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Geophysical VLF prospecting for vein-type gold-bearing polymetallic sulphide deposits in the Sudetes (SW Poland)

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The abandoned historic gold mining areas in the Sudetes are prospective for vein-type sulphide and gold deposits. A VLF geophysical survey showed many linear anomalies, indicating the possible occurrence of unknown quartz-sulphide ore veins in areas of former mining exploitation of gold and arsenic in the Klecza-Radomice Ore District and As-polymetallic sulphides in the Czarnów deposit. These areas are very promising for further prospecting for gold-bearing polymetallic sulphide ores. A shallow drilling campaign is proposed to constrain the ore potential of the VLF anomalies detected.

Key words: gold, gold-bearing sulphides, VLF survey, Klecza-Radomice, Czarnów, Sudetes.

INTRODUCTION

The application of geophysical methods such as VLF (Very Low Frequency electromagnetic technique) in the search for vein-type gold deposits in former metal ore mining areas has long been used (Singh and Sharma, 2016). In many places it has detected continuations of the courses of already known ore veins or indicated completely new occurrences of them (Eppelbaum, 2021 and references therein). Polymetallic sulphide deposits of vein type are common in the Sudetes. Some have been exploited since the Middle Ages (Dziekoński, 1972). Owing to difficult geological conditions, ore mining was carried out on an ad hoc basis, in many places with long breaks. The prevalence of small ore veins, commonly cut by faults, posed mining problems for pre-modern operations and hindered their extraction. In addition to gold and silver, arsenic, iron, copper, lead, cobalt, tin and uranium have also been recovered from these deposits. Vein deposits in the Sudetes were exploited mainly in the shallower zones of the ore deposits and today they remain very poorly explored at greater depths and between areas of former exploitation (Madziarz, 2009). Quartz-sulphide vein deposits occur mostly in the metamorphic basement, consolidated in pre-Permian time. These deposits are commonly overlain by Permian-Mesozoic and Cenozoic strata and by weathering cover. Outcrops of vein-bearing rocks form rugged parts of the landscape and are usually densely forested where the accessibility is limited. Extensive mining in the region ended in the 1930–50s. So far the Sudetic vein deposits have only been the subject of local geophysical research and interest (Stefaniuk et al., 2011; Ostrowski, 2014). In 2017, the PGI-NRI started a systematic research programme on vein ore deposits in the Sudetes including a pilot geophysical VLF geophysical survey (Mikulski and Ostrowski, 2023a, b). The VLF technique was used to survey two former areas of exploitation of gold-bearing vein polymetallic deposits: the area of the Klecza-Radomice Ore District and the area of the Czarnów deposit in the West Sudetes (Fig. 1).

GEOLOGICAL SETTING OF GOLD-BEARING VEIN TYPE DEPOSITS

The Klecza-Radomice Ore District (KROD) and the Czarnów As-polymetallic deposit are located in the Western Sudetes, which is considered to be a continuation of the Saxothuringian Zone of the European Variscides in the north-eastern part of the Bohemian Massif (e.g., Mazur et al., 2006). These deposits are small and their total resources are relatively limited. They are located in marginal zones of Lower Paleozoic rocks within the basement of the Western Sudetes, which was affected by Cadomian and Variscan metamorphism (Fig. 1). The Paleozoic geological evolution of the Western Sudetes is characterized by rifting during Cambrian-Ordovician to Devonian times, with a Late Devonian to Early Carboniferous subduction-collision setting (e.g., Franke and Żelaźniewicz, 2002). In the Western Sudetes, granitoid intrusions were placed during the Carboniferous. These Variscan granitoids consolidated several crystalline blocks that consist of a meta-

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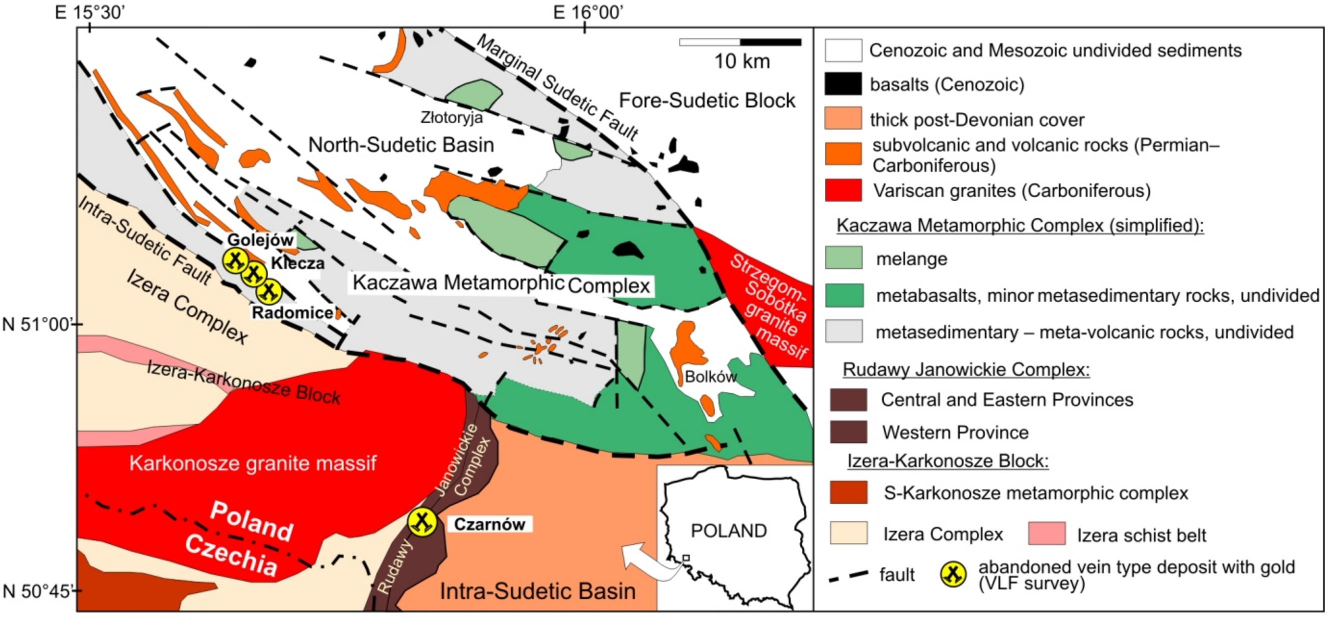

Fig. 1. Location of the Klecza Radomice Ore District and the Czarnów As-polymetallic deposit on a simplified geological map of the West Sudetes (after Cymerman, 2002)

morphosed sedimentary-submarine-volcanic succession with well-documented bimodal-volcanic and ophiolitic rocks (e.g., Mazur et al., 2006). This mosaic geologic structure has been interpreted as a metamorphic terrane assemblage (e.g., Matte et al., 1990; Cymerman and Piasecki, 1994). In the Middle Carboniferous, major NW–SE-trending dextral strike-slip regional faults developed as a result of the oblique convergence between the amalgamated Bohemian Massif with blocks already accreted to the East European Craton (Aleksandrowski et al., 1997).

The deposits under consideration occur within regional shear zones: around the Karkonosze granite massif and in a second-order structure (Czarnów and KROD, respectively). In the Western Sudetes the vein-type ore deposits are associated wtih hydrothermal metamorphic and igneous processes of the pre-Variscan and Variscan cycles (Mikulski, 2007; 2015).

THE KLECZA-RADOMICE ORE DISTRICT

The KROD is hosted by rocks of to the Kaczawa Metamorphic Complex (KMC), which belongs to the basement of the Western Sudetes. The KMC is represented there by flysch-like metasedimentary rocks of Ordovician-Devonian age, which have been deformed and metamorphosed to lower greenschist facies (Kryza and Muszyński, 1992). The KMC shows features of an accretionary prism, and comprises several nappe units and mélange bodies composed of various components of the Paleozoic sedimentary-volcanic succession. In the KROD gold mineralization occurs in the flysch-like rocks of the Pilchowice Unit located between gneisses of the Izera-Karkonosze Block to the south and the Rotliegend strata that fill the Wleń trough to the north (Gierwielaniec, 1956). At least 8 main and more than 9 secondary gold-bearing quartz veins with sulphide mineralization are known in the KROD (Mikulski, 2007). The veins strike predominantly NE–SW with a secondary NW–SE trend, and dip at 65–85° to the W. They have been examined for ~90–150 m along strike and down to 100 m below the surface, and vary in thickness from 0.25 to 1.5 m. Most commonly the veins cut bedding/foliation but locally may occur as saddle reefs. Larger veins are preferentially located in fracture zones that are discordant to the bedding and run close to, or along, the axial planes of F_1 anticlines. Several veins in the immediate vicinity of the reverse Pławna fault zone strike obliquely to the fault (Fig. 2).

Small-scale mining of arsenic and gold ores was carried out in the KROD in the 1920s (Grimming, 1933). The ore was mined from quartz veins intersecting schists of Lower Paleozoic age. The ore mineralization, which is the richest in gold, is of a massive type and is dominated by arsenopyrite and (locally) pyrite. The gold and arsenic content in ore veins was in the range of 3–40 ppm Au and 2–12% As (Grimming, 1933; Domaszewska, 1964; Dziekoński, 1972). Sericite and graphite schists are favourable hosts for sulphide mineralization. These rocks are strongly altered due to silicification, sericitization, carbonatization, chloritization, feldspathization and sulphidization (Mikulski, 2007). The massive ore mineralization is fractured and overprinted by sparse base metal sulphides (chalcopyrite, galena and sphalerite) associated with common carbonates (mainly ankerite and dolomite). Gold occurs as refractory and microscopic gold (Mikulski, 2007). Pyrite and arsenopyrite extracted from the ore contain up to 68.5 and 15 ppm of gold, respectively. The fineness of the microscopic gold varies from very low (630) to very high (940) (Paulo and Salomon, 1973; Olszyński and Mikulski, 1997; Mikulski, 2007). The mineralization in the KROD has been classified as an orogenic gold deposit (as defined by Groves et al., 1998 and subsequent modifications according to Goldfarb et al., 2001) due to the geological setting between metamorphic terranes, strong structural control on the ores, low Au/Ag ratios, insignificant base-metal contents, and low salinity of the mineralizing fluids (<7 wt.% NaCl equivalent; Mikulski, 2003). The Re-Os isotopic age obtained for Co-arsenopyrite from the northern ore field at Klecza was 316.6 ±0.4 Ma (Mikulski et al., 2005).

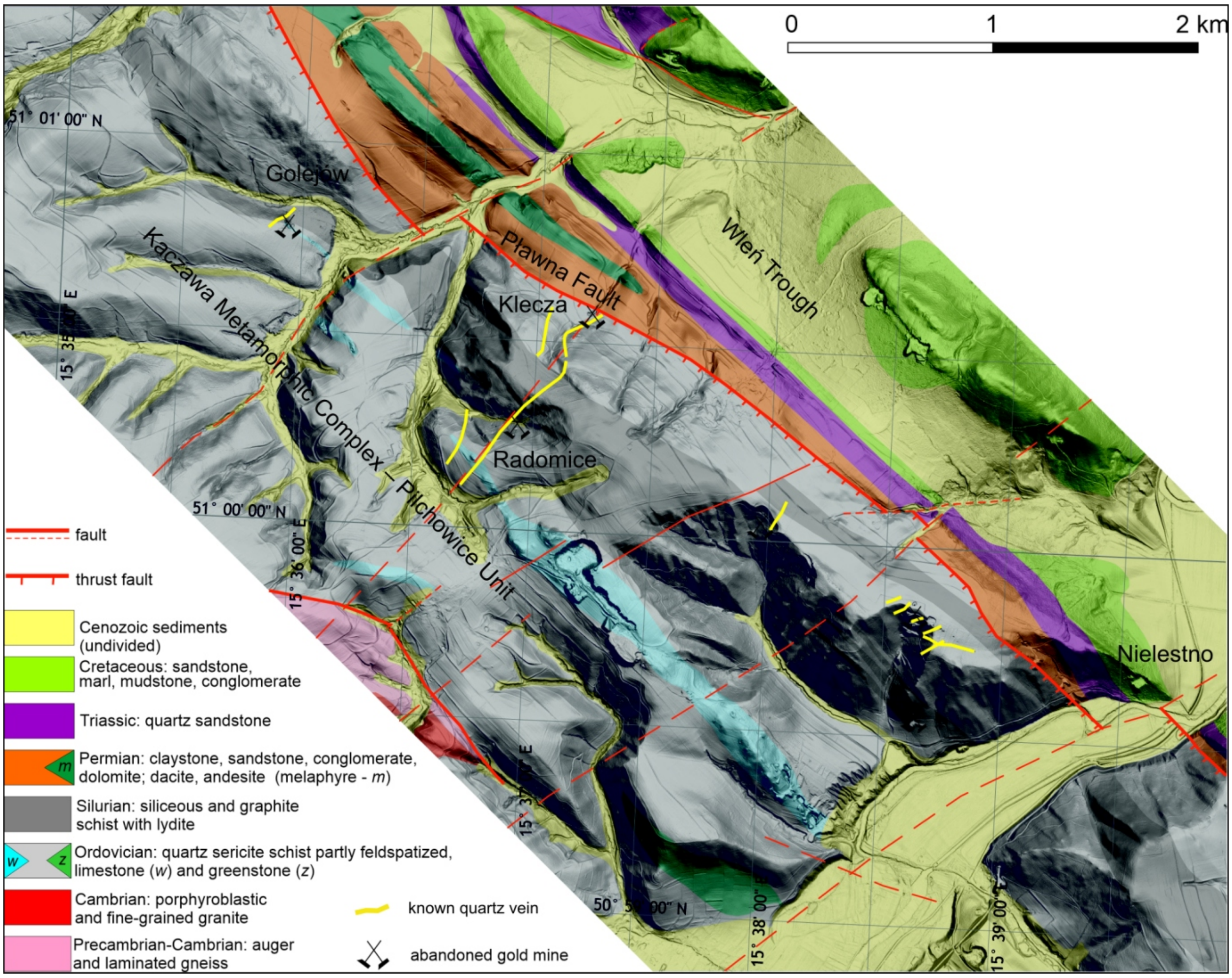

Fig. 2. Location of the gold-bearing quartz veins in the Klecza-Radomice Ore District (after Mikulski, 2007) on a schematic geological map (modified from Milewicz, 1962; Szałamacha, 1970, 1974; Milewicz and Frączkiewicz, 1983)

THE CZARNÓW As-POLYMETALLIC DEPOSIT

The Czarnów deposit is hosted by metamorphic rocks of the Rudawy Janowickie and Lasocki Ridge in the Sudetes (Teisseyre, 1973), which are part of the Karkonosze-Izera Block belonging to the northeastern extension of the Saxothuringian zone of the Variscides of Central Europe (Franke and Żelaźniewicz, 2000). The Czarnów deposit is hosted by rocks belonging to the Kowary-Czarnów Unit and is located within the Leszczyniec shear zone (Kozdrój, 2003). It is bounded to the west by the Karkonosze granitoid and to the east, along a dislocation, by the Leszczyniec Unit (Fig. 3). The core of the Karkonosze-Izera Block is formed of the post-Variscan Karkonosze granite, dated to ~315–303 Ma (SHRIMP U-Pb zircons; Mikulski et al., 2020, with references therein). Rocks of the Kowary-Czarnów Unit are affected by contact metamorphism. The deposit is built of a NE–SW trending quartz vein dipping at an average angle of ~80°SE. The vein is divided into 2 or 3 parts along the dip, giving it a lenticular shape. The host rocks are represented by various types of carbonate-silicate rocks, hornfels, schists, amphibolites, gneisses and marbles. According to mining archives, the length of the vein along strike exceeds 500 m, and its average thickness is ~0.5 m (up to 3 m). The vein is cut by numerous fractures and faults. The most prominent faults are NW–SE (perpendicular to the foliation) sinistral-, and dextral strike-slip faults that have dislocated the vein and deposit zone. The main ore mass of the vein comprises sulphide arsenic-polymetallic mineralization. The massive mineralization zones are lens-shaped with a maximum thickness of 4 m (average ~40 cm). The intensity of mineralization varies spatially. In some places the mineralization is represented by disseminated impregnation or is completely absent.

From the beginning of the 18th century until 1925, with numerous interruptions, mining was carried out in 5 ore fields on 10 mining levels to a depth of 250 m (Dziekoński, 1972). In prosperous years the annual production was ~3,000 tonnes of arsenic ore with an average arsenic content of 10%. Small quantities of copper, zinc, lead, tin and iron, as well as limited quantities of silver and gold, were also produced. The main ore mineral exploited was arsenopyrite, accompanied by chalcopyrite, pyrrhotite, pyrite and minor amounts of galena, sphalerite, bornite and stibnite (Mochnacka, 1982; Zimnoch, 1985; Mochnacka et al., 2009, 2015; Mikulski, 2010). Cassiterite and magnetite occurrences are known in some parts of the vein and its salbands (Mikulski et al., 2007). Gold occurs in a submicroscopic form, mainly in arsenopyrite, and as microscopic gold (native gold and electrum) in paragenesis with base metal sulphides, and Bi- and Ag-minerals (Mikulski, 2010).

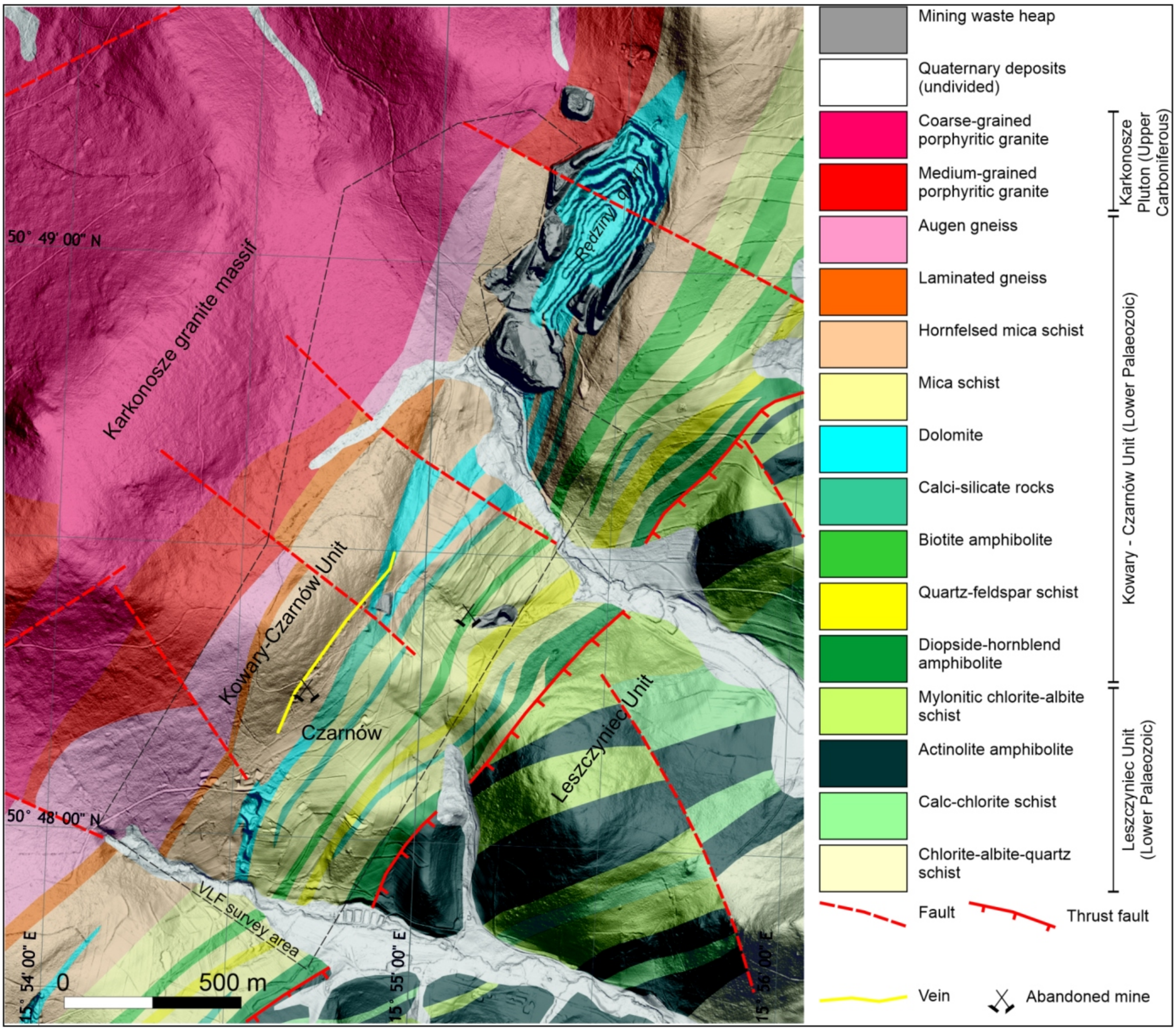

Fig. 3. Location of the gold-bearing quartz sulphide vein in the historic Czarnów As –polymetallic deposit (after Mikulski et al., 2020) on a schematic geological map (modified from Szałamacha and Szałamacha, 1988)

Arsenopyrite occurs in two forms: massive and coarse-grained euhedral crystals in quartz or host rocks. Massive arsenopyrite is associated with patches of fine-grained pyrrhotite, pyrite and chalcopyrite. The average gold content in rich sulphide ores was ~1.1 ppm (range 0.7–12.6 ppm) and arsenic and copper contents were 5.6% As (3–30%) and 0.75% Cu (0.1–4%), respectively (n = 47; Mikulski, 2010). The ore host rocks show strong contact-metasomatic alteration; the rocks are hornfelsed, and strongly silicified and carbonatized. Individual high concentration of Ag (380 ppm), Bi (0.55%) and Sn (0.4%) have been documented in polymetallic ores. The genesis of the ore deposit was considered to be the result of multiple hydrothermal activities associated with the Late Carboniferous post-kinematic granitoid intrusion of the Karkonosze massif (Mochnacka, 1982; Zimnoch, 1985) and later remobilization of metallic elements within regional shear zones (Mikulski, 2010; Mikulski and Stein, 2013). Banaś (1967) argued that the Czarnów ore deposit is genetically linked to polymetamorphic processes that predated the intrusion of the Karkonosze granite.

GEOPHYSICAL PROSPECTING USING VLF METHODS

The geophysical survey was carried out in 2017–2018 both in the Klecza-Radomice Ore District and on the Czarnów deposit. The survey was carried out using the VLF technique, with an innovative approach to survey and interpretation. Measurements were acquired along 44 acquisition lines 0.3 to >1.5 km in length, with a total length of over 45 km, covering an area of ~6 km^2 – virtually the entire area of interest in the KROD. In the Czarnów ore field the measurements were acquired along 24 lines up to 1 km long and covering an area of ~2 km^2.

The survey layout was designed to take account of known structural features: the lines should be close to perpendicular to geological boundaries and cross faults and veins. Existing infrastructure such as power lines, pipelines and buildings were considered as potential noise sources and buffer zones (no-survey zones) were established around these elements. The survey lines were evenly spaced at 100 m intervals to cover the entire area of interest. Figure 4 illustrates the planned survey layout in the vicinity of the Czarnów deposit.

The very low frequency electromagnetic (VLF) technique is well established, although it is considered to be an outdated geophysical prospecting method. A full description of the technique and its intricacies can be found in the literature (Paterson and Ronka, 1971; Phillips and Richards, 1975; Sharma et al., 2014). In principle, the VLF surveying technique is based on the phenomenon of electromagnetic induction in the subsurface medium. An electromagnetic field (primary field) propagating through the subsurface medium induces eddy currents in the conductors encountered. These eddy currents generate a secondary electromagnetic field that can be detected. The most prominent eddy currents are induced in vertical sheet-like conductive geological objects, although any dipping resistivity contrasts in the subsurface medium will generate the response. Direct measurement of the primary and secondary fields is almost impossible in the field, so the relative phase shift between the primary and induced fields is measured. The magnitude of the phase shift is related to the current density in the subsurface medium. Quantitative modelling of the resistivity values based on apparent current density is still underdeveloped (Singh and Sharma, 2016); however, qualitative analysis based on lateral changes in phase shift can provide valuable information on the spatial location of some geological objects, such as fault or shear zones, ore bodies, dipping boundaries, or mineralized veins (Ramesh Babu et al., 2007; Gnaneshwar et al., 2011).

Electromagnetic geophysical techniques use some form of primary field source in the frequency range of <1 Hz to a few tens of kHz, either controlled (internal) or external with respect to the measurement equipment. The VLF technique utilizes the upper part of the spectrum between 15 to 30 kHz and the external source. Such frequencies are emitted as radio waves (very low frequency radio communication) from military high-energy installations, and are primarily used as a means of producing a global-scale long-distance communication band receivable by submerged submarines. The VLF geophysical surveying technique piggybacks on the system and uses it as a spatially, temporally and spectrally stable energy emitter. Transmitting stations are distributed around the globe, and there are several reliable stations in Europe that can be used for geophysical purposes. The electromagnetic waves propagate between the earth's surface and the ionosphere for up to several thousand kilometres and, when they reach the survey area (usually at least hundreds of kilometres from the source), can be considered as planar waves: the energy distribution along the wave head is uniform and the wave curvature is negligible, a condition necessary for reliable geophysical measurements.

The VLF geophysical measurement is performed by registering of the phase shift of the magnetic component of the secondary electromagnetic field with respect to the primary field. The phase shift is decomposed into two vectors known as in-phase and out-of-phase, quadrature or imaginary vector (component). Although the single measurement carried out in the field registers the phase shift of the secondary field induced in the geological objects, it is almost meaningless in itself. Only the spatial variation of the phase shift can be interpreted in terms of geological objects. Technically, the field measurements are carried out at discrete intervals along the traverse. A separate measurement is made at each point along the traverse, and the total field strength (primary), in-phase (IP) and quadrature (QUAD) components of the phase shift are measured and recorded. The values obtained are combined into a line (profile) and can be analysed. Strong spatial variations in the component value indicate the position of a resistivity boundary or the presence of a conductive object in the subsurface. Prominent changes in component value associated with changes in sign (known as cross-overs) indicate the presence of a sheet-like, conductive body in the subsurface. The more symmetrical the course of the cross-over, the more similar the object is to a vertical sheet of conductor. Thus, analysis of phase-shift component plots along the traverse may indicate the location of boundaries in the subsurface medium that differ with regard to resistivity, especially near-vertical sheet-like structures e.g. shear zones or mineralized veins. Straightforward interpretation of phase shift plots provides only crude, qualitative results. The application of some mathematical filtering allows the precise localization of anomalies (Fraser filter; Fraser, 1969) or even the calculation of the equivalent current density producing the anomaly and the construction of a simple pseudo-section (Hjelt filter; Karous and Hjelt, 1983). A more quantitative approach to VLF data interpretation is possible (Singh and Sharma, 2016), but commercial software tools have not yet been developed.

An approach based on VLF surveys carried out along isolated traverses and aimed at detecting fault zones or zones of mineralization works well where the general strike of the geological structures is known and the survey is intended to precisely locate some of them. In more complex geological settings, or in the absence of sufficient structural information, where more aerial knowledge is required, the survey setting must be significantly adjusted.

In our survey we aimed to map structural features in the vicinity of three abandoned mines of polymetallic ore in the Klecza-Radomice Ore District and the Czarnów deposit. In the KROD, the ore is genetically linked to quartz veins that are hosted in schist of the Pilchowice Unit that belongs to the Kaczawa metamorphic complex, and the underground mining operations followed these veins. In the Czarnów deposit, the only quartz vein containing sulphide mineralization is hosted in metasedimentary rocks of the Kowary-Czarnów Unit. Underground structural observations for both locations, other than the general plan of the mines, are scarce and hard to obtain, due to safety considerations in the abandoned mines. Therefore, the potential of geophysically surveying the area to search for linear anomalies that can be attributed to structural elements – quartz veins, ore-bearing veins and permeable fault zones – was employed, using the VLF technique. In the KROD, the survey was conducted in three areas (sites), within a radius of approximately 1 km from the historic mines, located to the north-west and south-east of the village. In the Czarnów deposit, the survey was conducted on an elongated area following the general orientation of the previously mined vein. Due to lack of structural information on the distribution of the veins, the survey was planned and carried out as a semi-2D survey. Between 15 and 24 parallel traverses, spaced at 100 metre intervals, were distributed over each site. Point measurements were taken every 10 metres along each line. Traverses across the central site in the KROD followed an azimuth of 130° and were perpendicular to the main plane of the mined vein system; and at the W and E sites traverses followed an azimuth of 80° oblique to the fault zone bounding the Permian-Mesozoic trough and dominant vein strike. At the Czarnów deposit, traverses followed an 80ş azimuth (nearly perpendicular to the vein). The field survey at each site took approximately 1 week of one-man work. The field campaign was performed in late autumn and early spring, partly on snow-covered ground and partly in rugged, wooded terrain, and thanks to the exceptional versatility of the survey equipment, the survey could be performed entirely on foot.

The VLF measurements were carried out simultaneously on three frequencies, emitted by three different radio transmitters. In the VLF measurements, the strongest signal is gener-

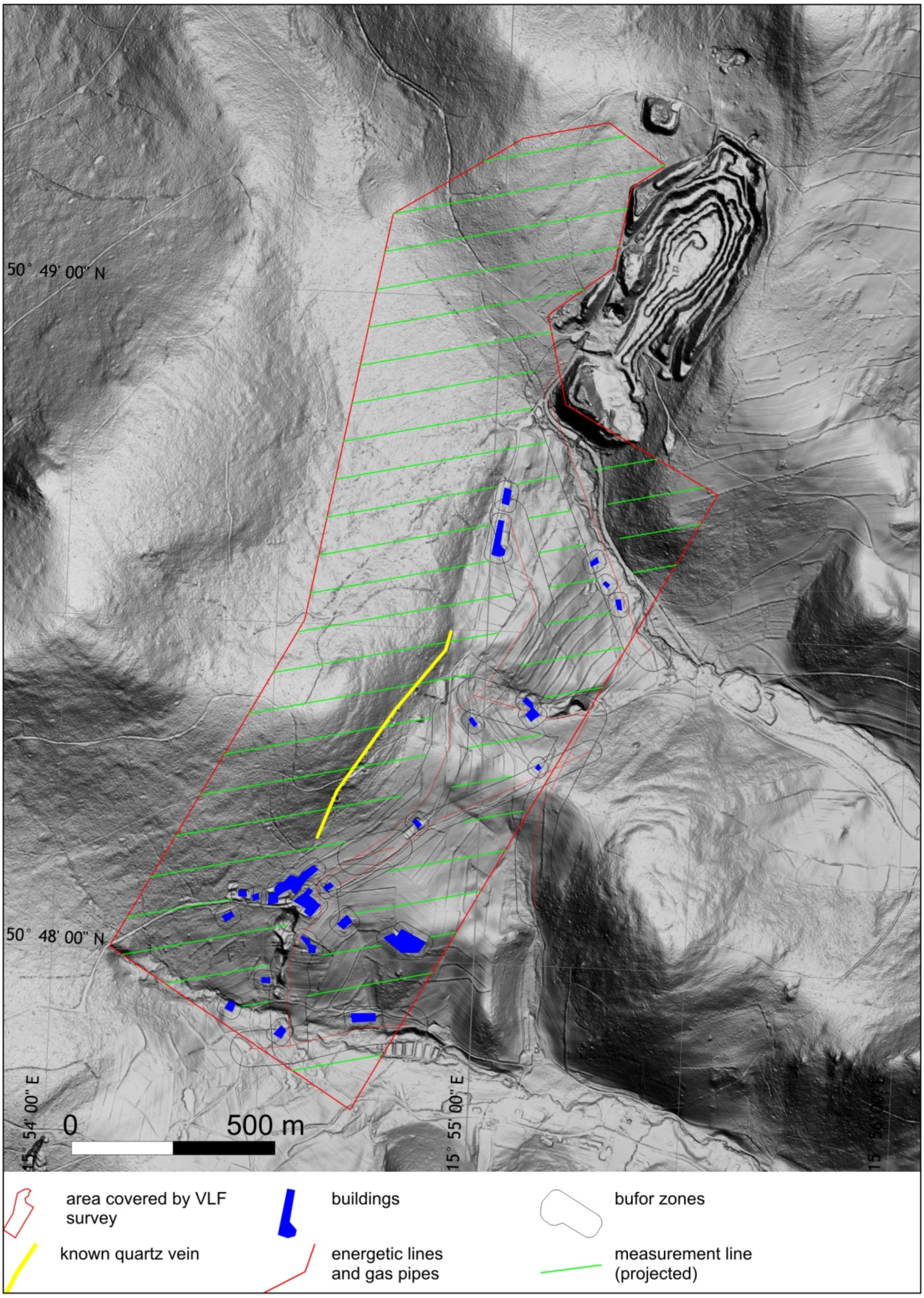

Fig. 4. Illustration of the survey layout in the area of the Czarnów As-polymetallic deposit

ated by subsurface structures striking in or close to the direction of the transmitter. The transmitters chosen for the survey were located at an azimuth of 295° (Burlage, Germany, frequency 23.4 kHz), 296° (Skelton, UK, 22.1 kHz) and 204° (Isola di Tavolara, Italy, 20.3 kHz). This orientation of the transmitters was very convenient. The German and British stations are located at almost the same azimuth and cover structural features striking between ~85–145°, including the main structural azimuth occurring in the Western Sudetes, while the Italian stations cover structures striking between 175–235°. The near right angle incidence of the waves from the selected transmitters allows for relatively good directional coverage, leaving only two narrow zones of poorer coverage.

The phase shift decomposed into two components (IP and QUAD) was registered separately for all three frequencies, resulting in 6 sets of data, and the position was determined by the GPS receiver for each measurement point. A matrix of geographic location and six phase parameters was the primary result of the field survey.

DISCUSSION

For the quartz-sulphide vein deposits in the Klecza-Radomice Ore District (Kaczawa Mountains) and for the Czarnów deposit (Rudawy Janowickie Ridge), a series of maps were prepared showing each component (colour classification symbol) against a shaded relief map (Figs. 5 and 6). The phase shift data were then processed. The Fraser filter (Fraser, 1969) was applied separately to each transect from all datasets. The Fraser filter is essentially a tool for calculating the equivalent of the first derivative function for discrete data, and the results of filtering: (i) equalize the values of the phase shift components, and (ii) place the maxima at the intervals where the gradient of the original value is maximal. In this way, an anomaly shown as filtered values is centred over the geological object generating the anomaly, and is confined to one maximum instead of two extremes (maximum and minimum) as in unfiltered data. Fraser filtering was found to be sufficient to show the course of linear structures. Again, a set of maps of filtered data (a separate map for each component and each transmitter frequency) was prepared for the two areas with the quartz-sulphide vein-type deposits in the Western Sudetes (Figs. 7 and 8). All prepared maps were integrated into a GIS project, where the VLF data sets for each component were represented by separate layers.

The next logical step in the presentation of the data acquired and preparation for geological interpretation appeared to be spatial (2D) interpolation of the datasets. However, the distribution and size of many of the recorded anomalies showed that, although anomalies could be properly represented by discrete data along the traverses, the spacing between traverses was greater than the extent of some anomalies. In such a situation, automatic interpolation was doomed to produce serious errors due to the phenomenon known as aliasing. Alternatively, guided interpolation would imprint the interpretation deep into the resulting (interpolated) fields – a result considered undesirable. We decided that the best approach was to present the data (both unfiltered and filtered) as a colour-classified point map, and to interpret the probable course of linear anomalies by hand over several traverses (Figs. 9 and 10).

From the prepared maps of the Fraser filtered datasets the course of linear anomalies that continued across adjacent traverses was picked by hand. Linearity, similarity of anomaly, shape and anomaly intensity were considered when picking a given anomaly. The anomaly picking was performed for each dataset representing a separate component of each frequency (transmitter) as “blank” picking – each dataset was picked independently and without consultation between datasets. As the intensity of electromagnetic induction response is angle-dependent, decreasing with the angle between the structure strike and the transmitter azimuth (to zero at right angles), datasets for the German and British transmitters were searched for anomalies striking 55–175°, and datasets for Italian transmitters were searched for anomalies striking 0–85° and 145–180°. Picking resulted in obtaining sets of lineaments, which are considered as linear VLF anomalies generated by geological features – fault zones or sulphide veins. All lineaments selected were then integrated on a map for each area (layers in the GIS database), but the link to the dataset of the individual lineament was maintained. Some lineaments overlap, and are considered to be more prominent or more certain than those selected from only one dataset.

CONCLUSIONS

The lineaments derived from the VLF survey and processed using an innovative semi-2D workflow were translated into geological features, assisted in structural interpretation of the area surveyed and can be used to plan further ore exploration. The lineament map for the KROD is shown in Figure 9, and for the Czarnów deposit in Figure 10. Subtle morpholineaments identified on the LIDAR map are also shown on the map for the KROD. There are four lineament populations (or modes) on the map of the KROD (Fig. 9) and 3 lineament populations on the map of the Czarnów deposit, which can be attributed to different structural elements and different stages of deformation (Fig. 10).

In the KROD, lineaments following a general NW–SE trend can be attributed to lithological boundaries, and lineaments following a NE–SW trend relate to faults perpendicular to the folds. The N–S trending lineaments are most likely due to mineralized veins. A cluster of lineaments present in the central part of the KROD, following the general E–W trend and bending to the north (mode 4), may represent the effects of an as-yet unknown vein or fissure system. Slight discordance in the lineaments between the central and northwestern sites suggests that the NW site is on a dextrally rotated block.

In the Czarnów deposit, NW–SE trending lineaments can be attributed to faults perpendicular to the general strike of the structures. Lineaments with an azimuth of 10–20° are probably associated with lithological boundaries and quartz veins. A cluster of such lineaments to the west of the quarry is arranged in an en echelon pattern and may relate to the occurrence of veins. The lineaments with a near-N–S trend that cross the central part of the area are of unknown origin.

We believe the most promising locations for further ore exploration (including drilling) in the KROD are nexuses where lineaments of mode (7) and mode (10) and (9) intersect and ore enrichment may occur. These zones are located in the vicinity or extension of previously exploited ore veins containing sulphide mineralization with gold. Mining in these abandoned workings was carried out from the surface to a depth of probably no more than 150 m below the surface. The VLF results indicate the possibility of new ore veins or extensions of old ore veins structurally related to the visible tectonic directions and their mutual intersections (nodes). In the case of the Czarnów deposit, the situation is not obvious. Some adjustments to the course of the faults (based on the VLF lineaments) can be made; however, no obvious continuation of the known vein can be detected. En echelon lineaments detected to the west of the quarry are a possible prospecting target where ore enrichment

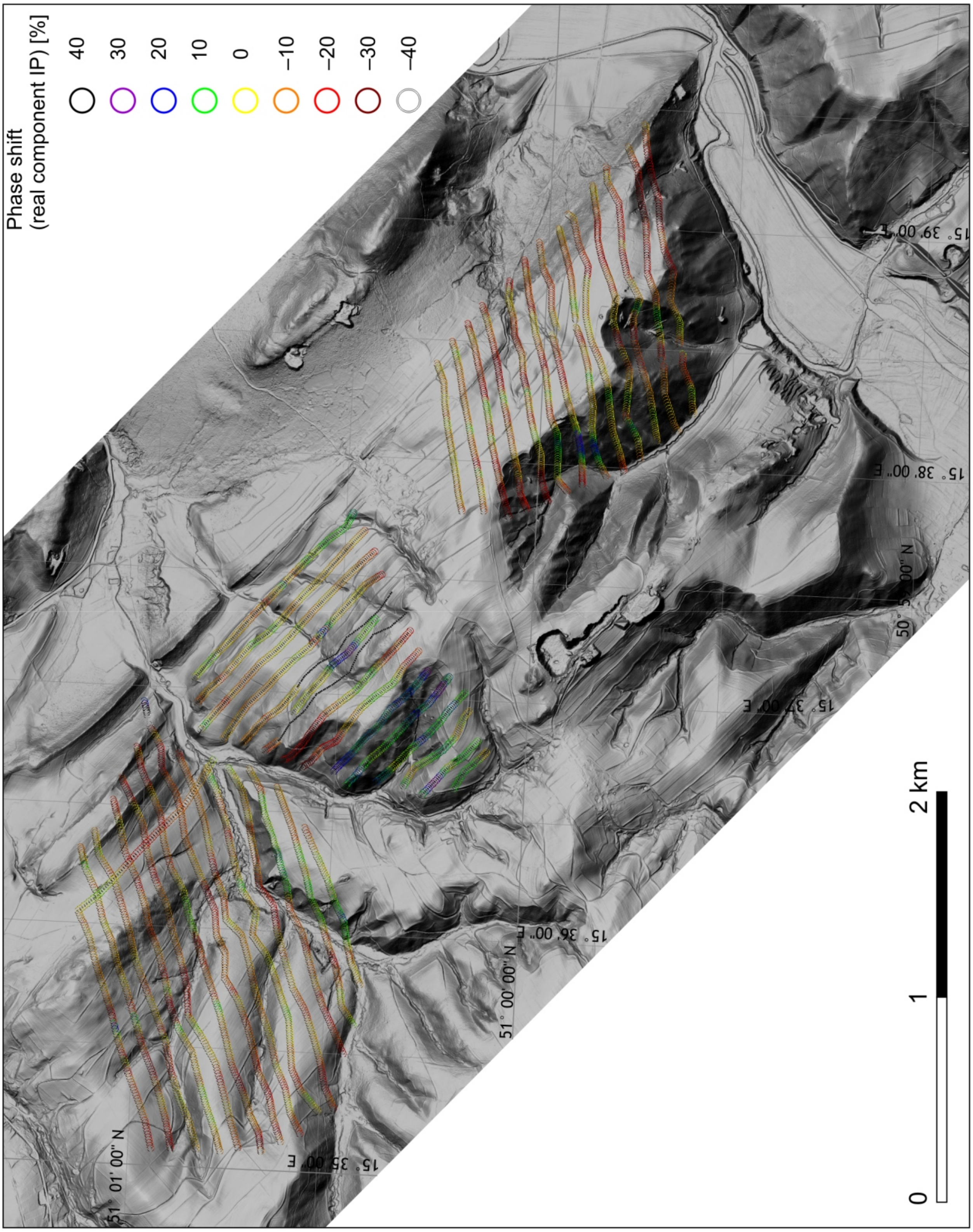

Fig. 5. Point-map of in-phase component of induced VLF field

Illustration of the survey setting and one of the unfiltered phase shift components in the abandoned Klecza-Radomice Ore District

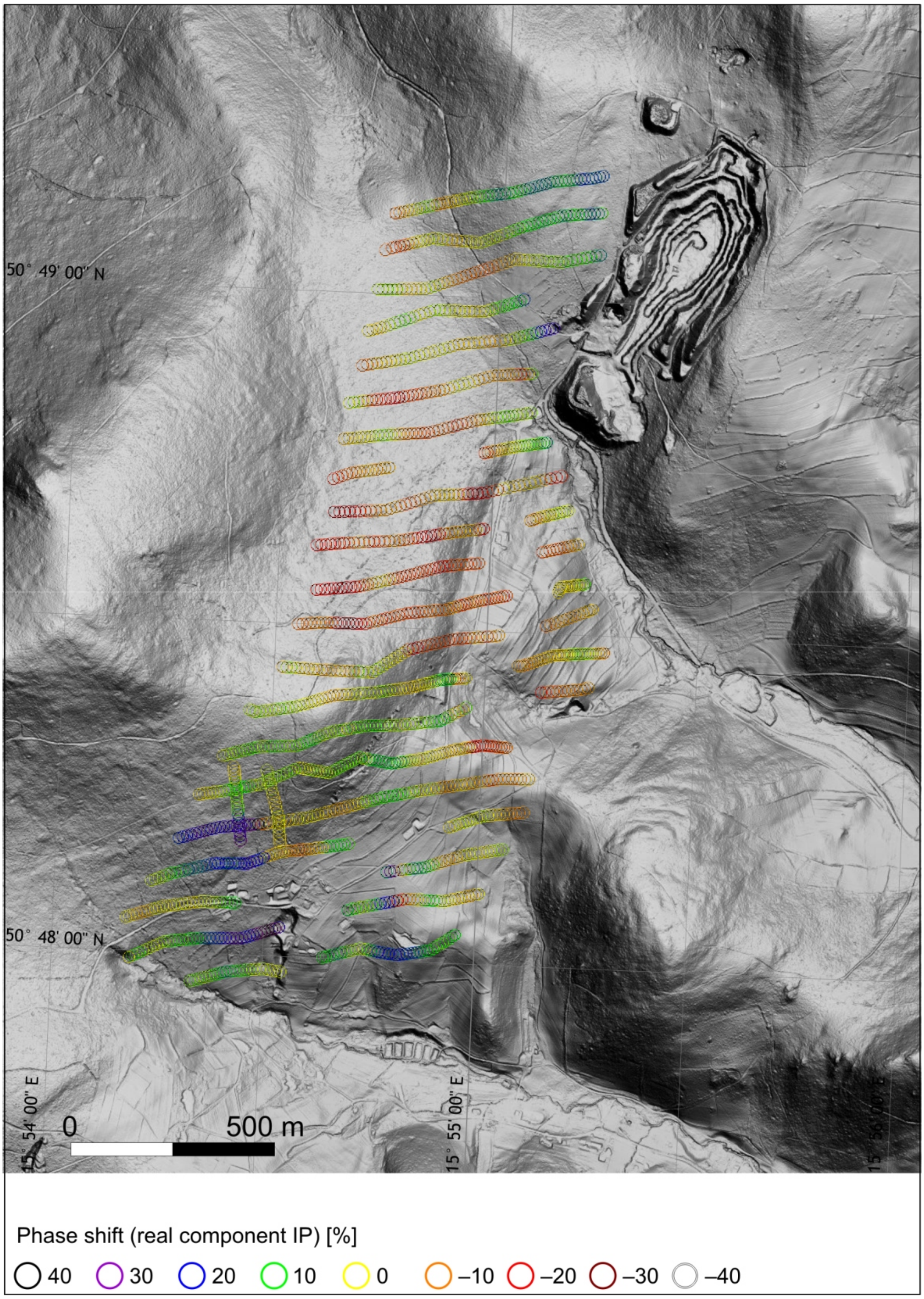

Fig. 6. Point-map of in-phase component of the induced VLF field

Illustration of the survey setting and one of the unfiltered phase shift components in the abandoned Czarnów As-polymetallic deposit

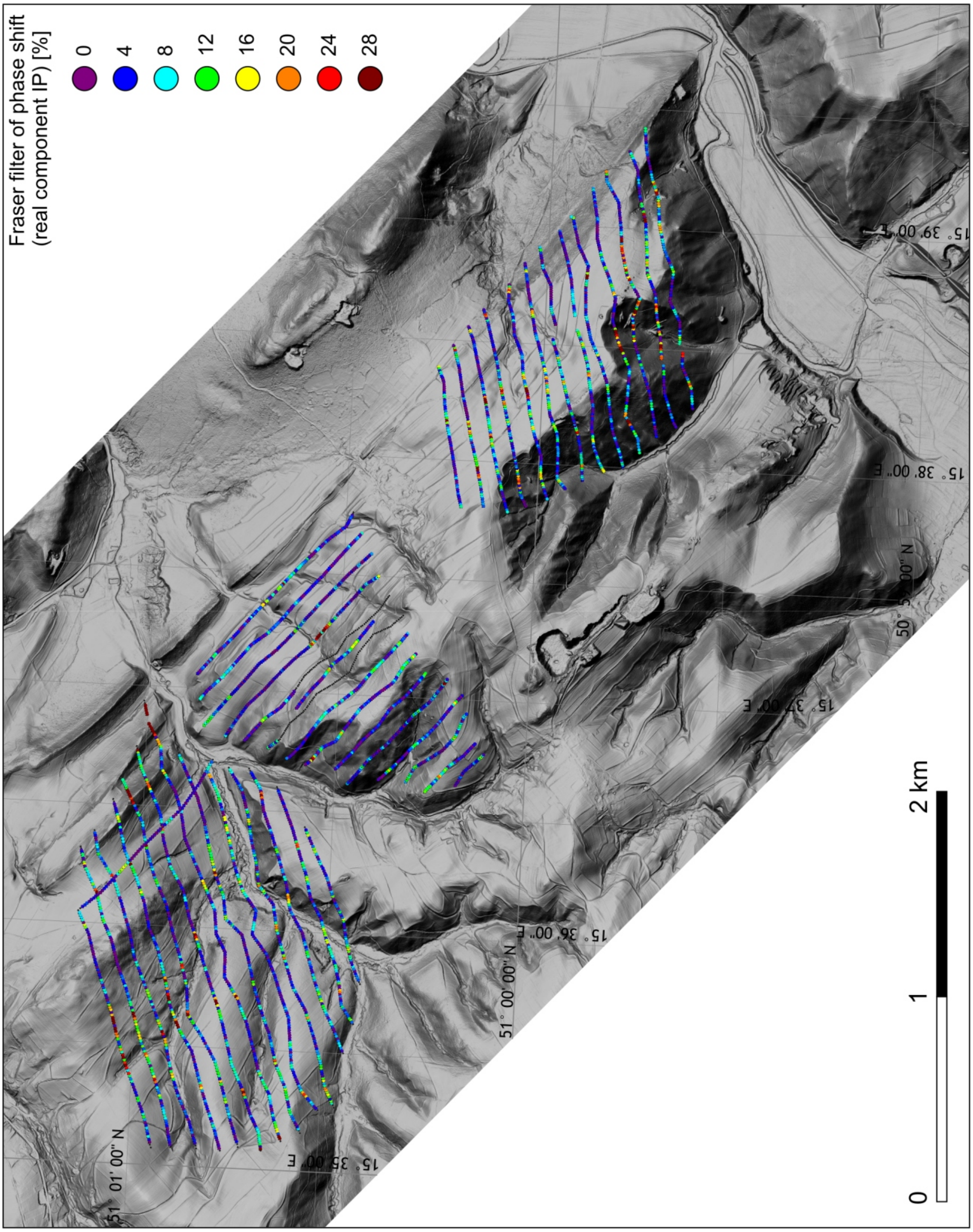

Fig. 7. A point map of the result of Fraser filtering of the in-phase component obtained for the Skelton transmitter in the abandoned Klecza-Radomice Ore District

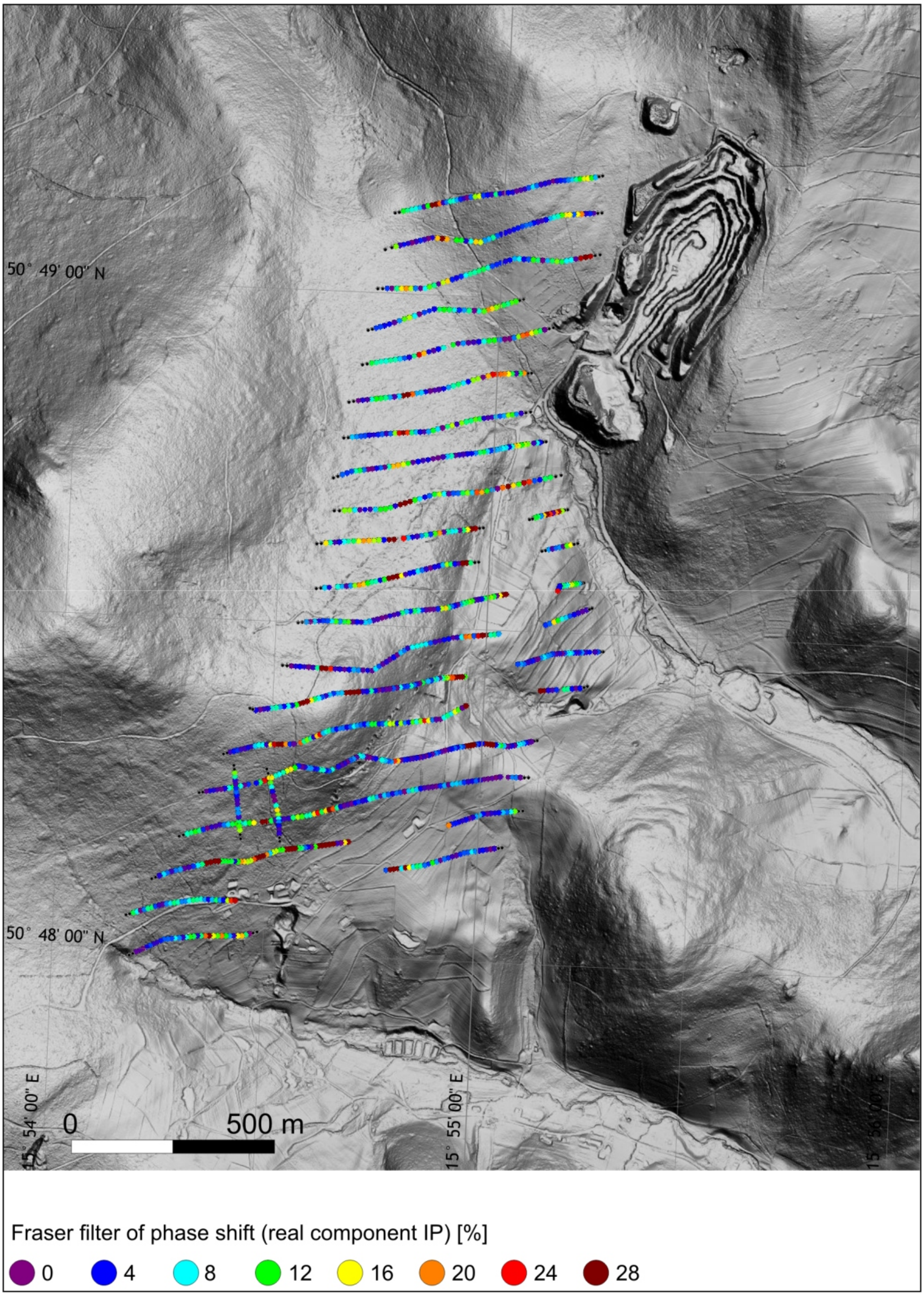

Fig. 8. A point map of the result of Fraser filtering of the in-phase component obtained for the Skelton transmitter in the abandoned Czarnów As-polymetallic deposit

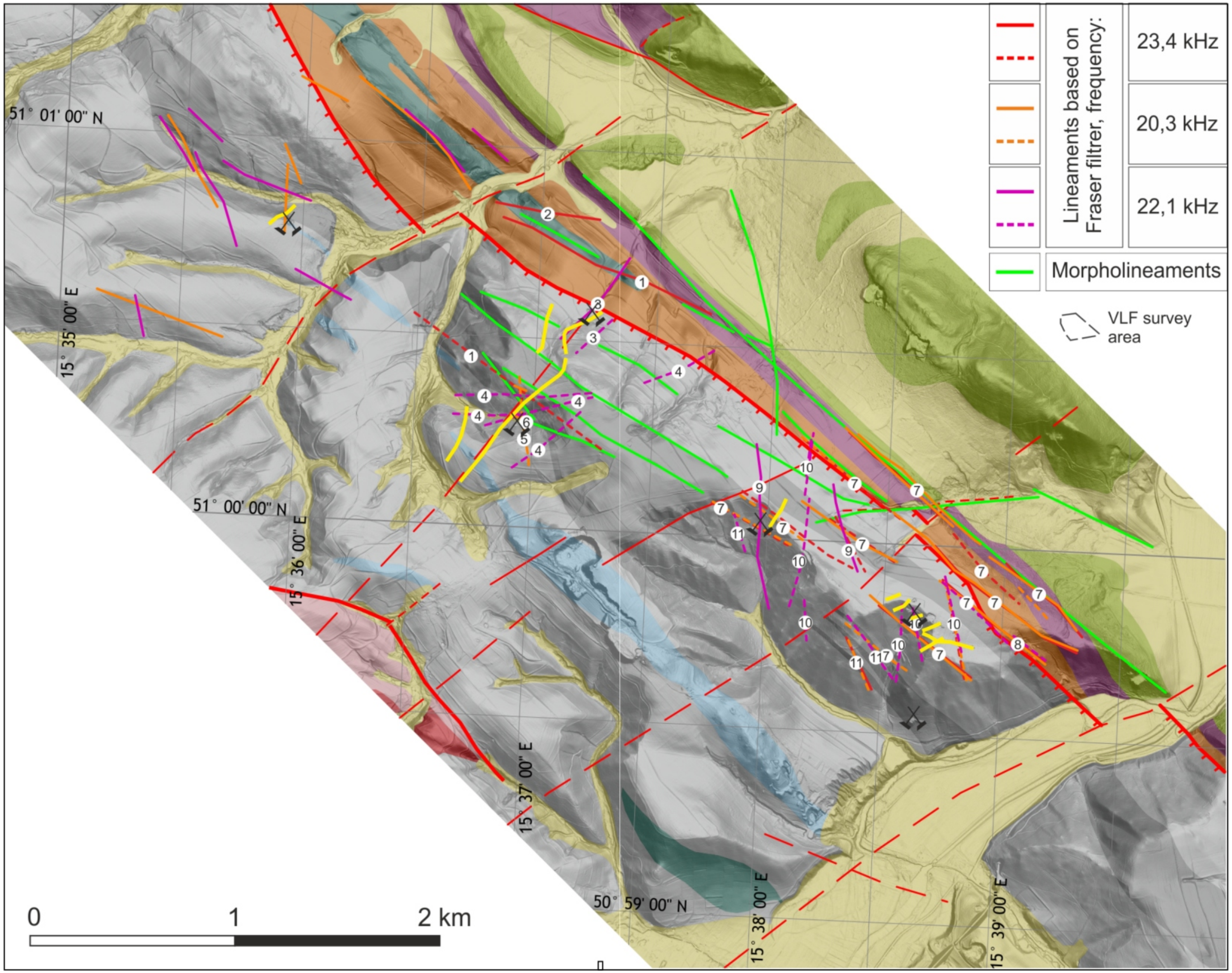

Fig. 9. A map of interpreted linear VLF anomalies in the abandoned Klecza-Radomice Ore District

The anomalies are results of linear structural features with conductivity contrasting with the surrounding medium

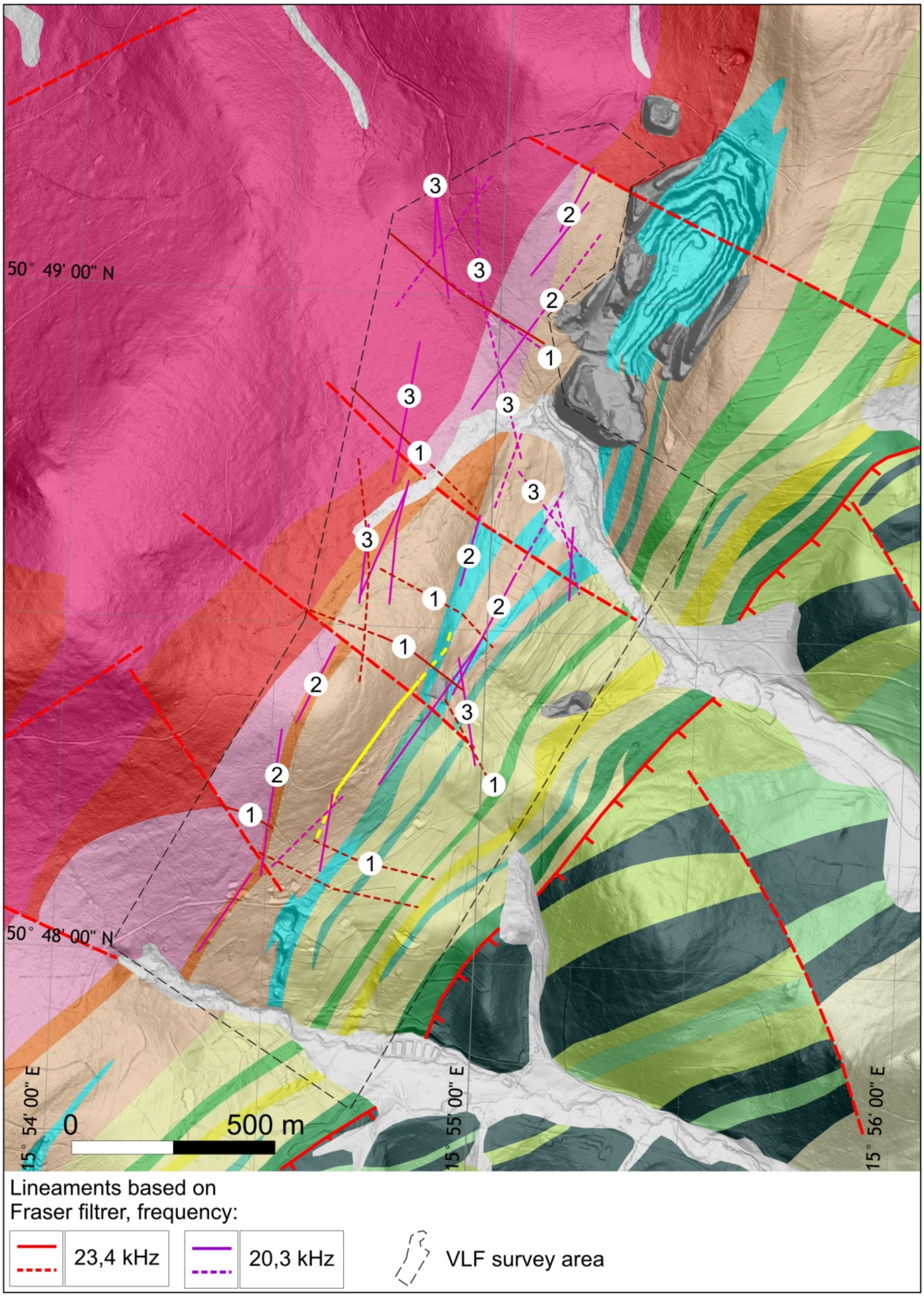

Fig. 10. A map of interpreted linear VLF anomalies in the Czarnów As-polymetallic deposit

The anomalies are results of linear structural features with conductivity contrasting with the surrounding medium might have taken place. Direct continuation of the vein to the NNE is doubtful in the light of the survey results obtained, but the occurrence of separate mineralised veins to the west of the quarry is consistent with previous observations of polymetallic sulphide mineralisation and a series of secondary bismuth and tellurium minerals described from the quarry (Parafiniuk and Domańska, 2002; Pieczka et al., 2005). An extension of the mineralized zones to the NE of the Czarnów deposit may be present, but probably as a separate set of veins. The NW–SE trending lineaments can be attributed to faults perpendicular to the general strike of the structures (1). Lineaments with an azimuth of 10–20° are probably related to lithological boundaries and quartz veins (2). The cluster of such lineaments present to the west of the quarry is arranged in an en echelon pattern, and may be an effect of the occurrence of veins. Lineaments close to a N–S trend that cross the central part of the area are of unknown origin (3).

The results obtained from the VLF survey in the former polymetallic gold mining areas give hope for the discovery of new ores in these historic shallow mining areas in difficult forested mountainous terrain. This innovative approach to an otherwise obsolete prospecting technique has yielded useful results, particularly on small targets.

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