are included, including rc- and other samples, with Pampalo (Pam) and Suurikuusikko (Suu) presented for comparison.

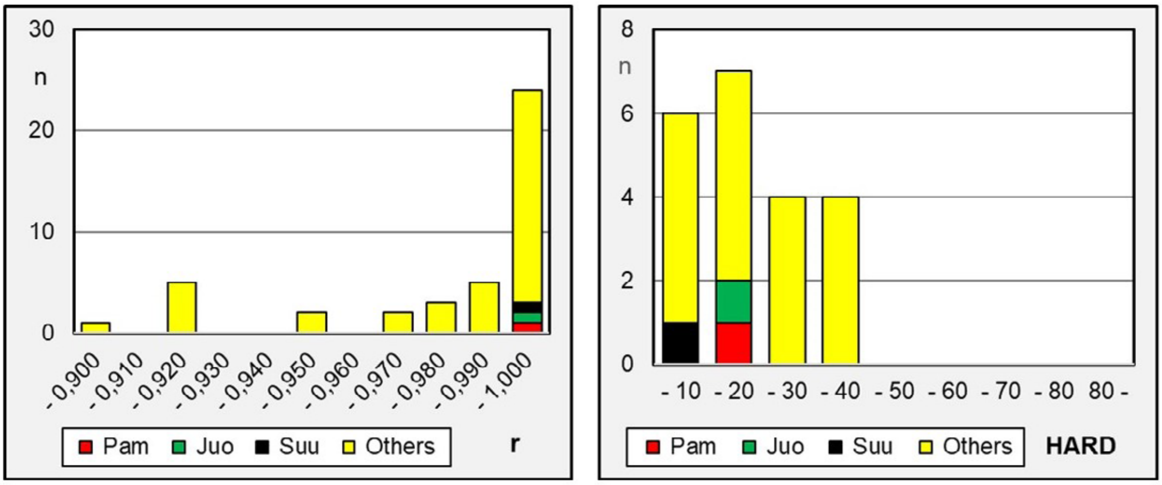



Fig. 66. The correlation distribution of pulp duplicates according to the correlation coefficient (r) and half absolute relative difference (HARD) at the 90% cumulative confidence limit. All deposits are included, with Pampalo (Pam), Juomasuo (Juo) and Suurikuusikko (Suu) presented for comparison.

Table 41. Median r values according to grain-size classes of the gold deposits in different replicate-duplicate classes with the study deposits presented for comparison. The coarsest classes (c and mc) were combined because of the small number of deposits.

| Gold grain size class | f | mf | m | c+mc | Pam | Juo | Suu |
|---|---|---|---|---|---|---|---|
| Field replicate | 0.940 | 0.845 | 0.856 | 0.760 | 0.891 | 0.975 | |
| Crushed duplicate | 0.996 | 0.989 | 0.980 | 0.990 | 0.973 | | 0.998 |
| Pulp duplicate | 0.999 | 0.992 | 0.905 | 0.947 | 0.993 | 0.999 | 0.999 |

The median HARD values of the replicate-duplicate classes in Figure 67 display a systematic increase in HARD values as a function of an increasing grain size of gold in all classes. Precision improves with decreasing gold grain size and possible nugget effect in the gold deposits. Both the correlation and HARD values of the study deposits are better than generally in the same gold grain-size class.

The nugget value in variography represents the correlation at a zero distance in a variogram. Thus, it should correlate with field replicates, which almost have a mutual zero distance, especially in the scale of a variogram. The correlation is clear, but not strong (r = 0.428). Nugget values typically differ greatly in separate variograms of a deposit and this difference depends a great deal on interpretation. Thus, this estimated nugget value is less accurate than the HARD values in a deposit. The distribution of nugget values is presented in Figure 68 and correlation coefficients in Table 42. Nugget values are also higher in the coarse gold deposits (median 42%) than in the fine-grained gold deposits (median 25%), as could be expected.

The gravity recovery data of the deposits included are incomplete. The recovery using gravity methods (mainly the Knelson concentrator or a shaking table) depends on whether it is a theoretical maximum recovery or economic recovery before flotation or cyanidation, and what the targeted gold grade of the concentrate is. The high values in the distribution of the collected gravity recoveries in Figure 68 are dominated by coarse grained gold deposits (median recovery 52%), compared to the medium-sized gold deposits (median recovery 32%). The correlation with HARD values of the duplicate samples is weak. A high gravity recovery should indicate a high nugget effect and HARD values in pulp duplicates. This would perhaps be the case with accurate and comparable gravity recovery data.

The HARD values correlate between the replicate-duplicate sets (Table 42), which is natural with the same material processed from field replicates to crushed duplicates and finally to pulp duplicates.

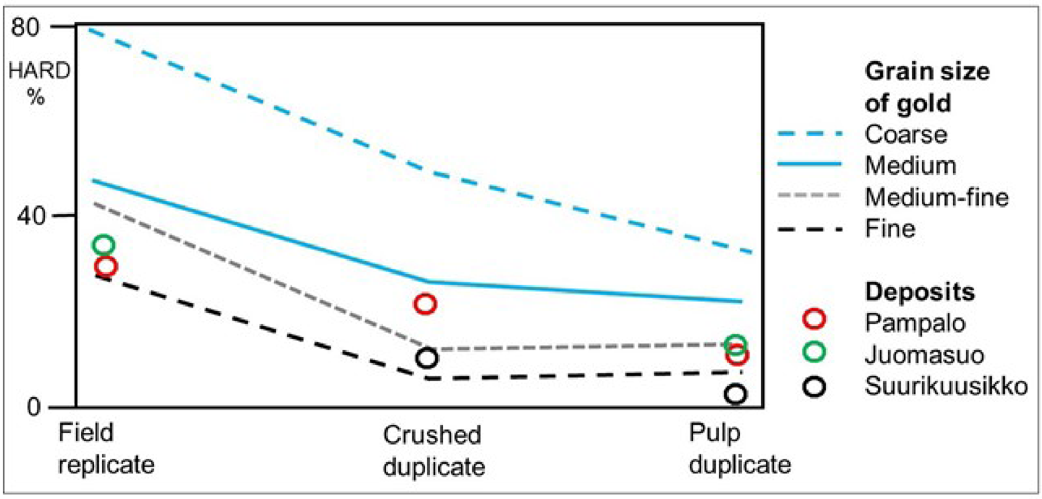



Fig. 67. Median HARD% value distribution according to grain size classes of the gold deposits in different replicate-duplicate classes with the Finnish study deposits included for comparison.

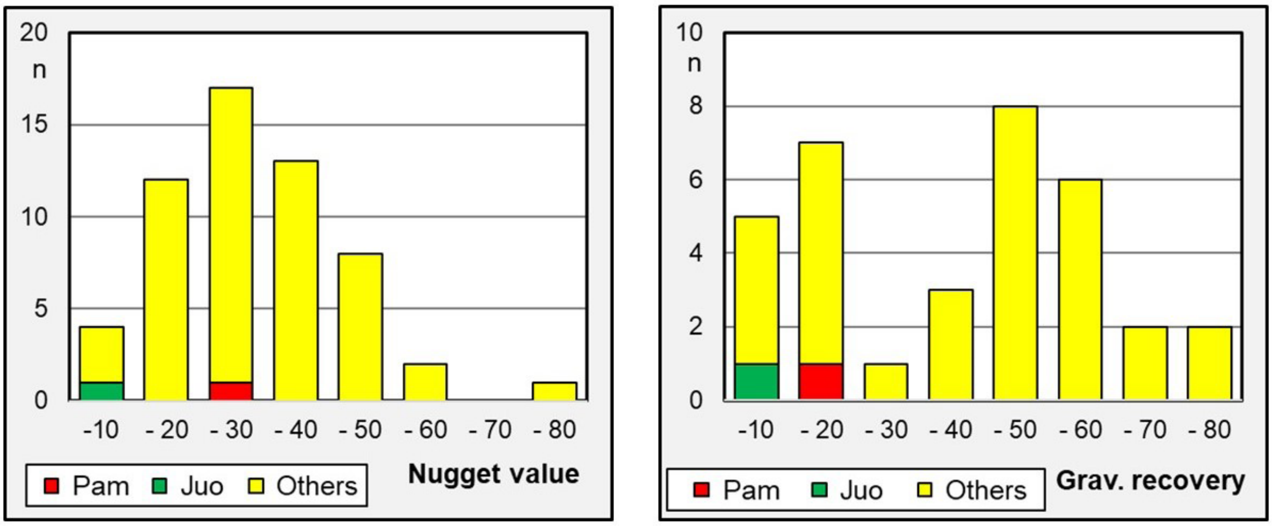



Fig. 68. Distribution of the nugget values (%) in variograms and the gravity recovery (%) with the values of Pampalo (Pam) and Juomasuo (Juo).

Table 42. Correlation of the nugget value, the gravity recovery and the HARD values of the replicate and duplicate classes of the gold deposits.

| | Field repl./ duplicate | Crushed duplicate | Pulp duplicate | Grav. recovery |
|---|---|---|---|---|
| **Nugget value** | 0.428 | -0.071 | 0.053 | 0.266 |
| **Grav. recovery** | -0.103 | 0.296 | 0.185 | |
| **Field repl./dupl.** | | 0.833 | 0.776 | |
| **Crushed duplicate** | | | 0.936 | |

The precision of bedrock replicates and duplicates of the Finnish study deposits in Ilomantsi, Kuusamo and Kittilä is generally similar to or better than in the comparison data of the gold deposits worldwide, indicating good quality in sampling, preparation and analysis.

## 6.2 Till

### 6.2.1 Comparison between the datasets

The five aliquots in one square of the till panels were found to differ from each other. It could be expected that large samples covering an area of 1 $m^2$ would have smoothed grades compared to the aliquots only covering an area of 0.01 $m^2$. Means and relative variances of gold and copper grades are calculated in Table 43. The mean gold grades are higher in the large and more representative CD aliquots than in small AB aliquots, except in Rämepuro, indicating that the large aliquots collect the few clusters of high gold grade, which the small aliquots seldom hit. However, the variances of the large aliquots (CD) are also higher than those of the small aliquots (AB). This is illogical, but understandable. Till probably contains a few high-grade spots in a low-grade background and small samples seldom hit those high-grade spots that are included in the large samples.

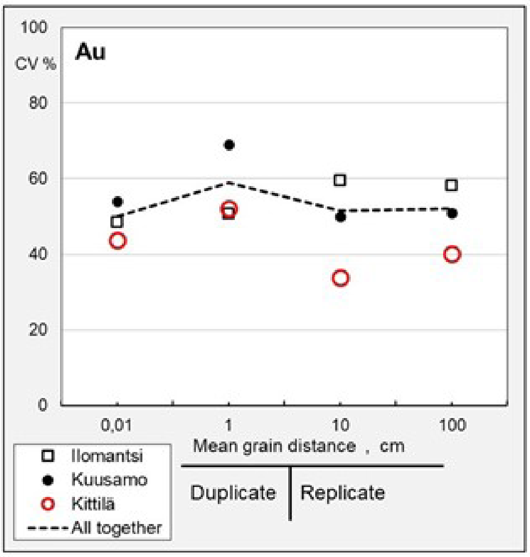
For the copper grades, both the means and relative variances have only small differences. The copper grades are low and variances in higher copper grades could be also larger. In a large replicate sampling test by GTK, the correlation between the primary and replicate samples was also good in high copper grades (Mäkinen 1995) indicating a homogeneous distribution of copper in till.

Table 43. Arithmetic means and relative variances ($\sigma^2$) of gold and copper grades in the till panels. A and B samples are combined as AB and C and D as CD.

| | Au | | | | Cu | | | |
|---|---|---|---|---|---|---|---|---|
| | AB | | CD | | AB | | CD | |
| | Mean | $\sigma^2$ | Mean | $\sigma^2$ | Mean | $\sigma^2$ | Mean | $\sigma^2$ |
| Pampalo | 5.7 | 0.45 | 9.7 | 0.35 | 16.9 | 0.022 | 17.7 | 0.004 |
| Rämepuro | 20.4 | 0.30 | 17.7 | 0.71 | 18.1 | 0.003 | 19.5 | 0.002 |
| Juomasuo | 3.1 | 0.89 | 6.4 | 1.24 | 19.4 | 0.020 | 17.2 | 0.016 |
| Hangaslampi | 2.2 | 0.08 | 4.8 | 1.13 | 23.5 | 0.009 | 21.7 | 0.009 |
| Kittilä | 4.8 | 0.17 | 6.6 | 0.33 | 54.2 | 0.006 | 50.6 | 0.009 |

The nugget and cluster effects in till can roughly be compared with bedrock samples. Exogenic processes, glacial erosion and deposition with pre- and postglacial weathering and re-mobilization have partly added and partly reduced natural precision (fundamental sampling error). Glacial erosion and transport produce more homogenized than sorted material, but in the depositional phase in water-rich conditions small scale sorting often occurs. This most strongly affects such heavy and small particles as gold grains.

Nugget and cluster effects and their proportion can be separately examined for each study area and by combining all the till panels of the five targets. Pampalo and Rämepuro are marked together as Ilomantsi and Juomasuo and Hangaslampi as Kuusamo. Four sample class pairs are selected, as for the rock samples, to represent various distances between gold grains in samples. The lowest variance should be between the sieved (-63 µm) fine fraction and its duplicates (sample pair D-E), marked as 0.01. The next sample-duplicate pair is the sieved -10 mm till fraction of a 1x1 m panel square (C-D), marked as 1. The third pair is the adjacent small sample pair of A-B, with a theoretical mean distance of 10 cm (marked as 10). The last pairs are



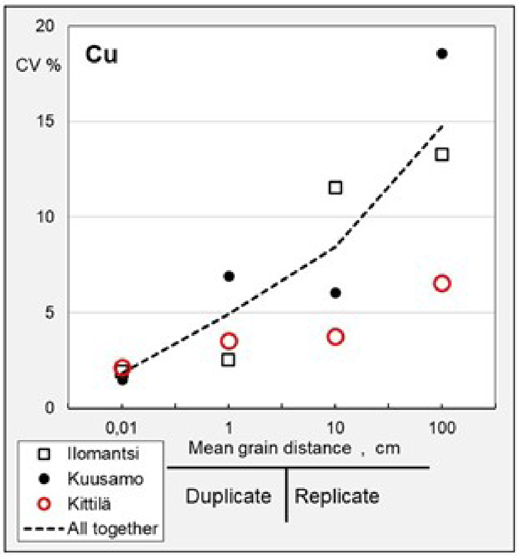




Fig. 69. Precision (as CV%) of gold and copper in the till sample types according to the study areas.

*Study areas:*
Ilomantsi: Pampalo + Rämepuro,
Kuusamo: Juomasuo + Hangaslampi, Kittilä,
All together: all the three targets combined,

*Mean grain distance (cm):*
0.01: splitting of the sieved (-63 µm) fraction, sample pairs D-E,
1: duplicate test of -10 mm fraction, sample pairs C-D,
10: replicate test of the primary sample pairs A-B,
100: replicate test of adjacent A-A and B-B samples both vertically and horizontally.

the small samples A–A and B–B of adjacent panel squares with a mean distance of 1 m (marked as 100). The calculated relative precision values (CV%) of gold and copper for the three targets and all combined are presented in Figure 69. The combined results of gold and other accompanied metals are collected in Table 44 and in Figure 70.

Two factors limit the interpretation of the results: the small number of samples in the test and the gold grade level, which is close to the detection limit (1 ppb). The precision (as CV%) of the duplicates of the finest fraction is about 50% and much higher than that of the rock pulp samples. This “pure nugget effect” is about 50% and is almost the same when increasing the distances between grains in till. The theoretical cluster effect is practically zero, which strongly differs from rock samples (Fig. 63). The precision of rock samples is dominated by the cluster effect at the sample distance of one metre, but in till samples the nugget effect dominates for all the sample types. Differences between the study areas are significant. Variations in the Kittilä panel are lower than in the other panels, perhaps partly reflecting the primary fine grain size of gold in the gold ore deposit.

Relative variation for the other metals in the combined data is very systematic (Table 44 and Fig. 70), which demonstrates the effectiveness of the method, and the completely different style of gold compared to the other investigated metals. The precision is much higher than the precision for gold and the distribution heterogeneity describes the precision instead of the nugget-cluster effect for gold. The correlation coefficient behaves similarly. Gold only correlates between A and B samples, while for the other metals, the high correlation decreases as a function of an increasing mean grain distance (mgd). Arsenic differs from the other metals having a weaker correlation than copper, cobalt and manganese.

Table 44. Precision (as CV%) and correlation coefficient (r) results for gold and other studied metals in sample combinations related to the mean grain distance (mgd). All the three targets and five till panels are combined in the data.

| | mgd | Panel | Au | Cu | As | Co | Mn |
|---|---|---|---|---|---|---|---|
| CV% | 0.01 | D E | 49.95 | 1.82 | 5.08 | 4.05 | 2.89 |
| | 1 | C D | 59.02 | 4.92 | 5.67 | 6.04 | 4.96 |
| | 10 | A B | 51.43 | 8.42 | 8.59 | 8.47 | 6.40 |
| | 100 | A-A + B-B | 52.16 | 14.72 | 14.64 | 16.24 | 12.75 |
| r | 0.01 | D E | 0.086 | 0.998 | 0.965 | 0.996 | 0.998 |
| | 1 | C D | 0.010 | 0.995 | 0.949 | 0.993 | 0.996 |
| | 10 | A B | 0.469 | 0.979 | 0.820 | 0.983 | 0.970 |
| | 100 | A-A + B-B | 0.365 | 0.944 | 0.456 | 0.919 | 0.901 |

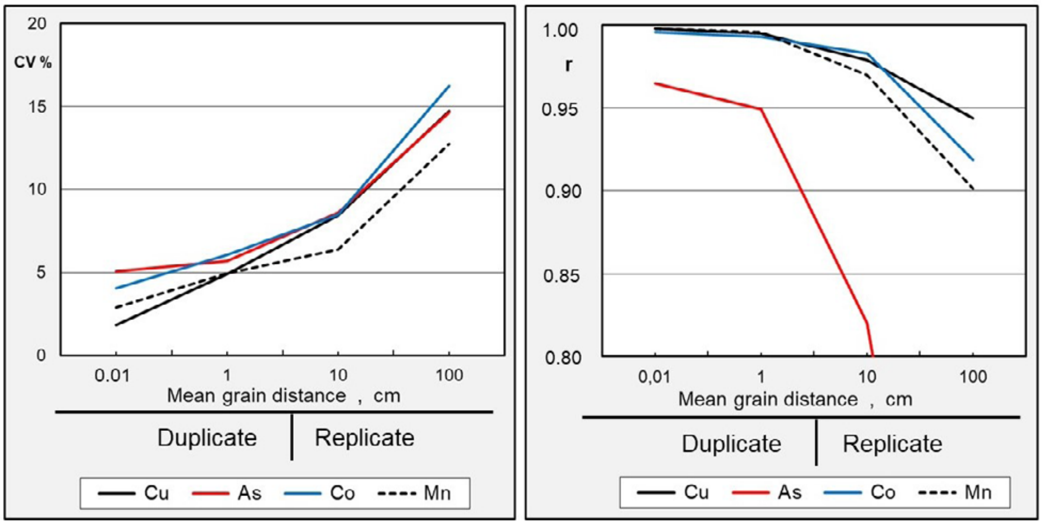



Fig. 70. Precision (CV%) and correlation coefficients (r) of copper, arsenic, cobalt and manganese in the till sample types of the combined data from the study areas.

The results indicate that the gold grade precision of till sampling is almost identical in all the tested sampling types and fractions. In the previous results of the replicate and duplicate sampling and analysis, no correlation existed between any sampling styles. When this is the case, it could be stated that it makes no difference how till is sampled, prepared or analysed, because the result is in any case a "coincidence". However, this is not the case. The natural precision is low, but each step in the procedure chain of sampling-analysis decreases the precision, if carried out incorrectly or un-professionally. Finally, the question is statistical: how many and how large samples are needed to find a positive gold indication in till and how can false anomalies be identified?

The mean, median and 95% confidence limit of gold grades in till in Finland, based on regional sampling by GTK, are 2.1 ppb, 0.9 ppb and 5.2 ppb respectively (Salminen 1995). Often, in practical exploration, a grade of 10 ppb is considered as a clear anomaly threshold. In the test panels, sample A and its replicate B have a "spotty" style representing a volume of less than one litre. Sample C and its duplicate (D) are large aliquots (10 l), collected evenly from an area of 1 m² representing a large volume. Gold grades of ≥10 ppb for these two types of targets are collected in Table 45.

Commonly, there are more anomalous grades in the large aliquots, except at Rämepuro. This supports the taking of large samples, which has also often been the practice in gold exploration. All these till panels were very close to a gold deposit, and to the south-east of a deposit predicting gold in till. The till panels did not extend to the bedrock surface, avoiding possible contamination by weathered bedrock that has possibly been mixed into the till. However, the panels also avoided the bottom layer of the till, with probably higher gold grades. Statistically, when taking only one sample, either small or large, only Rämepuro would be "discovered".

Table 45. Gold grades of ≥10 ppb in the test panels, as percentages, of all the samples in the group.

| Target | A+B | C+D |
|---|---|---|
| Juomasuo | 6 | 17 |
| Hangaslampi | 0 | 11 |
| Pampalo | 11 | 33 |
| Rämepuro | 83 | 50 |
| Kittilä | 6 | 11 |

The variance ratio, or F-factor, is often calculated to determine whether the variance within a sampling point (here a panel) is smaller than the variance between regional sampling points. As a "rule of thumb" this ratio should exceed 4.0 for sampling and analytical precision to be significantly smaller at the 95% confidence level (McCurdy & Garret 2016). Most of the F-factor values for gold are below four (Table 46), indicating uncertain interpretation of the regional analytical data for the fine fraction analysis of gold. The two ratio values of GTK are significantly different, but the ratio 2.72 can better be compared with the other areas having a similar regional sample grid distribution. The variance ratio of Kittilä is higher than the two others, slightly exceeding the ratio of four. The variance ratios (F-factors) of copper and arsenic are generally more than ten times higher than for gold, indicating reliable interpretation of the regional data for these elements.

Variances in the procedure chain of sampling–preparation–analysis can be estimated using the results of the till panels. The overall precision is the sum of variances of the fundamental sampling variance (error) (FE), preparation variance (PE), including

Table 46. Variance ratios (F) of regional samples / panel samples in the fine fraction analyses of gold, copper and arsenic in the different study areas.

| | Au | | Cu | | As | |
|---|---|---|---|---|---|---|
| | OM | GTK | OM | GTK | OM | GTK |
| Till / Ilomantsi | 2.46 | 2.72 / 21.62 | 33 | 62 | 84 | 156 |
| Till / Kuusamo | | 1.32 | | 23 | | |
| Till / Kittilä | | 5.65 | | 27 | | 37 |

delimitation, extraction, and other variances in preparation (Pitard 1993), and analytical variance (AE). The total overall variance (OE) is as follows:

$$OE = FE + PE + AE$$

and using variances ($\sigma^2$) and till panel sample indications (Fig. 17):

$$\sigma^2\ CC = \sigma^2\ FE + (\sigma^2\ CD - \sigma^2\ DE) + \sigma^2\ DE \quad \rightarrow$$
$$\sigma^2\ FE = \sigma^2\ CC - \sigma^2\ CD$$

In the till panels the overall variance (OE) could be either the adjacent CC- and DD-samples or AA- and BB-samples. Both represent a mean distance between samples of one meter, but differ in the sample sizes. The CD sample pairs are blind duplicate pairs of the sieved (-10 mm) fraction and DE duplicate pairs of the sieved (-63 µm) fine fraction representing laboratory duplicates. Preparation variance (PE) is $\sigma^2$ CD – $\sigma^2$ DE.

The estimated variance results for gold, copper and arsenic by targets are presented in Table 47. The variance distribution of gold completely differs from copper and arsenic. More than half of the total variance of gold is in the analysis and the remaining 20–30% in the combined phase of sampling (FE) and preparation (PE). For copper and arsenic, the fundamental sampling error (FE) is almost the same as the overall error (OE). Efforts at improving the

Table 47. Estimated relative variances of Au, Cu, As, Co and Mn as variance values (upper table) and percentages (lower table). Pampalo and Rämepuro are combined into Ilomantsi and Juomasuo and Hangaslampi into Kuusamo. Arsenic grades from Kuusamo are not included, because they are mainly below the detection limit.

*Abbreviations:*
FE = fundamental sampling variance,
PE = preparation variance,
AE = analytical variance and
OE = overall, total variance.

| | OE-type | FE | | PE | AE | OE |
|---|---|---|---|---|---|---|
| | | $\sigma^2$ FE × $10^{-}$ | $\sigma^2$ CD × $10^{-4}$ | $\sigma^2$ CD-DE × $10^{-4}$ | $\sigma^2$ DE × $10^{-4}$ | $\sigma^2$ OE × $10^{-4}$ |
| **Au** | AA+BB | 809 | 2593 | 233 | 2360 | 3402 |
| | CC | 490 | 2593 | 233 | 2360 | 3083 |
| **Cu** | AA+BB | 164.7 | 6.350 | 2.664 | 3.686 | 171.1 |
| | CC | 53.56 | 6.350 | 2.664 | 3.686 | 59.91 |
| **As** | AA+BB | 91.90 | 19.20 | 7.47 | 11.73 | 111.1 |
| | CC | 62.23 | 19.20 | 7.47 | 11.73 | 81.43 |
| **Co** | AA+BB | 426.6 | 17.75 | 6.23 | 11.52 | 444.4 |
| | CC | 226.2 | 17.75 | 6.23 | 11.52 | 244.0 |
| **Mn** | AA+BB | 71.46 | 12.63 | 2.48 | 10.15 | 84.09 |
| | CC | 55.35 | 12.63 | 2.48 | 10.15 | 67.95 |

| | Target | $\sigma^2$ FE % | $\sigma^2$ CD | $\sigma^2$ CD-DE % | $\sigma^2$ DE % | $\sigma^2$ OE % |
|---|---|---|---|---|---|---|
| **Au** | AA+BB | 23.8 | | 6.8 | 69.4 | 100 |
| | CC | 15.9 | | 7.6 | 76.5 | 100 |
| **Cu** | AA+BB | 96.2 | | 1.6 | 2.2 | 100 |
| | CC | 89.4 | | 4.4 | 6.2 | 100 |
| **As** | AA+BB | 82.7 | | 6.7 | 10.6 | 100 |
| | CC | 76.4 | | 9.2 | 14.4 | 100 |
| **Co** | AA+BB | 96.0 | | 1.4 | 2.6 | 100 |
| | CC | 92.7 | | 2.6 | 4.7 | 100 |
| **Mn** | AA+BB | 85.1 | | 2.9 | 12.0 | 100 |
| | CC | 81.5 | | 3.6 | 14.9 | 100 |

precision of copper and arsenic should be directed at sampling, but for gold it should be concentrated on the analysis.

To test the dominant effect of sampling variance generally, not only for copper and arsenic, two other common metals, cobalt and manganese were selected. The till panels of Pampalo and Rämepuro were combined as *Ilomantsi*, and Juomasuo and Hangaslampi were combined as *Kuusamo*. The variance distribution is similar as for copper and arsenic (Table 47). Most of the variance (75–95%) is in the sampling phase, whereas the analytical variance is small, mostly much smaller than the preparation variance. The precision of the base metals is strongly concentrated in the primary sampling phase, which should be considered in planning and executing till sampling programmes.

#### 6.2.2 Reference data from other studies

Most of the till sampling studies in Canada have included no or only minor replicate-duplicate testing results. A till study in British Columbia yielded quite similar variance ratio results (as F-factor) compared to the Finnish targets, being 4.0 for gold and 621 and 53 for copper (Plouffe & Ferbey 2016). Open file reports of the Geological Survey of Canada contain many replicate-duplicate tests in connection with the regional sampling data. Hundreds of reports had to be read, because some duplicate data mainly existed only in the younger reports, and in many reports, practically all gold grades were below the detection limit and then useless. In addition, many reports included no QAQC data, with comments such as "no problems with QAQC". The samples have mainly been collected with small spade or hand-auger from the B-horizon, and some from the C-horizon in the pozsol profile of till (Fig. 71). The primary sample weight has commonly been 0.5-1 kg. The samples have usually been sieved through -80 mesh (0.18 mm) or -150 mesh (0.10 mm), and sometimes pulverized after sieving. The analytical sample size has varied from 20 g to 50 g, mostly being 30 g. The detection limit in the studies has varied from 0.1 to 5 ppb, and 30% of the results, at minimum, had to be above the detection limit to be included in this reference data test by the author. The number of samples had to be 150 at minimum. The duplicate tests were subdivided into field replicate (duplicate) and laboratory pulp or sieved fraction re-analysis. Field replicates were sampled from the same hole or very close to the primary sample with similar qualities.

Two analytical groups were identified. In the first group samples were processed using the fire assay, with four acid or aqua regia leaching followed by AAS or ICP analysis. The analytical laboratories were large Canadian laboratories, and the primary and duplicate samples were analysed by the same laboratory and using the same method. These results represent "total gold" and can be compared with the analyses of the Finnish study cases. Copper results were collected for comparison. Copper was analysed by aqua regia leaching, commonly using a 0.5 g sample weight and followed by ICP analysis.

Fig. 71. Typical brown B-horizon in Canadian surface till sampling (from Carscallen 2009).

In the second analytical group, the method was the Mobile Metal Ions Process (MMI), for which the SGS laboratory was the sole provider in Canada. The target elements, here gold and copper, were extracted using weak solutions of organic and inorganic compounds. The MMI extractants have been designed to both detach adsorbed ions reproducibly and provide an analytical medium for reproducible low-level analysis in ICPMS instruments. Typically, less than 10% of the total metal content of a soil sample is adsorbed and used for MMI analysis (Fedikow 2018). However, despite the lower detection limits (commonly 0.1 ppb for gold), many or almost all of the MMI results are below the detection limit and were thus unsuitable for this statistical analysis.

The author collected and processed the analytical data directly from the primary laboratory certificates and calculated the precision, correlation coefficients and F-values of 51 till sampling programmes in Ontario. The names of the projects are listed in Table 48 and the results are presented in Tables 49 for gold and 50 for copper.

Table 48. Projects and references with indication numbers, subdivided to FA/acid leaching and MMI analytical procedures.

*FA*

1 Powell Property, Douglas et al. 1989,
2 Opeepeesway Lake, Brenton 1992,
3 Hackl Property, Dillman 1995,
4 Renabie-Missanable Area Properties, Brown 1997,
5 Hematite Hill, Bowdidge 1998,
6 McKewan Project, Fekete & Castonguay 1998,
7 Wawa Properties, Archibald 1998,
8 Tannahill Project, Keast 1999,
9 Benton TWP, Lashbrook 2000,
10 Langdon Gold Property, Bowdidge 2001,
11 Matachewan, 2002 East Grid, Zalnieriunas 2004a,
12 Matachewan, 2003 Oka Grid, Zalnieriunas 2004b,
13 Smoke Lake Property, MacLachlan & Londry 2004,
14 Sungold Property, Hoy 2004,
15 Chartre-Dufresne Property, Burden 2005,
16 Hotstone, Gibson 2006,
17 Merico-Ethel Property, Kettles et al. 2006,
18 Goldcreek Property, Scodnick 2008,
19 Carscallen Property, Goodwin 2009,
20 Abitibi West and Mortimer Properties, Salo 2010,
21 Sky Lake Property, Canam et al. 2010,
22 West Shebandowan IOCG Property, Keogh 2010,
23 Hemlo North Property, Marsh 2011,
24 Leeson-Brackin Property, Troup 2011,
25 Goldlund Project, Fingas 2012,
26 Lincoln-Nipissing Property, Eckfeldt & Madsen 2013,
27 Off Lake Property, Buck 2013,
28 Watershed Property, Ronacher 2014,
29 St. Andrew Goldfields, McKenzie 2015,
30 TME/Arimathaea East Property, Roach 2016,
31 Boyer Lake, Ross 2017,
32 Kir Vit Project, Boucher 2017,
33 Borden Area, Shultis 2018,
34 Junior Lake Property, Johnson 2019,
35 McKinnon Deposit, Sutcliffe 2019,
36 Pen Gold Project, Chouinard et al. 2020,

*MMI*

37 Gullrock Project, Hughes 2001,
38 Magusi Property, Troup 2001,
39 Ranger Township, Hobbs 2001,
40 Birch-Uchi Project, Lee 2003,
41 Horseshoe Island Property, Smith 2007,
42 Alcock Base Property, Fedikow 2009,
43 Carscallen Property, Goodwin 2009,
44 Goldpines North Property, Render et al. 2010,
45 King Solomon´s Pillars Property, Therriault 2010,
46 Byshe Township, Laidlaw 2011,
47 Blakelock Project, Byrnes 2012,
48 Cameron Gold Project, Cooper 2015,
49 Cree Lake Property, Fedikow 2017,
50 Nova Property, Fedikow 2018,
51 Van Horne Project, Carr & Baker 2018

Table 49. Precision of field replicates/duplicates, laboratory pulp duplicates and regional samples for gold as CV%, correlation coefficients (r) and F-values.

n = number of samples / sample pairs,
$F_F$ = variance of regional gold grades / variance of paired field replicates,
$F_L$ = variance of regional gold grades / variance of paired laboratory pulp duplicates,
Ref. 1–36 analysed by FA+AAS/ICP,
Ref. 37–51 analysed by MMI,
Bold F numbers indicate F-value <4.

| Au | Field replicates | | | Pulp duplicates | | | Reg. samples | | F | |
|---|---|---|---|---|---|---|---|---|---|---|
| Ref. | n | CV% | r | n | CV% | r | n | CV% | $F_F$ | $F_L$ |
| 1 | | | | 193 | 39.3 | 0.979 | 1 789 | 76.2 | | **3.8** |
| 2 | | | | 57 | 22.7 | 0.964 | 453 | 73.7 | | 10.6 |
| 3 | | | | 41 | 40.1 | 1.000 | 532 | 146.9 | | 13.4 |
| 4 | | | | 28 | 39.0 | 0.710 | 291 | 74.4 | | **3.6** |
| 5 | | | | 30 | 29.9 | 0.996 | 258 | 91.2 | | 9.3 |
| 6 | | | | 38 | 28.2 | 0.999 | 259 | 77.3 | | 7.5 |
| 7 | | | | 38 | 46.3 | 0.842 | 374 | 98.5 | | 4.5 |
| 8 | | | | 158 | 42.7 | 0.984 | 1 278 | 65.5 | | **2.4** |
| 9 | | | | 33 | 31.1 | 0.702 | 200 | 55.8 | | **3.2** |
| 10 | | | | 34 | 61.1 | 0.719 | 582 | 107.6 | | **3.1** |
| 11 | 55 | 53.9 | 0.813 | 109 | 34.8 | 0.975 | 1 273 | 77.0 | **2.0** | 4.9 |
| 12 | 64 | 67.3 | -0.063 | 99 | 28.9 | 0.999 | 1 539 | 88.2 | **1.7** | 9.4 |
| 13 | | | | 61 | 42.1 | 0.952 | 662 | 108.6 | | 6.7 |
| 14 | | | | 64 | 36.4 | 0.634 | 654 | 61.0 | | **2.4** |
| 15 | 31 | 50.1 | -0.072 | | | | 1 344 | 278.3 | 30.9 | |
| 16 | | | | 29 | 41.8 | 0.961 | 389 | 87.5 | | 4.4 |
| 17 | | | | 12 | 66.2 | 0.855 | 179 | 66.0 | | **1.0** |
| 18 | | | | 299 | 45.0 | 0.795 | 3 077 | 91.2 | | 4.1 |
| 19 | 12 | 84.1 | 0.304 | | | | 227 | 182.8 | 4.7 | |
| 20 | | | | 34 | 61.1 | 0.719 | 582 | 107.6 | | **3.1** |
| 21 | | | | 21 | 46.8 | 0.994 | 322 | 106.9 | | 5.2 |
| 22 | | | | 120 | 47.2 | 0.204 | 1 279 | 75.1 | | **2.5** |
| 23 | | | | 16 | 59.6 | 0.299 | 300 | 102.4 | | **2.9** |
| 24 | | | | 31 | 27.3 | 0.999 | 374 | 119.5 | | 19.1 |
| 25 | | | | 83 | 49.4 | 0.749 | 846 | 112.1 | | 5.2 |
| 26 | 108 | 62.6 | 0.093 | | | | 2 625 | 98.0 | **2.4** | |
| 27 | 35 | 56.2 | 0.076 | | | | 944 | 127.8 | 5.2 | |
| 28 | | | | 62 | 51.7 | 0.037 | 1 450 | 177.8 | | 11.8 |
| 29 | | | | 117 | 48.2 | 0.414 | 1 816 | 120.5 | | 6.2 |
| 30 | | | | 66 | 44.2 | 0.297 | 791 | 69.3 | | **2.5** |
| 31 | | | | 11 | 58.3 | 0.009 | 139 | 59.6 | | **1.0** |
| 32 | 35 | 55.7 | 0.123 | | | | 669 | 79.0 | **2.0** | |
| 33 | | | | 67 | 52.1 | 0.562 | 2 304 | 123.9 | | 5.7 |
| 34 | 44 | 52.9 | 0.861 | | | | 1 041 | 79.0 | **2.2** | |

Table 49. Cont.

| Au | Field replicates | | | Pulp duplicates | | | Reg. samples | | F | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Ref.** | **n** | **CV%** | **r** | **n** | **CV%** | **r** | **n** | **CV%** | **$F_F$** | **$F_L$** |
| **35** | | | | 21 | 21.3 | 0.634 | 234 | 39.9 | | **3.5** |
| **36** | | | | 14 | 76.6 | 0.522 | 466 | 161.3 | | 4.4 |
| **37** | | | | 128 | 40.7 | 0.999 | 1 480 | 146.0 | | 12.9 |
| **38** | | | | 35 | 36.8 | 0.360 | 407 | 60.9 | | **2.7** |
| **39** | | | | 35 | 35.0 | 0.915 | 399 | 68.7 | | **3.9** |
| **40** | | | | 18 | 6.9 | 0.973 | 194 | 74.9 | | 118.5 |
| **41** | | | | 29 | 25.0 | 0.979 | 324 | 103.0 | | 17.0 |
| **42** | 16 | 33.3 | 0.544 | 33 | 24.6 | 0.661 | 386 | 109.3 | 10.8 | 19.8 |
| **43** | | | | 21 | 50.3 | 0.782 | 255 | 232.0 | | 21.3 |
| **44** | | | | 171 | 31.6 | 0.837 | 1 979 | 71.6 | | 5.1 |
| **45** | | | | 62 | 34.8 | 0.999 | 729 | 168.4 | | 23.4 |
| **46** | | | | 24 | 42.1 | 0.418 | 278 | 48.8 | | **1.3** |
| **47** | 11 | 41.1 | 0.393 | 48 | 32.8 | 0.358 | 573 | 30.6 | **0.6** | **0.9** |
| **48** | | | | 267 | 31.2 | 0.895 | 3 721 | 86.0 | | 7.6 |
| **49** | 12 | 42.6 | 0.096 | 49 | 38.5 | 0.905 | 793 | 184.9 | 18.8 | 23.1 |
| **50** | | | | 18 | 35.4 | 0.952 | 222 | 160.0 | | 20.4 |
| **51** | 8 | 56.0 | 0.929 | 52 | 41.5 | 0.806 | 783 | 73.3 | **1.7** | **3.2** |
| **Ilo** | 36 | 59.2 | -0.199 | 18 | 48.6 | 0.032 | 544 | 93.3 | **2.5** | **3.7** |
| **Kuu** | 24 | 83.6 | -0.008 | 18 | 54.0 | 0.902 | 2 273 | 130.8 | **2.4** | 5.9 |
| **Kit** | 12 | 34.6 | -0.168 | 9 | 43.8 | -0.025 | 1 020 | 111.4 | 10.4 | 6.5 |

Table 50. Precision of field replicates/duplicates, laboratory pulp duplicates and regional samples for copper as CV%, correlation coefficients (r) and F-values.

n = number of samples / sample pairs,
$F_F$ = variance of regional copper grades / variance of paired field replicates,
$F_L$ = variance of regional copper grades / variance of paired pulp duplicates,
Ref. 4-36 analysed by FA+AAS/ICP,
Ref. 39-51 analysed by MMI.

| Cu Ref. | Field replicates | | | Pulp duplicates | | | Reg. samples | | F | |
|---|---|---|---|---|---|---|---|---|---|---|
| | n | CV% | r | n | CV% | r | n | CV% | $F_F$ | $F_L$ |
| **4** | | | | 26 | 9.1 | 0.995 | 291 | 85.4 | | 89 |
| **13** | | | | 59 | 7.9 | 0.999 | 634 | 95.0 | | 144 |
| **14** | | | | 71 | 23.4 | 0.705 | 701 | 56.3 | | 6 |
| **18** | | | | 97 | 7.8 | 0.997 | 971 | 61.1 | | 82 |
| **20** | | | | 34 | 3.8 | 0.998 | 582 | 71.2 | | 357 |
| **21** | | | | 21 | 3.4 | 0.993 | 322 | 72.4 | | 441 |
| **23** | | | | 7 | 5.7 | 0.994 | 305 | 89.5 | | 248 |
| **24** | | | | 33 | 5.7 | 0.996 | 374 | 67.2 | | 138 |
| **27** | 36 | 19.7 | 0.978 | | | | 928 | 70.0 | 13 | |
| **28** | | | | 62 | 15.1 | 0.993 | 1 450 | 123.2 | | 67 |
| **29** | | | | 66 | 15.3 | 0.972 | 1 786 | 66.0 | | 19 |
| **30** | | | | 49 | 4.7 | 0.991 | 753 | 47.3 | | 102 |
| **31** | | | | 9 | 3.1 | 0.994 | 140 | 33.9 | | 122 |
| **32** | 35 | 31.6 | 0.623 | | | | 669 | 41.3 | **1.7** | |
| **33** | | | | 69 | 4.7 | 0.999 | 2 304 | 123.9 | | 695 |
| **34** | 44 | 23.3 | 0.982 | | | | 1 041 | 85.5 | 14 | |
| **36** | | | | 14 | 4.0 | 0.997 | 467 | 56.5 | | 197 |
| **39** | | | | 35 | 5.9 | 0.998 | 399 | 50.6 | | 73 |
| **41** | | | | 29 | 14.7 | 0.959 | 324 | 157.9 | | 116 |
| **42** | 16 | 57.3 | 0.544 | 33 | 25.6 | 0.755 | 386 | 77.9 | **1.9** | 9 |
| **45** | | | | 62 | 9.0 | 0.984 | 729 | 69.4 | | 59 |
| **46** | | | | 24 | 13.3 | 0.960 | 278 | 59.1 | | 13 |
| **47** | 11 | 6.4 | 0.993 | 48 | 8.8 | 0.979 | 573 | 87.4 | 189 | 100 |
| **48** | | | | 267 | 8.2 | 0.985 | 3 721 | 97.6 | | 140 |
| **49** | 12 | 36.2 | 0.928 | 49 | 9.7 | 0.965 | 793 | 188.8 | 27 | 380 |
| **50** | | | | 16 | 10.0 | 0.998 | 222 | 163.7 | | 268 |
| **51** | 8 | 26.9 | 0.909 | 52 | 7.9 | 0.996 | 783 | 67.3 | 6 | 63 |
| **Ilo** | 36 | 8.2 | 0.801 | 18 | 1.9 | 0.934 | 222 | 78.7 | 92 | 1716 |
| **Kuu** | 24 | 15.3 | 0.364 | 18 | 1.5 | 0.993 | 1 848 | 67.1 | 19 | 2001 |
| **Kit** | 12 | 8.1 | 0.573 | 9 | 2.1 | 0.973 | 526 | 52.0 | 41 | 613 |

The projects differed in the sampling area and till quality, number of samples, analytical laboratory and method. The reported gold grades were commonly close to the detection limit and the number of samples in many projects was too small for a statistically reliable interpretation. Relatively poor precision is predicted at concentrations near the lower detection limit, but precision improves as concentrations increase to an optimum level for the instrument being used, and then falls off at the upper limit of concentration that the instrument is capable of measuring (Fletcher 1981). Thus, it is natural that the results also differ great deal. Duplicate variation would probably be much smaller at the optimum gold grade level of tens to hundreds of ppb. However, many interesting observations can be made. In paired data, the precision (CV%) should increase, when grades are normally distributed. In some cases, poor precision is connected to a high correlation, when one or two high-grade sample pairs strongly affect the correlation coefficient. The F-factor is essential in assessing the confidence of a test. As a "rule of thumb" this ratio should be >4.0 for sampling and analytical errors to be significantly smaller at the 95% confidence level (McCurdy & Garret 2016). F-factor values lower than four are marked as bold in the Tables 49 and 50. About half of the F-values for gold are below four, indicating caution in the interpretation of regional gold results. Median values in Table 49 indicate the small but clear difference between "total" gold and MMI gold. The duplicate precision of the tests using MMI technology should be much better than in conventional "total" leaching analysis because of the absence of the nugget effect. However, the results yielded by MMI are only slightly better than by FA-acid analysis. The weak leaching by MMI might include some factors that increase variation. The median values for precision and the F-factor in Table 51 demonstrate the small difference between the analytical methods and again the major difference between gold and copper.

Distribution of F-factors is illustrated in Figures 72 for gold and 73 for copper. The Finnish study areas have quite a similar distribution compared to the Canadian cases, both for gold and copper. Most of the Canadian samples are from the B-horizon of till and the Finnish ones from the C-horizon. The former horizon is more strongly influenced by later precipitation processes, compared to the C-horizon with a more primary glaciogenic origin. Despite these differences. the variance factors are quite similar. About half of the gold results of the F-factor statistics, both in Canada and Finland, are below the "reliability limit" of four, indicating problems and caution in regional interpretation of gold grades. Respectively only two studies in F-statistics of copper in Canada are below the limit four and all the Finnish cases are clearly above the limit, indicating the significant precision difference between gold and copper grades in till.

Table 51. Median values of precision as CV% and and F-factor of gold and copper, separately for FA-acid+AAS/ICP and MMI analysis.

| Precision CV% | Au | | | | Cu | | | |
|---|---|---|---|---|---|---|---|---|
| | FA | | MMI | | FA | | MMI | |
| | n | CV% | n | CV% | n | CV% | n | CV% |
| **Regional samples** | 36 | 89 | 15 | 86 | 16 | 71 | 10 | 83 |
| **Field replicates** | 8 | 56 | 4 | 42 | 3 | 23 | 4 | 31 |
| **Lab. duplicates** | 30 | 42 | 15 | 35 | 30 | 6 | 10 | 9 |

| F-factor | Au | | | | Cu | | | |
|---|---|---|---|---|---|---|---|---|
| | FA | | MMI | | FA | | MMI | |
| | n | F | n | F | n | F | n | F |
| **Reg. / Field** $\sigma^2_R / \sigma^2_L$ | 8 | 2.3 | 4 | 6.3 | 3 | 13 | 4 | 17 |
| **Reg. / Lab.** $\sigma^2_R / \sigma^2_L$ | 30 | 4.4 | 15 | 12.9 | 13 | 122 | 10 | 86 |

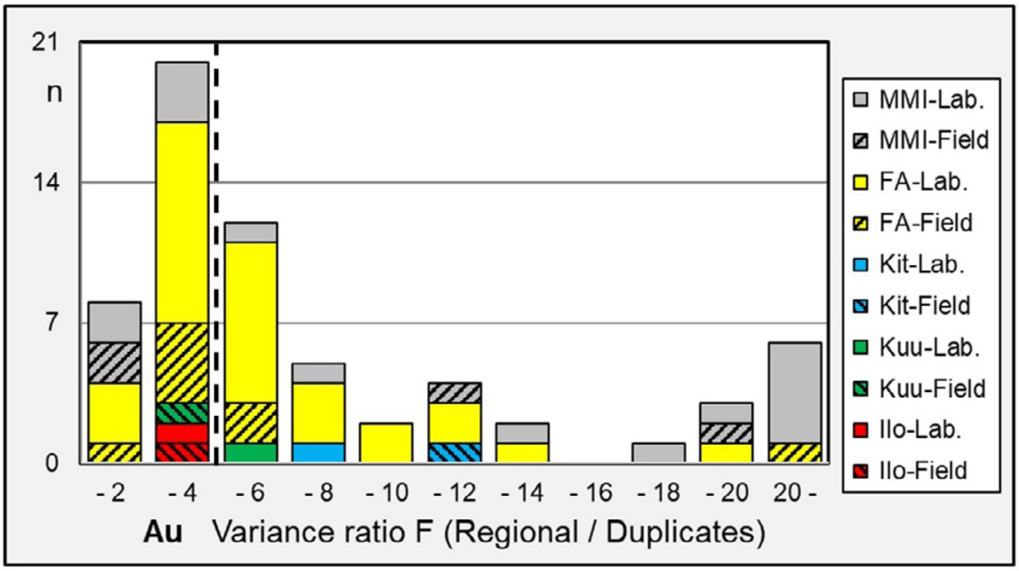



Fig. 72. Variance ratio (F-factor) distribution of gold, subdivided into field and laboratory duplicates and according to the analytical method (FA/MMI). Variance ratios of Ilomantsi (Ilo), Kuusamo (Kuu) and Kittilä (Kit) are also included. The dashed line at F = 4 indicates the "reliability line", under which the regional results are difficult to interpret.

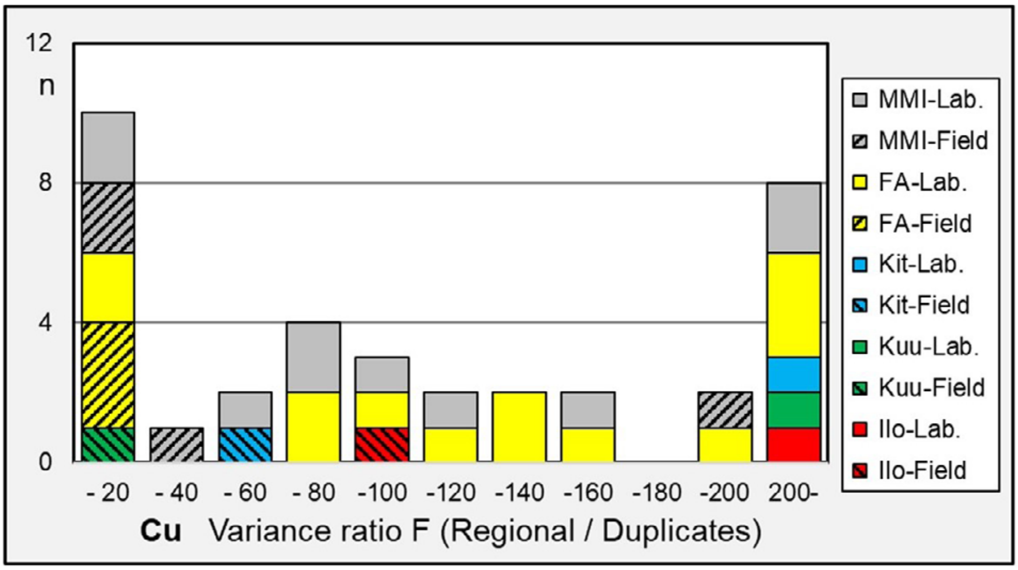



Fig. 73. Variance ratio (F) distribution of copper, subdivided into field and laboratory duplicates and according to the analytical method (FA/MMI). Variance ratios of Ilomantsi (Ilo), Kuusamo (Kuu) and Kittilä (Kit) are also included.

The Geological Survey of Newfoundland and Labrador has carried out systematic regional surface till sampling over many years in eastern Canada. The samples have been taken from a depth of 0.5-1.0 m (C- or BC-horizon) and the sample size has been 1 kg. Approximately 5-10% of the sampling sites were re-sampled to provide a field duplicate (replicate). The sieved fraction of –180 μm was analysed both by induced neutron activation analysis (INAA) using a sample weight of 24 g and by inductively-coupled plasma optical emission spectrometry (ICP-OES) after four acid digestion with a sample weight of 0.5 g. Laboratory duplicates of the -180 μm fraction were also analysed. The analytical and field precision of the sample pairs were estimated either with the Pearson correlation coefficient (r) or the overall estimation error as percentages using ±95% confidence limit (Thompson & Howarth 1978, Pitard 1993). The precision of gold, arsenic and copper is collected in Table 52 with similar data from Ilomantsi (Pampalo and Rämepuro compined), Kuusamo (Juomasuo and Hangaslampi combined) and Kittilä. The correlation coefficients were calculated between adjacent C-samples (CC, field duplicate / replicate) and laboratory duplicates of the -63 µm fraction (DE, analytical duplicate).

The poor precision of gold can be seen in Table 52. In some Canadian results, the precision of analytical duplicates is worse than that of field duplicates. Theoretically this should not be possible, because the analytical precision is only one part of the overall field precision. The gold grades are mostly close to the detection limit of 1 ppb and precision does not consider the variability in relation to the concentration level. These two factors together with the small number of duplicate sample pairs, could explain these random and "erratic" results. A similar phenomenon commonly also exists with the gold results from the till panels of Ilomantsi, Kuusamo and Kittilä, but should not be the case with a large data set. Many of the correlation coefficients are higher in data from the Canadian studies than from the Finnish test panels. The reason for the high analytical correlation of Kuusamo is one abnormally high sample pair in Juomasuo. The gold grades correlate very weakly at most or not at all with other elements in these Canadian cases. Very poor precision was also noted in a large study of stream sediment duplicates consisting of 1600 samples (Amor et al. 2014).

Precision for arsenic and copper grades is much better than for gold. This was also noticed in the Martiniére Property in Québec, where the correlation of field duplicates of till was 0.62 for Au and 0.90 for Cu (Voordouw & Perk 2015). The overall field precision for As and Cu is clearly lower than the analytical precision in the tests. It includes variances in sampling, preparation and analysis. Precision at Ilomantsi and Kittilä in terms of correlation coefficients for As and Cu is lower than in the same type of Canadian examples. The reason for this is the very narrow grade scale for both arsenic and copper in the Finnish targets. Laboratory precision can have a dominant role, when the replicate or duplicate results are low and very close to the primary results, leading to random correlation.

Table 52. Analytical (Anal.) and overall field duplicate (Field) precision of gold, arsenic and copper in eastern Canada in studies by the Geological Survey of Newfoundland and Labrador compared to the results from Ilomantsi (Ilo.), Kuusamo (Kuu.) and Kittilä (Kit). References: 1. Organ & Amor 2017a, 2. Organ & Amor 2017b, 3. Brushett & Amor 2016, 4. Brushett 2012, 5. Brushett 2011, 6. Batterson & Taylor 2009, 7. Smith et al. 2009, 8. McCuaig et al. 2006.

Pr%: overall precision (estimation error with ±95% confidence limit).

| Ref. | Item | Number of pairs | Au Anal. | INAA Field | As Anal. | ICP Field | Cu Anal. | ICP Field |
|---|---|---|---|---|---|---|---|---|
| **1** | Pr% | 44 | 188.9 | 160.7 | 67.8 | 74.4 | 20.4 | 50.1 |
| **2** | Pr% | 51 | 146.6 | 176.8 | 14.5 | 127.3 | 21.4 | 71.0 |
| **3** | Pr% | 39 | 158.2 | 185.8 | 7.1 | 107.5 | 18.7 | 87.9 |
| **4** | r | 30 | 0.208 | -0.025 | 0.964 | 0.945 | 0.929 | 0.832 |
| **5** | r | 30 | -0.025 | | 0.945 | | 0.832 | |
| **6** | r | 56/38 | 0.352 | 0.886 | 0.995 | 0.694 | 1.000 | 0.937 |
| **7** | r | 65 | 0.105 | 0.543 | 0.998 | 0.862 | 0.995 | 0.780 |
| **8** | r | 11/16 | 0.356 | 0.552 | 1.000 | 0.782 | 0.999 | 0.778 |
| | | | | | | | | |
| **Ilo.** | r | 18/36 | 0.032 | -0.199 | 0.930 | 0.534 | 0.934 | 0.801 |
| **Kuu.** | r | 18/24 | 0.902 | -0.008 | | | 0.993 | 0.364 |
| **Kit.** | r | 9/12 | -0.025 | -0.168 | 0.731 | 0.132 | 0.973 | 0.507 |

### 6.3 Precision of gold in bedrock and till samples

The precision of gold in the bedrock and till samples can be compared using the variances. The variance of the grid drilling results in bedrock and the variance of a metre sampling distance between adjacent A- and B-samples in till, are defined as $\sigma^2$ OE (over all or total variance). The analytical variance of the pulp samples in bedrock and the fine fraction in till is the second pair of comparison, defined as the analytical variance ($\sigma^2$ AE, Table 53). The preparation variance ($\sigma^2$ PE) is the difference between the crushed rock variance and pulp variance for bedrock samples and the difference between the duplicate variance ($\sigma^2$ CD) and analytical variance ($\sigma^2$ AE). Then, the fundamental sampling variance ($\sigma^2$ FE) is:

$$\sigma^2 \text{ FE} = \sigma^2 \text{ OE} - \sigma^2 \text{ PE} - \sigma^2 \text{ AE}$$

Only the Pampalo data sets for bedrock and till samples were complete enough for comparison. The variances of gold, and their distribution as percentages are presented in Table 53.

The total variance (OE) is almost the same for the bedrock and till data, as well as the preparation variance (PE). Most of the variance of the bedrock data is concentrated in the fundamental sampling variance, which represents the cluster effect. On the contrary, the analytical variance (AE) is dominant in the till samples, pointing to the nugget effect. This can also be seen by using relative precision values (CV%) in Figures 63 and 69. The use of variances allows a direct comparison of the data sets. The weakest point of an individual sample in the sampling of bedrock, in the procedure of sampling–analysis, is the sampling phase, with a significant cluster effect. Respectively, in till sampling, gold analysis is the weak point, with a large nugget effect. The sampling and preparation methods are different, but they do not explain such a large difference. Differences exist in the preparation of the fine fractions. With rock samples, they are pulverized, whereas till samples are sieved. Pulverization of the sieved fine fractions of till, before the final splitting, would probably reduce the analytical variance. The dominance of analytical variance in the total variance for the till samples partly explains the missing correlation of replicate and duplicate aliquots in section 5. Qualified preparation and splitting in a laboratory are extremely important.

Table 53. Estimated relative variances as variance values and percentages at Pampalo also including the Rämepuro data.

*Abbreviations:*
OE = overall, total variance,
FE = fundamental sampling variance,
PE = preparation variance,
AE = analytical variance.

| | Bedrock | | Till | |
|---|---|---|---|---|
| | $\sigma^2 \times 10^{-4}$ | % | $\sigma^2 \times 10^{-4}$ | % |
| OE | 3856 | 100.0 | 3402 | 100 |
| FE | 2889 | 85.1 | 809 | 23.8 |
| PE | 266 | 6.9 | 233 | 6.8 |
| AE | 310 | 8.0 | 2360 | 69.4 |

### 6.4 Effects of the primary grain size of gold

The primary grain size differs between the target deposits. It is difficult to give an absolute mean grain size, because the grain size distribution is commonly large, and the form of grains also affects the theoretical mean grade size. The following estimate (Table 54) is based on available mineralogical reports. The weighted mean size is the gold grain size under which the mass of gold is equal to the mass above it. The gravimetric recovery is the percentage of the total recovery, achieved by gravimetric methods, in practice by using a shaking table or Knelson concentrator. Gravity concentration is commonly followed by flotation and then the gravity concentration recovery is not maximized, because the best possible total recovery and concentrate grades are the targets. For this reason, the lower grain size limit for gold in the gravity concentrate is typically about 50 µm, although it could be slightly lower.

The analytical variance, which describes the constant nugget effect in analysis of the pulp fraction of bedrock samples (Fig. 63), correlates with the grain size of gold in the deposits. Both mineralogical studies on the grain size of gold and analyses of the pulverized fraction of the drill cores use the same material without mixing or contamination. In the 75 deposits referred to this study, the primary grain size of gold generally has a clear influence

Table 54. Estimated weighted mean sizes of gold grains, recovery percentages (of the total recovery) using gravimetric concentration in the deposits, analytical variances of the pulp samples in the rock data and analytical variances of the fine fraction of till (codes DE). References: [1] Leppinen & Laukkanen 1998, Mörsky et al. 1998, [2] Klemetti 2012, [3] Sotka & Toikkanen 1991, Johansson et al. 1995, Himmi 1993, [4] Juvonen et al. 1997, Chernet et al. 2000, Koppström 2012.

| | Weighted mean size µm | Gravimetric recovery % | Variance Rock / pulp $\sigma^2 \times 10^{-4}$ | Variance Till / fine fr. $\sigma^2 \times 10^{-4}$ |
|---|---|---|---|---|
| **Pampalo [1]** | 30 | 20-30 | 310 | 1142 |
| **Rämepuro [2]** | 30 | 30-45 | | 3577 |
| **Juomasuo [3]** | 20 | 9-20 | 139 | 4134 |
| **Kittilä Au [4]** | 1 | - | 40 | 1917 |
| **Kittilä Py, Apy [4]** | <500 | - | | |

on precision of replicates and duplicates. Precision improves from coarse to fine grain sizes of gold in the deposits (Fig. 67).

In till the comparison of grain sizes in adjacent gold deposits and till is more complicated. The gold grain size in the primary source deposits presumable affects the gold occurrence in till, but there are also influences of other gold occurrences and possible weathering or modification of gold in till. Gold has enriched and formed nuggets during weathering processes in the lateritic weathering terrain in Australia (Mann 1984) and Africa (Mbenoun et al. 2013). The history of gold in till is long, especially in Lapland, where the style of nuggets and the origin of gold has been studied since the discovery of the first nuggets in 1868 (Saarnisto & Tamminen 1987, Ojala 2007, Tuisku & Peronius 2018) The grain size of gold in Ilomantsi and Kuusamo deposits is similar, but in the Suurikuusikko deposit the grain size is much smaller. This should influence the fine fraction duplicates, in which the nugget effect is dominant, as in the rock pulp samples (Table 54). However, there are no large differences between the deposits. Instead, in the replicate samples of till, the CV%-values are clearly lower in Kittilä than in the other deposits (Fig. 69). This indicates that the cluster effect is not significant in Kittilä. The gold grades of the till samples from Kittilä and Kuusamo are low and close to the detection limit, and then the analytical precision consequently affects the results. Only a proportion of the gold in till is from the adjacent gold deposit, which complicates comparisons between deposits.

# 7 CONCLUSIONS

The significant precision of gold grades in the sampling of many geological materials is a natural phenomenon that should be accepted and understood. The correlation between the original sample and re-sampled material is generally weak and leads to the question of which figure most realistically represents the target. Extra sampling improves the situation, and the mean grade then approaches the true mean. However, economic and other limitations commonly restrict the amount of sampling to a level that is not theoretically adequate, and other forms of assistance are then necessary. These can be subdivided to three types:

1. Different sample fractions or sample types. Gold commonly does not correlate with these, but indications can be discovered in some of them, especially in exploration.
2. Pathfinder elements or minerals that correlate with gold and chemical or physical features connected to gold. Common potential pathfinder elements include As, Te, Bi, Sb, W and base metals. They do not generally have a direct correlation with gold and commonly they are spatially related to simultaneous or successive ore forming processes. An interpretation with gold can give indications about

the gold potential locations, which cannot be found by looking at gold alone. Nevertheless, the best pathfinder element for gold is gold.
3. Chemical and physical qualities include either primary formation features, alteration, shearing and so on, or later enrichment process indications in hard rock or till.

Clear differences in the precision of gold data exist between bedrock and till samples. The nugget effect of the finest grain fraction of till is much higher, being about three times higher in terms of precision (CV%) values compared to bedrock samples. The grain size distribution is approximately the same compared to pulverizing (about 80% of −0.075 mm) and sieving (100% of −0.06 mm). The reason is probably the pulverization process, in which gold particles contaminate other minerals much more than in the sieving process commonly used with till samples. In coarse replicates, the cluster effect increases in bedrock samples and the variation is larger than in till samples, in which the variation is quite constant, and the cluster effect is small. Pulverization of sieved till samples would reduce the nugget effect and improve precision.

The nugget effect is found in every gold analysis. It is smaller than the total analytical variance or precision and always forms a constant part of the total, overall variance. The rest of the total variance is defined by the cluster effect, which is commonly referred to as *distribution heterogeneity*. It dominates the sampling phase in bedrock sampling but is less important in till sampling. The exact siting of gold in a deposit is not statistically random, but spatially related to geological structures and textures. A *cluster* describes the physical occurrence of gold better than simply *heterogeneity.*

In the procedure chain of primary sampling–preparation–analysis, the total precision is the sum of the variances of each separate step. Because the variance is a power function, the highest variance is far more important to reduce. Primary sampling in bedrock has the highest variance both for gold and base metals, and gold has higher variances in every step compared to base metals. Improvements should be focused on the primary sampling, considering the nugget and cluster effects of gold and general quality in sampling processes. In till sampling, the highest variance is in the analytical phase, pointing to the presence of the nugget effect. The nugget effect can be estimated, to some extent, using the Gy`s theories, if some indications of the grain size of gold exist, but the cluster effect is generally unpredictable. For base metals, precision is strongly concentrated in primary sampling as distribution heterogeneity.

In exploration, the precision of gold affects the classification of anomalies, leaving some “anomalous” grades below the background threshold grade, and vice versa. The latter case is amended in detailed sampling only leading to some extra work and cost. In the former case, the anomaly will not be noticed and a gold deposit, in the worst case, will not be discovered. This can be compensated, but only to some extent, by using other fractions and utilizing pathfinder elements or other indirect indications of gold. However, a high gold grade in bedrock or till is always a fact, that should be clarified.

In mining, the precision of gold has a greater effect in practical mining than in global resource estimation. In global resource estimates, the number of gold analyses is commonly large enough to improve precision to an acceptable level. Then, the selection of the analytical method and accuracy are more important. However, in a mine, a local decision on whether a blasted unit is either ore or waste can be based on only one or a few gold analyses, resulting the danger of a wrong decision, and economic losses. All the other possible gold indications should be used to help in the decision, and quality in primary sampling should be prioritized.

The gold assay precision of bedrock samples of the five Finnish study gold deposits was found to be quite typical when compared to similar types of deposits in the reference data from 75 globally located gold deposits. Sampling of the study deposits in Finland belonged to the best practice QAQC category. The primary grain size of gold has a significant effect on precision in the whole procedure chain of sampling-preparation-analysis. Deposits with coarse-grained gold commonly have the poorest precision. The precision of till sampling was found to be quite similar compared to Canadian till sampling projects, including significant variances in replicate and duplicate testing and causing uncertainties in regional data interpretation.

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This volume of the Bulletin of the Geological Survey of Finland describes the precision of gold analysis in various geological environments and areas in Finland. The precision and accuracy of any analytical data are the key factors when interpreting geochemical data. The precision of gold grades is commonly poor compared to other elements. In this report it is subdivided into sampling, preparation and analytical phases and studied in both bedrock and till sampling procedures in three areas in Finland and compared with sampling programmes worldwide. The results confirm the poor precision of gold with varying nugget and cluster effects, which commonly depend on the grain size of gold particles.

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