Electrum from the Kongsberg silver district

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Introduction

Silver was discovered in Kongsberg in the early summer of 1623, and already in October the same year, mining started up. Mining continued for the next 335 years until close-down in 1958. Native silver from the Kongsberg deposits occurs principally in calcite vein fillings where it is associated with other phases such as silver sulfides and sulfosalts, base metal sulfides and Ni-Co sulfarsenides (*e.g.* Neumann 1944). In some mines, silver contains mercury and antimony, but only traces of gold (*e.g.* Münster 1892). However, electrum (silver-gold alloy) was reported from the Braunschweig mine in 1630 (Nortmann 1631; Brünnich 1777; Deichman 1777), and later from several other mines. In this article, we give an overview of findings of electrum from the Kongsberg silver district. Furthermore, we present new electron microprobe analyses of electrum from the district.

Occurrences of electrum

To our knowledge, electrum cannot be observed *in situ* in any of the mines of the Kongsberg silver district that are accessible today. Information about the geological setting of electrum is therefore limited to what is available in old publications. Deichman (1777), and also Brünnich (1777), gave overviews of the findings of electrum within the silver district during the first 150 years after the discovery of the silver deposits, while Strøm (1784) gave a description of electrum from the Skara area. Later updates about electrum from the district are given by Langberg (1846, 1847), Hiortdahl (1869), Münster (1894) and Neumann (1944). Figure 1 and Table 1 give an overview of the occurrences of electrum that have been reported.

According to Brünnich (1777), native gold has been found in several mines at Kongsberg; the first finding was done in the Braunschweig mine in 1630, and later it was found in the Fräulein Christiane mine. Brünnich (1777) distinguished between native gold and electrum, and pointed out that the occurrences of gold-bearing silver (*i.e.* electrum) were more important than the occurrences of gold. However, we are not aware of anyone else making this distinction between gold and electrum, and Neumann (1985) supposed that the gold reported by Brünnich (1777) in fact was electrum.

Deichman (1777) noted that electrum was associated with quartz. He referred to a quartz vein running through most of the mines along the Underberget fahlband and reported that electrum was found at the intersections between the silver-bearing veins and the quartz vein. In 1697 it was made significant investments for mining electrum associated with a quartz vein at the Beständige Liebe mine. However, after a few years it was recognized that the quartz-vein separated from the calcite vein toward depth; neither silver nor electrum was found, and the mine was closed down. Deichman (1777) reported that electrum occurred as thin flakes in calcite in samples from Juels mine (Underberget fahlband). However, at Nye Segen Gottes mine in the Vinoren area, electrum was found in a rock consisting

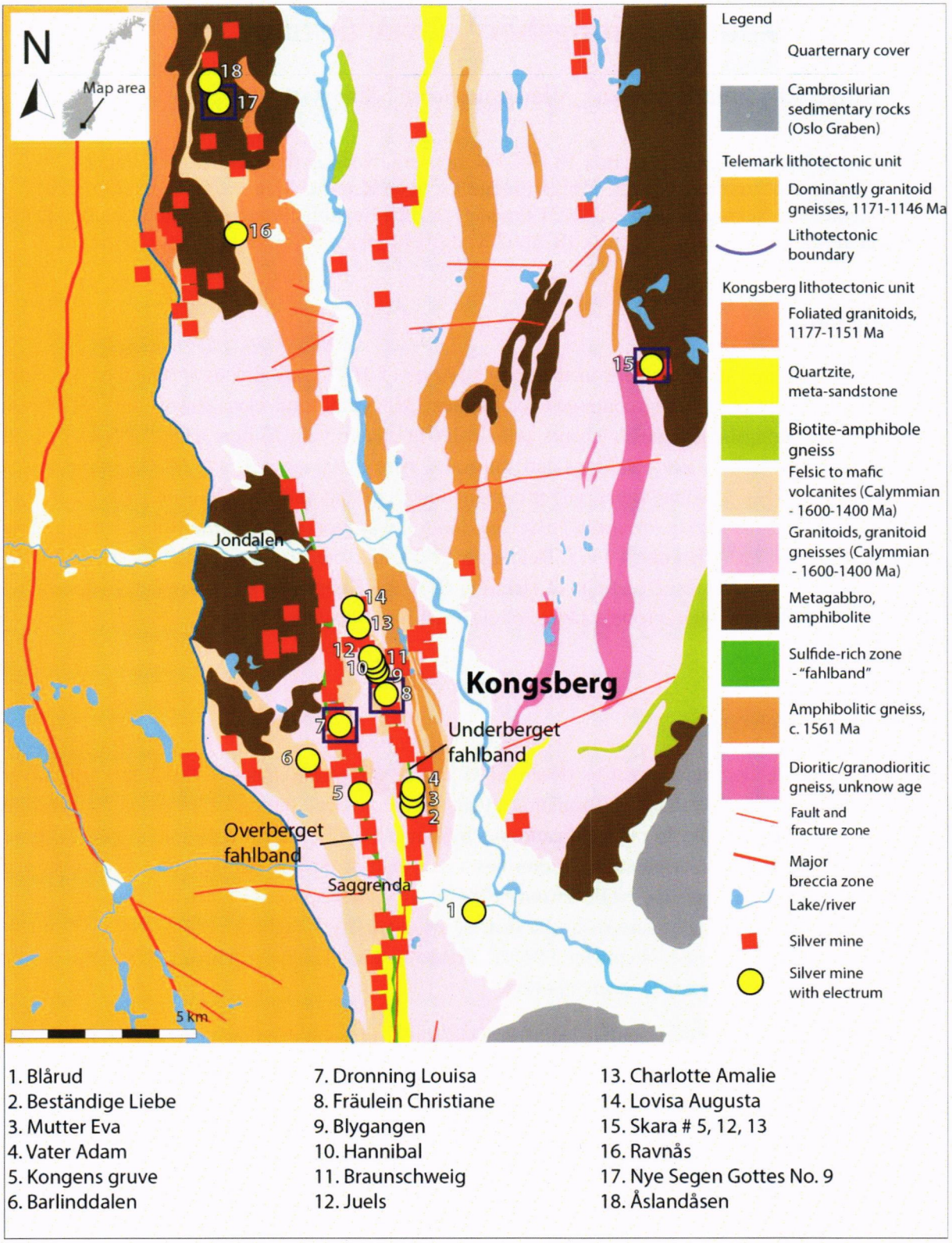

Fig. 1. *Geological map of the Kongsberg silver district modified from Viola et al. (2016) and Kotková et al. (2018), showing occurrences of silver mines (modified from http://geo.ngu.no/kart/mineralressurser_mobil/) and findings of electrum. Blue squares show the occurrences of the samples studied here.*

Table 1. *Occurrences of electrum in the Kongsberg silver district.*

#*	Name of mine	UTM 32 N	UTM 32 Ø	Discovery of electrum	References
1	Blårud	6609332	536548	1865, 1868	Hiortdahl (1869), Moen (1967), Neumann (1944)
2	Beständige Liebe	6611938	534871	1696/1697	Deichman (1777), Hiortdahl (1869), Münster (1892), Moen (1967), Neumann (1944)
3	Mutter Eva	6612049	534873		Münster (1892), Neumann (1944)
4	Vater Adam	6612152	534859	≈ 1700	Münster (1892), Neumann (1944)
5	Kongens	6612710	533470	1820	Langberg (1846),
6	Barlinddalen	6612950	532153	1798	Langberg (1846),
7	Dronning Louisa	6614337	532679		Sample NHM Oslo 000377
8	Fräulein Christiane	6614960	534099	1773	Brünnich (1777), Deichman (1777), Hiortdahl (1869), Münster (1892), Neumann (1944)
9	Blygangen	6615388	533872	1701,1760	Brünnich (1777), Deichman (1777), Hiortdahl (1869), Münster (1892), Neumann (1944)
10	Hannibal	6615534	533827	1699	Hiortdahl (1869), Münster (1892), Moen (1967), Neumann (1944)
11	Braunschweig	6615573	533831	1630, 1646	Nortmann (1631), Brünnich (1777), Deichman (1777), Hiortdahl (1869), Münster (1892), Neumann (1944),
12	Juels	6615664	533779	1646, 1701, 1728	Deichman (1777), Hiortdahl (1869), Münster (1892), Neumann (1944)
13	Charlotte Amalie	6623174	533413		Hiortdahl (1869), Münster (1892), Neumann (1944)
14	Lovisa Augusta	6616753	533343	1800	Langberg (1846), Hiortdahl (1869), Münster (1892), Neumann (1944)
15	Skara #5	6623212	541007	1778	Strøm (1784), Ek & Homlebekk (1997)
	Skara #12	6623191	541016	1778	Strøm (1784), Ek & Homlebekk, (1997)
	Skara #13	6623174	541002	1778	Strøm (1784), Ek & Homlebekk (1997)
16	Ravnås	6627257	529854		Münster (1892, 1894), Neumann (1944)
17	Nye Segen Gottes No. 9	6630683	529435	1768	Brünnich (1777), Deichman (1777), Münster (1892), Neumann (1944)
18	Åslandsåsen	6631118	529279	≈ 1770	Deichman (1777),

*Numbers correspond to localities shown on Fig. 1.

partly of drusy quartz and partly of chert. Hiortdahl (1869) listed the following mines along the Underberget fahlband, from which electrum has been found: Beständige Liebe, Fräulein Christiane, Blygangen, Hannibal, Braunschweig, Juels, Charlotte Amalie and Louise Augusta. He pointed out that the high abundances of drusy quartz veins in many of these mines support the idea that there is a connection between the quartz veins and the occurrence of electrum. For the Skara mines, electrum occurred in the same setting as observed from other mines in Kongsberg. Following Strøm (1784), silver contained gold in places where silver-bearing calcite veins were in contact with, or cross-cut by quartz veins. Electrum was commonly found in quartz, but also in calcite.

Neumann (1944) suggested that native gold was initially present in quartz veins which were older than the silver bearing calcite veins. He proposed that the gold hosted in the quartz veins was dissolved by the silver-bearing ore-forming solution and subsequently precipitated together with silver as electrum during formation of the silver deposits.

Electrum-bearing samples

The Natural Historical Museum in Oslo (NHM) has a collection of about 30 samples of electrum from the Kongsberg silver deposits, while the Norwegian Mining Museum at Kongsberg (NBVM) has about five samples. Fig. 2a shows a very nice sample from the Beständige Liebe mine (collection of NHM). Two samples from Skara are shown in Fig. 2c and e (collection of NBVM). Thirteen of the samples at NHM and one of the samples at NBVM belonged to the collection of Jørgen Hiort (1737-1804), who was *overberghauptmann* (head administrator) of the governing body for the Norwegian mining industry. These samples are registered in Hiort's catalogue from 1786. The collection of Hiort was donated to the Norwegian Mining Seminar in 1786, and transferred to the University of Oslo in 1815. The labels of Hiort's samples of electrum are typically marked with sample number in addition to the alchemical symbol of gold, *i.e.* the sun – represented by a circle with a point in its centre (Fig. 2b). For most of the samples of electrum at NHM, however, information about when they were collected, and who collected them, are missing. Anyhow, the labels enclosed with several of the samples suggest that they are from the 18th century or older (*e.g.* Fig. 2d).

For the present project, small fragments from four samples from the collection of NHM (samples NHM Oslo 000366, NHM Oslo 000377, NHM Oslo 000378 and NHM Oslo 000485) and one sample from the collection of NBVM (sample NBVM-M 0006087) were prepared for reflected light microscopy and electron microprobe analyses. The locations of the samples are given in Table 2.

Table 2. *Samples studied.*

Sample number	Location	Collection
NHM Oslo 000366	Nye Segen Gottes No 9	NHM
NHM Oslo 000377	Dronning Louise	NHM
NHM Oslo 000378	Skara	NHM
NHM Oslo 000485	Fräulein Christiane	NHM
BVM-M 0006087	Skara	NBVM

Sample NHM Oslo 000366 is one of six rock specimens labelled 147 in Hiort's catalogue (Fig. 3). The finders of the other samples are unknown. It should be pointed out that the label enclosed with sample NHM Oslo 000377 indicating that it was collected from the Dronning Louise mine is the only evidence we have found for the presence of gold in this mine. We keep open the possibility that the sample locality might have been mixed up with Prinsesse Louise Augusta mine, where electrum was found in 1800 (Langberg 1846).

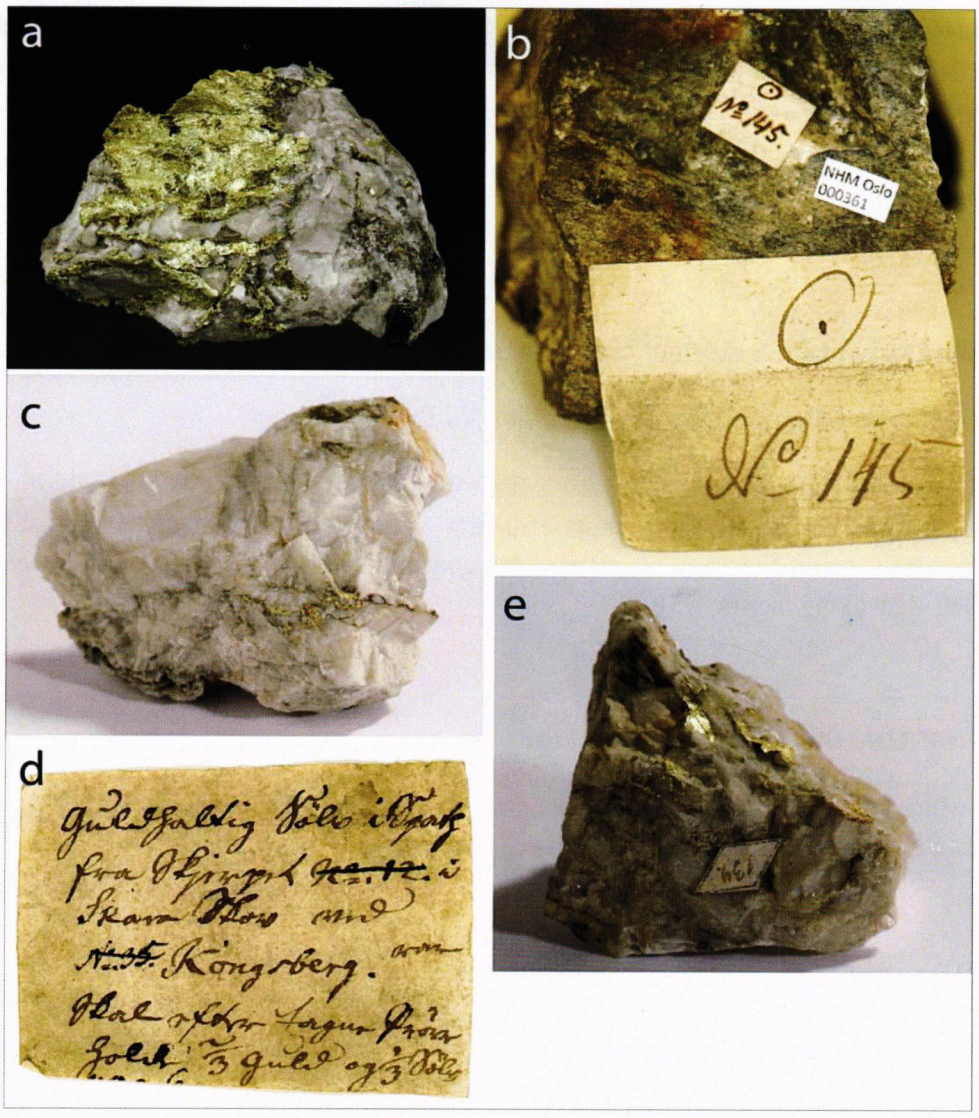

Fig. 2. *Electrum from the Kongsberg silver mines. a) Sample from the Beständige Liebe mine, collection of the Natural Historical Museum, Oslo. Photo: Øivind Thoresen. b) Sample from the collection of NHM with labels that are typical for the collection of Jørgen Hiort, with a circle with a point in its center. c) Sample from Skara, sample BVM-M 0003429 of the collection of the Norwegian Mining Museum, Kongsberg. Photo: Christian Berg. d) Label belonging to the sample shown in c). Transcribed text: "Guldhaltig Sölv i Spath fra Skjerpet ~~№. 12~~ i Skara Skov ved ~~№. 35.~~ Kongsberg.*[var] *Skal efter tagne Pröve holde ⅔ Guld og ⅓ Sölv". e) Sample from Skara, sample BVM-M 0006087 of the collection of the Norwegian Mining museum. Photo: Christian Berg.*

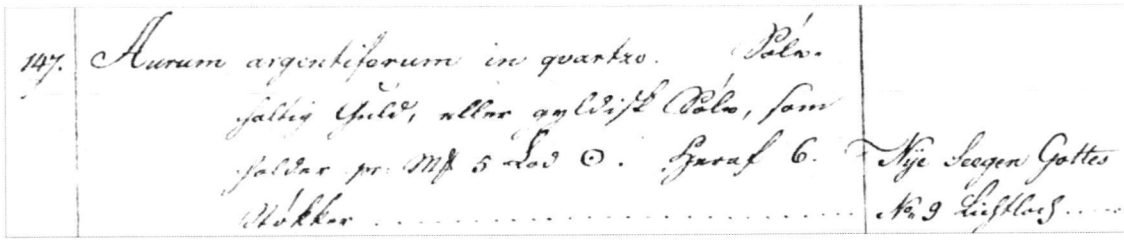

Fig. 3. *Excerpt from Hiort's catalogue from 1786 with information about the gold-bearing sample 147, corresponding to sample NHM Oslo 000366. Transcribed text: "147. Aurum argentiferum in qvartzo. Sølvhaltig Guld, eller gyldisk Sølv, som holder pr. Mk 5 Lod [symbol for gold]. Heraf 6. Støkker. Nye Seegen Gottes № 9 Lichtloch".*

Electrum textures, compositions[4] and associated minerals

Sample NHM Oslo 000366 – Nye Segen Gottes No 9

Plates and grains of electrum are very porous and often covered with Zn-bearing chlorite or a thin layer of opaline quartz. The matrix consists of quartz, which also contains aggregates of K-feldspar with variable Ba-content. Electrum shows variable concentration of gold (Au), with lower Au in the core of grains than along the rim (Fig. 4a).

Sample NHM Oslo 000377 Dronning Louise

Electrum, which has a lamellar or platy shape, occurs in a matrix of quartz (Fig. 4b). Electrum shows nearly constant compositions with 41-42 atomic % Au.

Sample NHM Oslo 000378 Skara

The sample contains irregular bright yellow grains with a content of 75-76 atomic % Au in a matrix of quartz and calcite (Fig. 4d). Associated ore minerals are boulangerite ($Pb_5Sb_4S_{11}$), and bournonite ($PbCuSbS_3$), galena and pyrite.

Sample NHM Oslo 000485 Fräulein Christiane

Electrum occurs as plates in quartz, containing 33-34 atomic % Au (Fig. 4c).

[4] Chemical analyses of electrum and associated minerals were carried out on a CAMECA SX100 electron microprobe at the Nature-Historical Museum in Prague, Czech Republic.

Sample NBVM-M 0006087 Skara

Electrum containing 42-44 atomic % Au occurs in a matrix of quartz and calcite (Fig. 4e). Associated minerals include hessite (Ag_2Te), arsenopyrite, galena and gersdorffite (NiAsS).

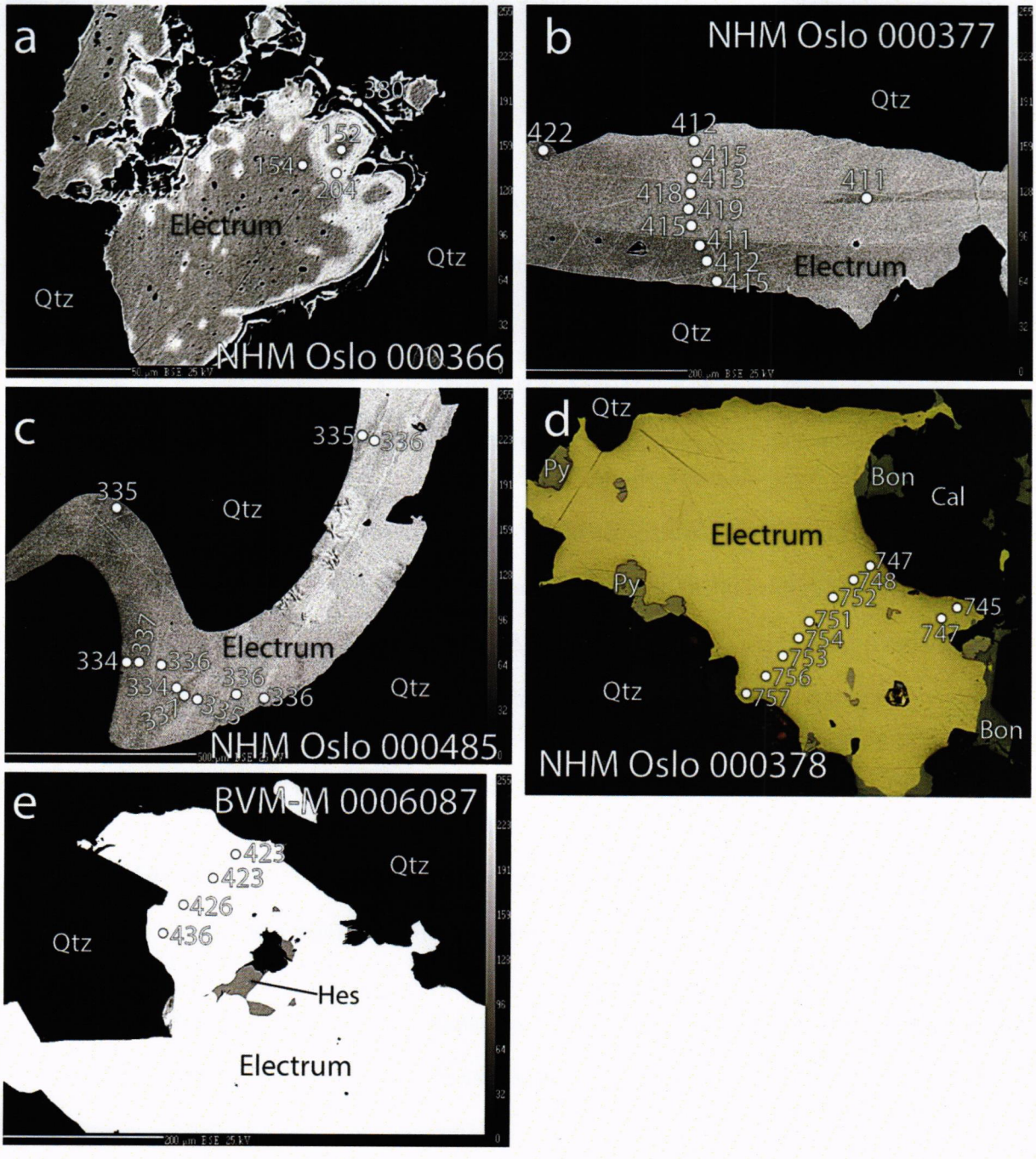

Fig. 4. *Electrum and associated minerals from the studied samples. White circles show points analyzed by electron microprobe. Numbers next to white circles indicate the atomic ‰ Au in electrum. See text for discussion. Mineral abbreviations: Qtz=quartz, Cal=calcite, Bon=bournonite, Hes=hessite.*

Concluding remarks

Electrum has been reported from more than 15 silver mines in the Kongsberg silver district. According to old reports and publications (*e.g.* Deichman 1777), electrum is typically associated with quartz veins. The present study shows that electrum occurs together with pyrite, arsenopyrite and galena. Furthermore, bournonite, boulangerite and hessite are for the first time reported from the silver mines. For the samples studied here, electrum shows large compositional differences, and the content of gold varies in the range 15 – 76 atomic % Au.

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