MAP002: D5.4 - Skarn testing report

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Name of the author/Responsible partner: Andreas Brosig, Beak Consultants GmbH
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Content

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1. Introduction

1.1. Review of 3-Part-Assessment

The 3-part-assessment is a statistical method to produce estimates of undiscovered mineral deposits in a certain area. The precondition for and first part of the assessment is the formulation of a descriptive model of the type of deposit under investigation: its geological environment, associated rock types, structural environment, age range and if applicable the depositional environment of the host rocks and the existence of associated deposits. Supplementary information includes the geochemical and geophysical signature of the deposit and any associated alteration zones. Based on this descriptive model a list of similar deposits from the same area or worldwide is compiled. In this step only deposits with published grade and tonnage data are useful for the construction of a Grade-Tonnage model.

In the second part permissive tracts are delineated within the assessment area. A permissive tract is defined as an area where the geological conditions for the formation of the investigated deposit type exist (or have existed in the past). If possible, areas of high and low perspectivity should be grouped in separate tracts such that the probability of finding an undiscovered deposit is approximately equal in each part of a given tract. The number of undiscovered deposits within each tract can be estimated from empirical deposit density functions or by convening a panel of experts who give their estimates of the number of undiscovered deposits at different levels of confidence (e.g. at the 90%, 50% and 10% level). From these estimates a probability density function of the number of undiscovered deposits for each permissive tract is calculated.

In the third part, a Monte Carlo simulation for each tract combines the probability density function of the ore tonnages, the grades of each commodity, and the number of undiscovered deposits. From this large number of simulated deposits statistical estimates of the undiscovered ore and commodity tonnages in each permissive tract are derived (Singer & Menzie, 2010).

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1.2. Review of MAP software

The MapWizard software consists of a set of tools to perform an assessment of undiscovered mineral resources.

The grade-tonnage model tool estimates probability density functions (pdf) for ore tonnage and metal grade data or metal tonnage data of well-known deposits input by the user. The tool provides summary statistics and plots of the data and estimated probability distributions, and saves the distribution probability density function(s) for use in the Monte Carlo simulation. Several probability density functions can be created in successive runs using different combinations of input parameters, and the final model to be used can be selected among these and saved permanently for further use in other assessments.

The tract delineation tool is used to delineate the outer limits of the permissive tract and to classify the tract based on prospectivity using mineral potential mapping methods Fuzzy logic (Fuzzy) or Weights of evidence (WofE).

The undiscovered deposits tool estimates a probability mass function (pmf) for the number of undiscovered deposits that might exist within a permissive tract. The tool provides summary statistics and plots of the input data and estimated probability distribution, and saves the distribution probability mass function for use in the Monte Carlo simulation.

The Monte Carlo simulation tool produces a set of simulated undiscovered deposits and a probabilistic estimate of the amount of undiscovered mineral resources contained by these deposits. The tool uses the probability mass function estimated for the number of undiscovered deposits within a permissive tract by the undiscovered deposits tool together with the probability density functions estimated for ore tonnage and metal grades, or for metal tonnage, by the grade-tonnage model tool. It creates a large number (default 20,000 simulation rounds) of simulated undiscovered deposits and calculates their metal contents. It produces summary statistics and plots of the results, as well as a .csv file containing all the simulated deposits.

The aggregate results tool combines estimates of the number of undiscovered deposits for several permissive tracts and produces an aggregated estimate. The tool accepts as input either a combined tract probability distribution file or separate probability distribution files for each tract. In the latter case, the tool combines the separate files into one. The other required input is a correlation matrix of user-defined dependencies among the tracts to be aggregated. The tool estimates a probability distribution for the number of deposits for the aggregated tracts. It reports the results for three scenarios: assuming total independence between the tracts, assuming total dependence between the tracts, and using the user-defined matrix of correlations between the tracts (GTK, 2020).

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1.3. Descriptive model

(adapted from Cox & Singer, 1996)

General description

Tin skarns are stratiform bodies of metasomatically altered rock. The fluid source is typically an intrusion of high-silica granites generated by partial melting of the continental crust. Tin skarns can form within a distance of several hundred metres from the fluid source from carbonate-bearing rocks, such as limestone, marble, marl or some basic volcanic rocks (diabase). The lateral extent can vary from metres to more than one kilometre while the thickness may vary from centimetres to a few tens of metres. Often, several closely associated skarn bodies are encountered. The principal minerals depend on the source rock and fluid composition (typically magnetite, garnet-pyroxene or magnesian skarns), but the economically recoverable tin is usually present in the form of cassiterite.

Examples

Cleveland	Collins, 1981
Moina	Meinert, 1992
Lost River	Meinert, 1992
Dachang	Pohl, 2011

Geological Environment

Rock Types: Leucocratic biotite and/or muscovite granite, specialized phases or end members common, felsic dikes, carbonate rocks.

Structures and textures: Plutonic textures most common (granitic, seriate, fine-grained granitic). Also porphyritic-aphanitic; skarn is granoblastic to hornfelsic, banded skarn common.

Age Range: Proterozoic to recent

Depositional Environment: Epizonal(?) intrusive complexes in carbonate terrane.

Associated Deposit Types: W skarn, Sn greisen, and quartz-cassiterite-sulfide veins; at increasing distances from intrusive-carbonate contact Sn replacement and fissure lodes may develop (as at Renison Bell).

Mineralogy: Cassiterite ± minor scheelite ± sphalerite + chalcopyrite ± pyrrhotite ± magnetite ± pyrite ± arsenopyrite ± fluorite in skarn. Much Sn may be in silicate minerals (garnet, sphene, and vesuvianite) and be metallurgically unavailable.

Alteration

Greisenization (quartz-muscovite-topaz ± tourmaline, fluorite, cassiterite, sulfides) near granite margins and in cusps; topaz tourmaline greisens. vesuvianite + Mn-grossular-andradite ± Sn-

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andradite ± malayaite in skarn; late-stage amphibole + mica + chlorite and mica + tourmaline + fluorite

Ore Control

Mineralized skarns may or may not develop at intrusive contact with carbonate rocks; major skarn development up to 300 m from intrusion controlled by intrusion-related fractures; cross-cutting veins and felsic dikes.

Weathering

Erosion of lodes may lead to deposition of tin placer deposits.

Geophysical signature

Strong magnetic anomaly for magnetite skarns; may appear as high density bodies in gravimetry if sufficiently thick and close to the surface, typically associated with large negative gravity anomalies caused by the associated granite pluton

Geochemical Signature

Sn, W, F, Be, Zn, Pb, Cu, Ag, Li, Rb, Cs, Re, B. Specialized granites characteristically have SiO2 > 73 percent, K2O > 4 percent and are depleted in CaO, TiO2, MgO, and total Fe. They are enriched in Sn, F, Rb, Li, Be, W, Mo, Pb, B, Nb, Cs, U, Th, Hf, Ta, and most REE. They are depleted in Ni, Cu, Cr, Co, V, Sc, Sr, La, and Ba.

1.4. Grade tonnage model

The grade-tonnage data in the following Table 1 were compiled from the published literature, information published on mining company web sites and in the case of the Erzgebirge deposits from a previous compilation by the Saxon Ministry of Economics and Labour (SMWA). In some cases WO_3 is not listed among the recoverable commodities. For these deposits the WO_3 grade is set to 0.01%, slightly below the lowest reported commodity value (0.012% in the Ehrenfriedersdorf-Hahnrück deposit). This is justified because at these low grades there is no perspective for economic tungsten recovery and in consequence the exact shape of the grade curve in this interval is unimportant for the overall assessment of potentially economic resources.

Table 1 Grade and tonnage data for Tin skarns. Tungsten grades in italics are minimum grades where no grades are published.

ID	Name	Ore [t]	Sn grade [%]	WO_3 grade[%]	Source
001	Hämmerlein	13,770,000	0.4	*0.01*	Hösel, 2003
002	Tellerhäuser	13,058,000	0.71	*0.01*	Schuppan & Hiller, 2012

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ID	Name	Ore [t]	Sn grade [%]	WO_3 grade[%]	Source
003	Pöhla Globenstein	14,645,200	0.57	0.45	Schuppan & Hiller, 2012
004	Breitenbrunn	22,000,000	0.25	*0.01*	SMWA, 2008
005	Antonsthal	14,700,000	0.19	0.47	SMWA, 2008
006	Bernsbach SE	126,000,000	0.04	0.125	SMWA, 2008
007	Geyer SW	8,219,000	0.56	*0.01*	Hösel, 1996
008	Geyer NE	273,000	0.52	*0.01*	Hösel, 1996
009	Ehrenfriedersdorf Hahnrück	790,000	0.44	0.012	Hösel, 1996
010	Delitzsch SW	11,400,000	0.017	0.45	SMWA, 2008
011	Cleveland	1,312,000	0.69	*0.01*	Collins, 1981
012	Shizhuyuan	342,857,142	0.14	0.31	Jiang et al., 2018
013	Dachang	110,000,000	0.8	*0.01*	Pohl, 2011
014	JC Yukon Territory	1,250,000	0.54	*0.01*	Meinert, 1992
015	Moina	30,000,000	0.15	0.1	Meinert, 1992
016	Lost River 1	3,000,000	0.27	0.04	Meinert, 1992
07	Achmmach	7,000,000	0.8	*0.01*	Mouttaqui et al., 2012
018	Lost River 2	23,527,000	0.26	0.04	USGS, 1998
019	Mount Lindsay	45,000,000	0.2	0.1	Venture Minerals, 2012
020	Gillian	2,530,000	0.78	*0.01*	Consolidated Tin Mines Limited, 2020
021	Pinnacles	7,035,000	0.3	*0.01*	Consolidated Tin Mines Limited, 2020
022	Windermere	2,040,000	0.27	*0.01*	Consolidated Tin Mines Limited, 2020
023	Deadmans Gully	444,000	0.34	*0.01*	Consolidated Tin Mines Limited, 2020

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The grade models for tin and tungsten calculated with the MAP software have the following properties (The column Gatm refers to the actual grades from the grade and tonnage model; the column Pdf refers to the probability density function representing the grades):

Component: Sn

	Gatm	Pdf
Minimum	0.017	0.00542
0.25 quantile	0.213	0.20400
Median	0.340	0.35400
0.75 quantile	0.567	0.59600
Maximum	0.800	2.57000

Component: WO_3

	Gatm	Pdf
Minimum	0.01	0.00146
0.25 quantile	0.01	0.00927
Median	0.01	0.01450
0.75 quantile	0.10	0.09970
Maximum	0.47	2.57000

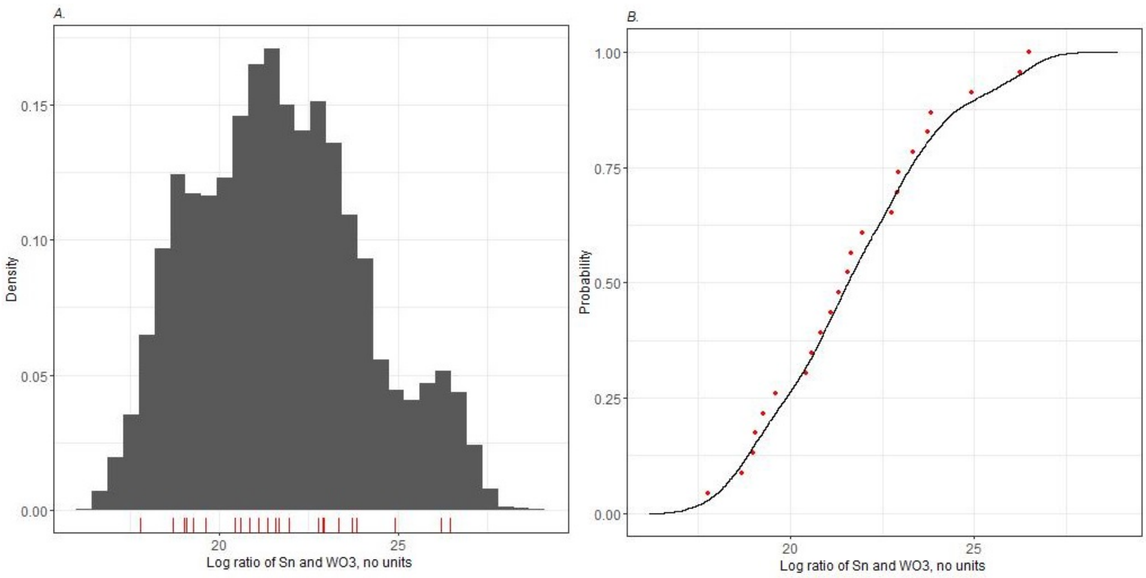

Figure 1 The grade model for tin and tungsten (calculated as WO_3)

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The tonnage model for the tin skarns calculated with the MAP software has the following properties:

	Gatm	Pdf
Minimum	2.73e+05	2.49e+04
0.25 quantile	2.16e+06	2.08e+06
Median	1.14e+07	9.68e+06
0.75 quantile	2.31e+07	2.63e+07
Maximum	3.43e+08	3.06e+09
Mean	3.48e+07	3.98e+07
Standard deviation	7.39e+07	9.76e+07

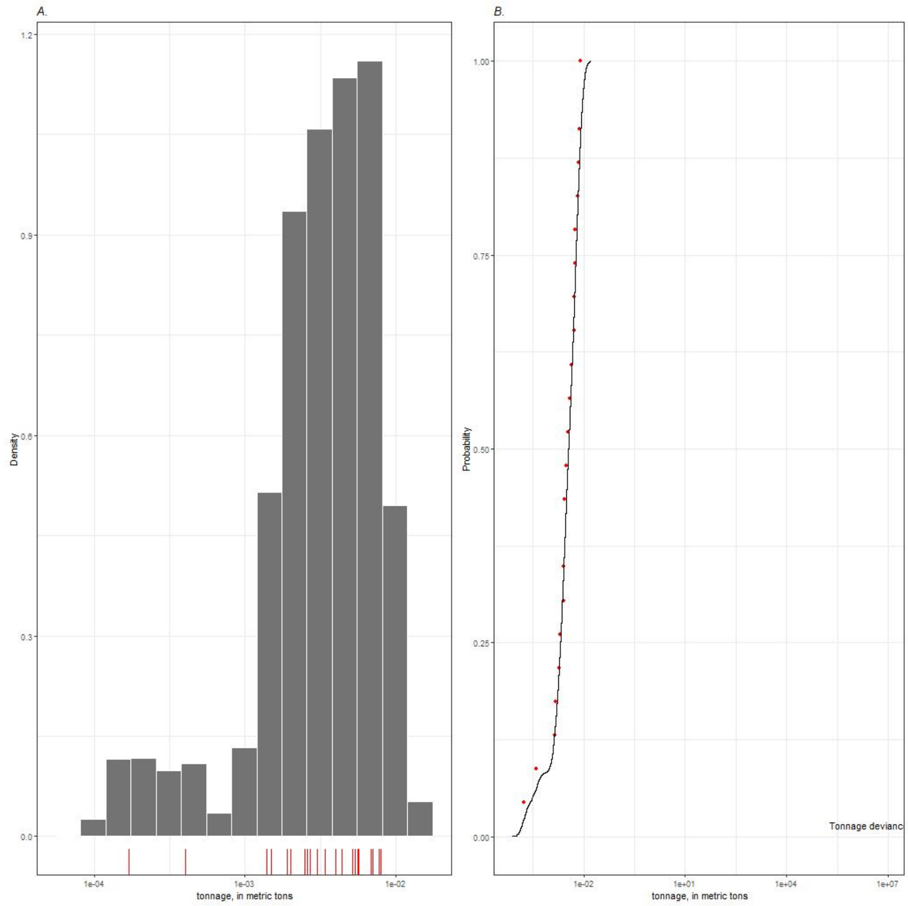

Figure 2 The tonnage model for tin skarns

The plots of the tin and tungsten contents in the simulated deposits show good agreement with the observed deposits (Figure 3). Most of the observed and simulated deposits are tungsten-poor

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but there are smaller groups of tin-poor but tungsten-rich deposits and of deposits enriched in both tin and tungsten.

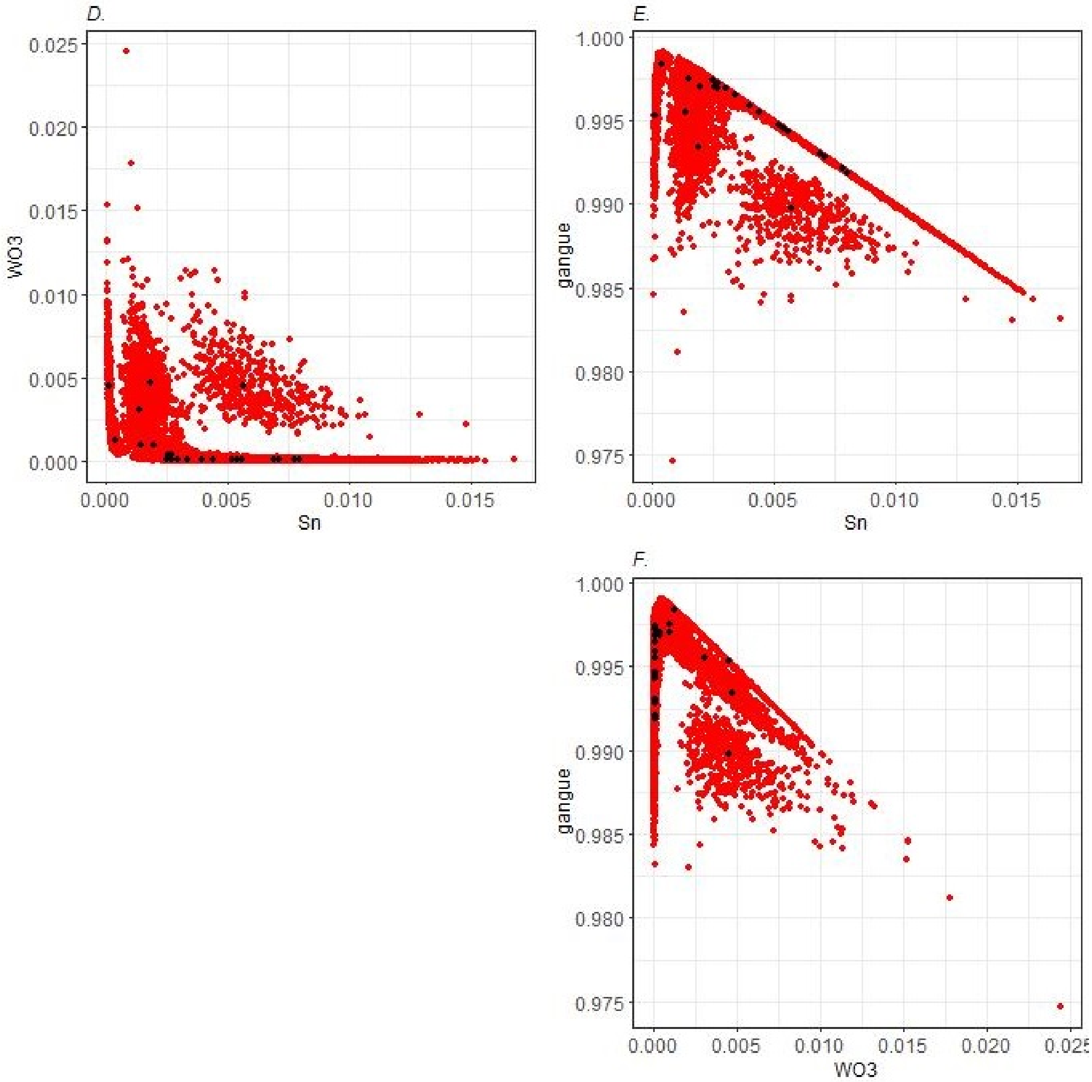

Figure 3 Plots of the tin, tungsten (calculated as WO_3) and gangue mineral content in the observed (black) and simulated (red) deposits

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2. Skarn Deposits in the Erzgebirge

2.1. Review of regional geology / minerogeny

The Erzgebirge is part of the Variscan orogen in Central Europe and more specifically of the Saxothuringian domain (see Figure 11 for a geologic map). The principal geologic and minerogenic processes that have affected the area can be grouped in several phases (Beak, 2019):

580(?) – 510 Ma: Cadomian Basement

During the late Proterozoic and the Cambrian, turbiditic sediments with intercalations of carbonates, contemporarily intruded by granodioritic batholiths, form an active continental margin of Northern Gondwana. Carbon bearing layers in metasediments act as geochemical traps in later stages. Possibly accumulation of Fe, As, Sb, Ag, ±Au in sedimentary strata.

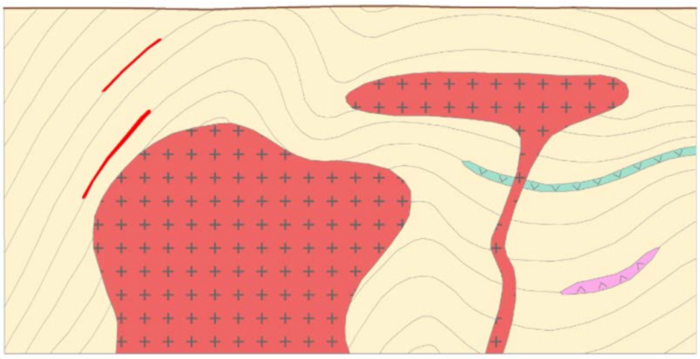

Figure 4: Schematic section of the assessment area during the formation of the Cadomian basement

470 – 360 Ma: Passive Continental Margin

From the Ordovician to the Devonian, extensive plate-reorganization due to back-arc rifting form passive continental margins with sequences of turbiditic sediments with intercalations of carbonates, quartz sandstones and conglomerates. Bimodal volcanism and hydrothermal activity with metal bearing mounds and mud were interbedded with the sediments. Main metals are Fe, Zn, Cu, Sn, W, Co, Bi, Sb, Ag, and Au.

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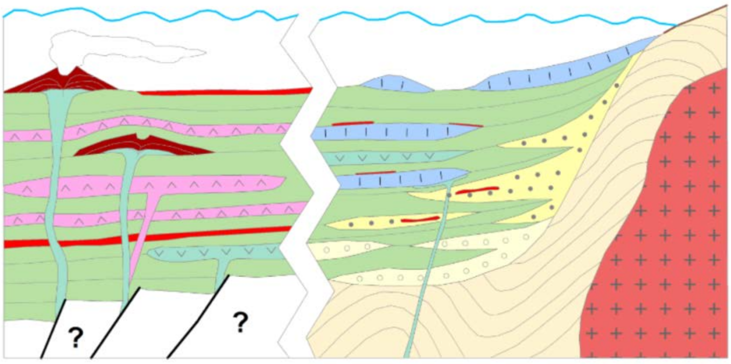

Figure 5: Schematic section of the assessment area during the passive continental margin phase

340-330 Ma: Variscan Orogeny

The Gondwana-Laurussia collision results in the Variscan orogeny. Peak metamorphic conditions (UHP) occurred around 340 Ma. At about 330 Ma, the orogenic collapse and exhumation of the subduction-accretionary complex led to the recently observed configuration of the nappe pile. Metal bearing mounds and muds form various stratiform mineralisations including sulfide seams, metamorphic skarns and similar metal-enriched formations. The redistribution of Hg, Sb, Au, As and Ag in different parts of the nappe pile depends on the specific metamorphic P-T conditions.

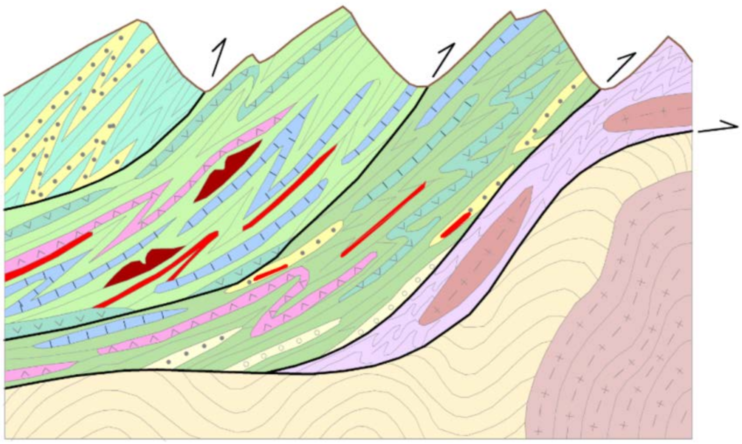

Figure 6: Schematic section of the assessment area during the peak phase of the Variscan orogeny

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325 – 290(?) Ma: Late Orogenic Stage

The main intrusion phase of the Variscan Granites lasts from 325 to 315 Ma, Minor extensive magmatic events occurred until 290 Ma. Rising fluid rich granitic melts assimilate metal bearing metasediments and redistribute the metal content. Sn, Li and W are enriched in suitable structures of apical parts of intrusions, volcanic pipes, breccias and fault zones, partly with a rich polymetallic component (Cu, Sb, Bi, Co, Au, In). Hydrothermal-metasomatic processes overprint preexisting stratiform deposits producing further enrichments in suitable lithologies. Hydrothermal-metasomatic processes overprint preexisting stratiform deposits producing further enrichments in suitable lithologies.

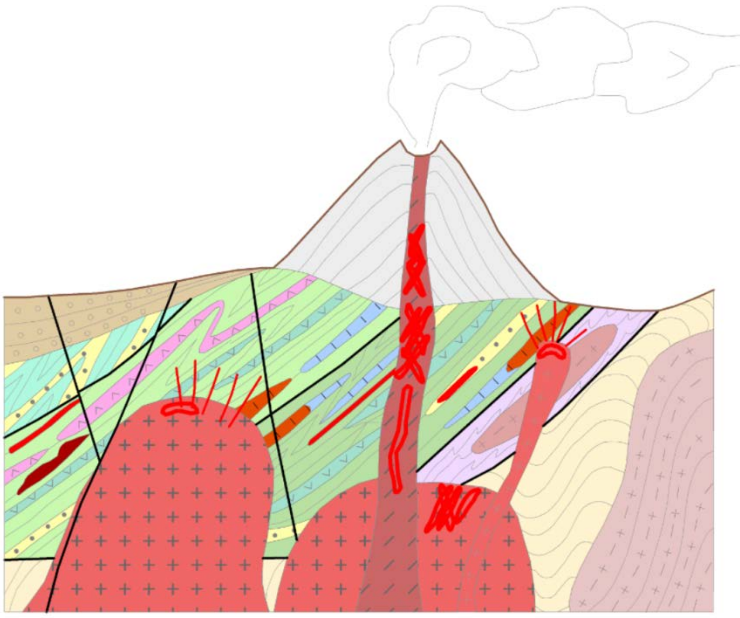

Figure 7: Schematic section of the assessment area during the late stage of the Variscan orogeny

290 – 70 Ma: Transition and Platform Stage

During the Permian to Cretaceous, fault zones with dominant NW-SE strike dissect the Erzgebirge/Vogtland into several tectonic blocks. Concurrent with the tectonic activities, heat domes produce several generations of metalliferous hydrothermal systems (e.g. fluorite, U, As, Sn, Cu, Pb, Zn, Au, Ag, relocating metals and minerals from former deposits into vein structures and seams using suitable lithologies as geochemical traps. Decreasing tectonic and thermal activities lead towards a slow cessation of endogenic activities in the upper Permian (257 Ma). In the Cenomanian to Turonian the area is partially covered by fluvial and shallow marine deposits hosting modest tin and gold placers.

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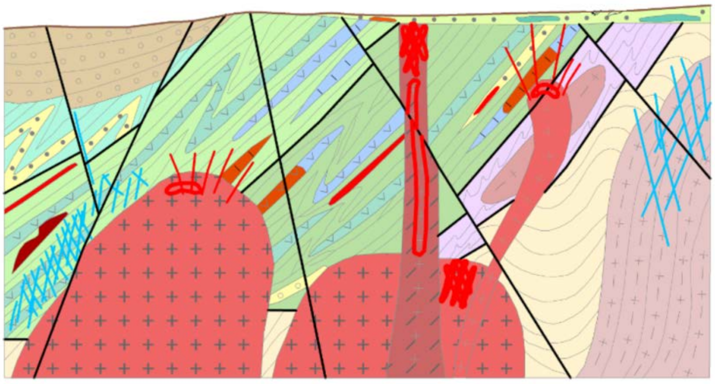

Figure 8: Schematic section of the assessment area during the transition and platform stage

70 – 0 Ma: Riftogenic Stage

The formation of the Eger rift above a mantle plume began with the intrusion of ultramafic alkaline dikes, followed by extensive volcanism (30 Ma). Small volumes of mafic and alkaline volcanics are emplaced throughout the Erzgebirge/Vogtland area in dykes, pipes and maars. Faults were reactivated; heat domes led to continued mineralisation processes in mostly pre-existing tectonic structures (e.g. barite and fluorite veins, U, Co, Ni, Ag, As, Bi veins).

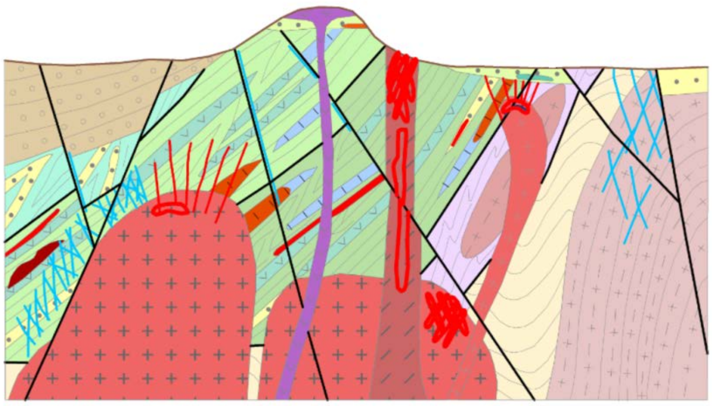

Figure 9: Schematic section of the assessment area during the Cenozoic rift phase

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2.2. Tract delineation

A compilation of minerogenic data relating to skarn deposits in the Erzgebirge and a predictive map for tin skarns modelled with a Neural Network algorithm (Figure 10) were available from the WISTAMERZ research project. The predictive map was produced with the advangeo® Prediction Software. The algorithm requires several known deposits in the area as training data and can then produce estimates of favourability from a wide range of model input data, in this case geological data, tectonic data, geophysical and geochemical data. The specific data sets and their weighting in the predictive map as determined by the Neural Network are given in Table 2.

The predictive map delineates the areas with the highest favourability for tin skarns. For the 3-Part-Assessment the permissive tracts should, however, not only contain the most favourable areas, but all areas where the geological condition could allow the existence of the deposit type in question. Therefore, the permissive tracts were expanded into geologically similar units adjoining the highly favourable regions. The selection was guided mainly by the presence or absence of concealed Variscan granites and the amount of calcareous lithologies in the cover rocks. Both criteria were also used to subdivide permissive areas into tracts of different likelihood for the existence of undiscovered deposits (e.g. areas with known underlying granite versus areas with suspected underlying granite). In total, 776 km² of the 4800 km² project area is regarded as permissive. The tracts are described in chapter 3 along with the Assessment results.

Table 2: Weighted model input data for the mineral predictive map for tin skarns which was used as a base for the delineation of permissive tratcs

Model Input data	Connection weights	Weighting from Garson´s Algorithm
Magnetics\ AnalyticalSignal	272,32	6,34
Geology\Jáchymov Group	69,82	3,43
Geology\Micaschuist complex	166,55	3,37
Magnetics\Horizontal Gradient	-72,4	3,22
Faults Length\ >10 km	4,23	3,21
Granite Distance\to type Bergen	62,37	2,93
Geology\Gräfenthal Group	61,52	2,49
Granite Distance\to Sn-granite	70,48	2,13
Geology\Garnet-phyllite complex	77,11	1,95
Gravimetry\ Gradient	-50,03	1,92
Gravimetry\ Profile Curvature negative	-5,75	1,63

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Model Input data	Connection weights	Weighting from Garson´s Algorithm
Faults Direction\ NE-SW	15,08	1,51
Faults Direction\ N-S	-2,92	1,37
Faults Length\2-4 km	-17,08	1,31
Gravimetry\Profile Curvature positive	6,07	1,09
Stream Sediment Geochemistry\Pb	-8,71	1,08
Faults_Length\4-10 km	11,52	1,07
Faults_Direction\E-W	14,78	1,05
Faults_Direction\Fault crossings	13,22	1,02
Stream Sediment Geochemistry\Cu	8,45	0,99
Faults_Length\<2 km	-0,13	0,97
Faults_Direction\ NW-SE	3,14	0,93

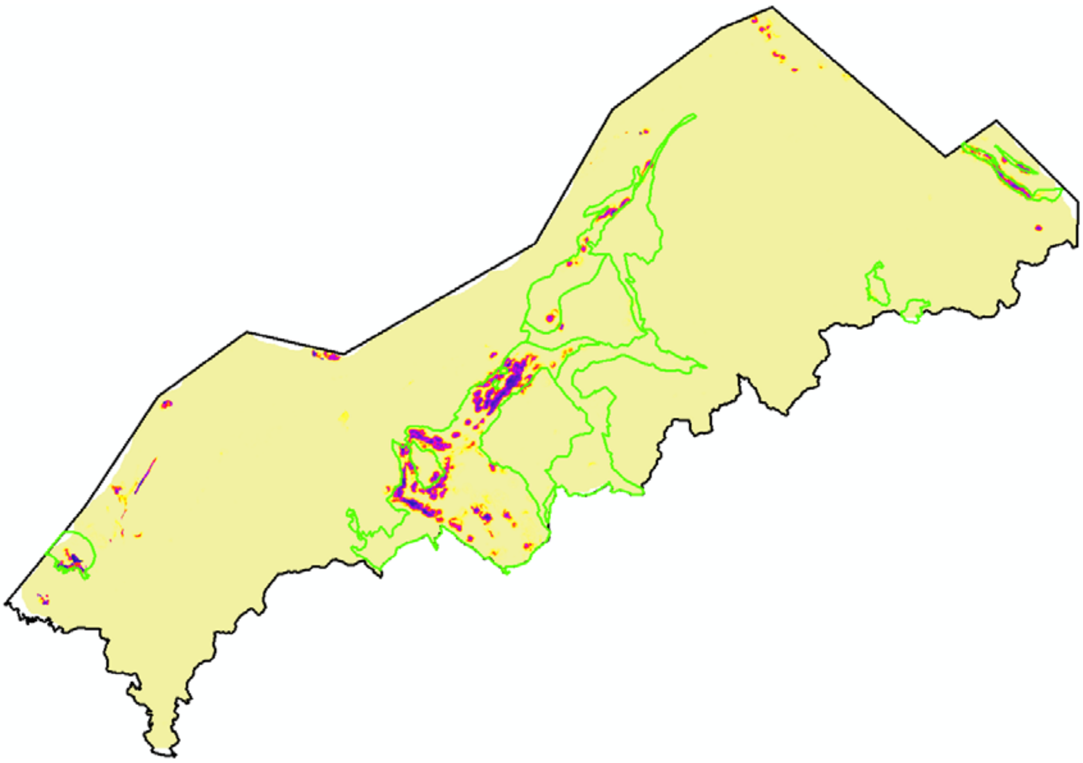

Figure 10: AI-based predictive map for tin skarns in the Erzgebirge with superimposed permissive tracts

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2.3. Estimation of number of undiscovered deposits

Five experts with between four and 40 years of experience in the economic geology of the project area and its skarn occurrences were asked to provide estimates for the number of undiscovered deposits in each tract and a short rationale for their estimate. The experts conducted their estimates independently based on their expert knowledge and on a map package containing geologic maps, maps of concealed granite plutons, geophysical and geochemical maps and a map of the known deposits. The estimates are for the number of undiscovered deposits down to a depth of 1000 m. Deeper deposits may exist but are excluded from the assessment as they are very unlikely to be of economic interest. Special emphasis was put on the fact that the estimated undiscovered deposits should conform to the grade tonnage model and that smaller mineralisations do not count as undiscovered deposits, as recommended by Singer & Menzie (2010). The submitted estimates are tabulated in Table 3.

Table 3: Expert estimates for the number of undiscovered deposits in Permissive Tracts (PT) 1 to 7. The estimates are reported at the 90%, 50 % and 10% levels of confidence.

	PT1			PT2			PT3			PT4			PT5			PT6			PT7		
	P90	P50	P10	P90	P50	P10	P90	P50	P10	P90	P50	P10	P90	P50	P10	P90	P50	P10	P90	P50	P10
A	1	2	3	2	3	4	0	0	0	2	3	5	1	2	3	0	1	2	1	2	3
B	0	1	2	3	5	8	0	0	0	1	2	3	0	0	0	0	0	0	1	3	5
C	0	1	2	1	3	5	0	1	1	0	1	1	0	0	0	0	0	0	0	0	1
D	0	1	2	1	3	5	0	0	1	0	1	3	0	0	1	0	0	1	0	1	4
E	0	1	3	2	4	8	0	0	1	1	2	3	0	0	2	0	0	1	0	1	3

The estimates show that the experts generally agree that the tracts are of different perspectivity. Tract 2 gets the highest rating by all experts whereas tracts 3, 5 and 6 are viewed as having low potential for undiscovered deposits. Tract one is rated with intermediate potential. Tracts 4 and 7 show some disagreement between experts, who variously gave low to intermediate estimates for the number of undiscovered deposits. The difference in expert opinion concerning tracts 4 and 7 is mainly due to the low level of exploration and the lack of discovered deposits in these tracts. In consequence, the estimates are biased by which of the better explored tracts the experts consider most closely comparable. Considering the fact that the estimates are still of the same order of magnitude, it was decided to keep all of the estimates and assign a weighting of 1 to each expert.

The following is a summary of the rationales given by the experts for the estimates of the number of undiscovered deposits in each tract:

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Permissive Tract 1: Tin skarns of low economic importance are known from 19th century mine works. A concealed granite cupola of small size is known to exist, however carbonatic lithologies in the cover rocks are rare. The cover rocks contain abundant diabase which can form skarn-like lithologies in case of pervasive metasomatosis.

Permissive Tract 2: Several tin skarns of high economic importance are known in this tract. Extensive concealed bodies of tin-specialised granite exist throughout the tract. The cover rocks contain numerous carbonatic layers. Large tracts of the cover rocks show geochemically anomalous enhanced tin contents which may have been remobilised during metasomatosis and contributed to the tin content of the skarns. The area is relatively well explored, but undiscovered deposits likely exist in some less well explored parts and at depths > 500 m.

Permissive Tract 3: No tin skarns are known in this tract but indications for tin anomalies are known from stream sediment samples. The lithology of the country rock is similar to Tract 2, with numerous calcareous layers, however no underlying granite pluton is known. Based on gravimetric data, the existence of a so far unknown concealed granite body of substantive size is unlikely.

Permissive Tract 4: Stratiform tin mineralisation of low economic importance is known from old mine works. Gravimetric data indicate the tract is underlain by an elongated concealed granite intrusion. Metabasic rocks may have acted as geochemical barriers and enhanced the concentration of the tin mineralisation.

Permissive Tract 5: Iron skarns are known from this tract but considered to be pre-Variscan and thus genetically unrelated to the tin skarns. Carbonatic lenses above concealed Variscan granites show no indications of skarn formation. Geochemical tin anomalies exist locally and one stratiform tin deposit was explored in the 1960ies. That deposit is probably related to a metasomatically altered shear zone and thus genetically different from tin skarns.

Permissive Tract 6: Stratiform Pb-Zn mineralisations are known from the extensive calcareous layers in this tract, but they are most likely genetically unrelated to skarns. No evidence for tin anomalies or skarn formation is known, however, the carbonatic layers and underlying Variscan granites are theoretically conductive to skarn formation.

Permissive Tract 7: Tin skarns of low economic importance are known from a narrow strip of Devonian carbonatic rocks. Tin-specialised granites of the Markersbach type occur in the southeast. The area most favourable for undiscovered deposits is small.

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3. Assessment Results

3.1. Assessment results for tract 1 (Oelsnitz)

Delineation of permissive tract

Permissive tract 1 is located above the concealed tin-enriched Eichigt Granite pluton. The granite contact was drilled in several holes near the apical part of the intrusion. The shape of the pluton is constrained fairly well by gravimetric and seismic data. The overlying rocks are Ordovician to Devonian sediments and basic volcanics of a passive continental margin.

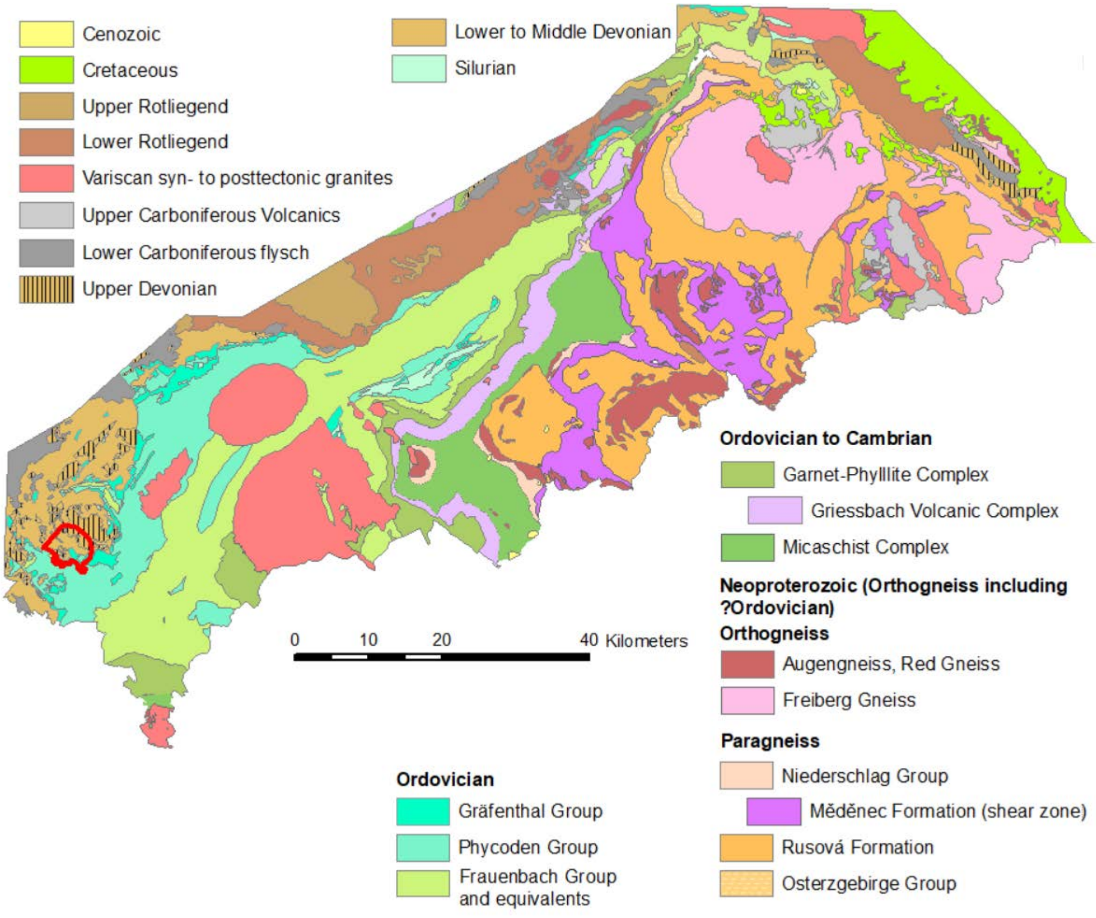

Figure 11 Location of permissive tract 1 on a geologic map of the assessment area

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Location and resource summary

The tract is a nearly circular area of 25 km² to the west of the town Oelsnitz in the Vogtland region. Skarns were mined up to the 19th century at Ludwig Fundgrube mainly for their iron content (SMWA, 2008). Cassiterite is known from samples but no grades and tonnages are reported, therefore this deposit is regarded as undiscovered for the purposes of the 3-Part-Assessment.

Estimation of the number of undiscovered deposits

From the expert estimates presented in Table 3 the probability distribution of the number of undiscovered deposits was modelled with the MAP software. Because of the small area above the concealed granite that could accommodate skarns, the experts estimated low numbers of undiscovered deposits. Four of the five experts expressed less than 90% percent confidence that the skarn at Ludwig Fundgrube is substantive enough to count as a deposit, but all experts agreed at the 50% confidence level that at least one undiscovered deposit should exist. The modelled probability distribution shows a 49.6% probability of zero undiscovered deposits. One and two deposits are rated at 35% and 12% respectively, whereas more undiscovered deposits are rated as improbable (<4%).

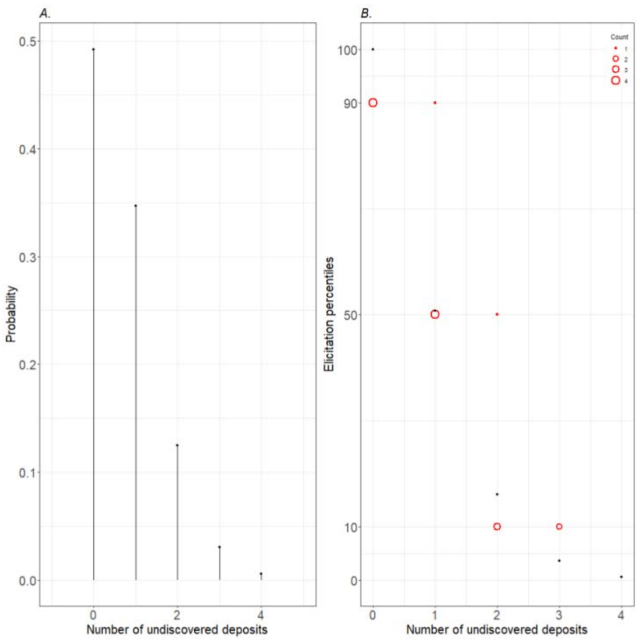

Figure 12 Modelled probability distribution of the number of undiscovered deposits in permissive tract 1

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Assessment of metal tonnages

The modelled tonnages of ore, tin and tungsten contained in undiscovered deposits within the permissive tract are shown in Figure 13 and Figure 14. For the ore tonnage the most likely values are in the range of a few 10^7 tons with a bit less than 100,000 tons of tin content. For tungsten (calculated as WO_3) a double-peaked distribution is observed with the most likely values around 1,000 tons and a bit below 100,000 tons. The arithmetic means are 27.2 Million tons of ore with 73,500 tons of Sn and 58,900 tons of WO_3. However there is a close to 50% probability that no deposit exists at all (the skarn at Ludwig Fundgrube would in that case be a subeconomic mineral occurrence). The median values for ore and metal content are therefore close to zero.

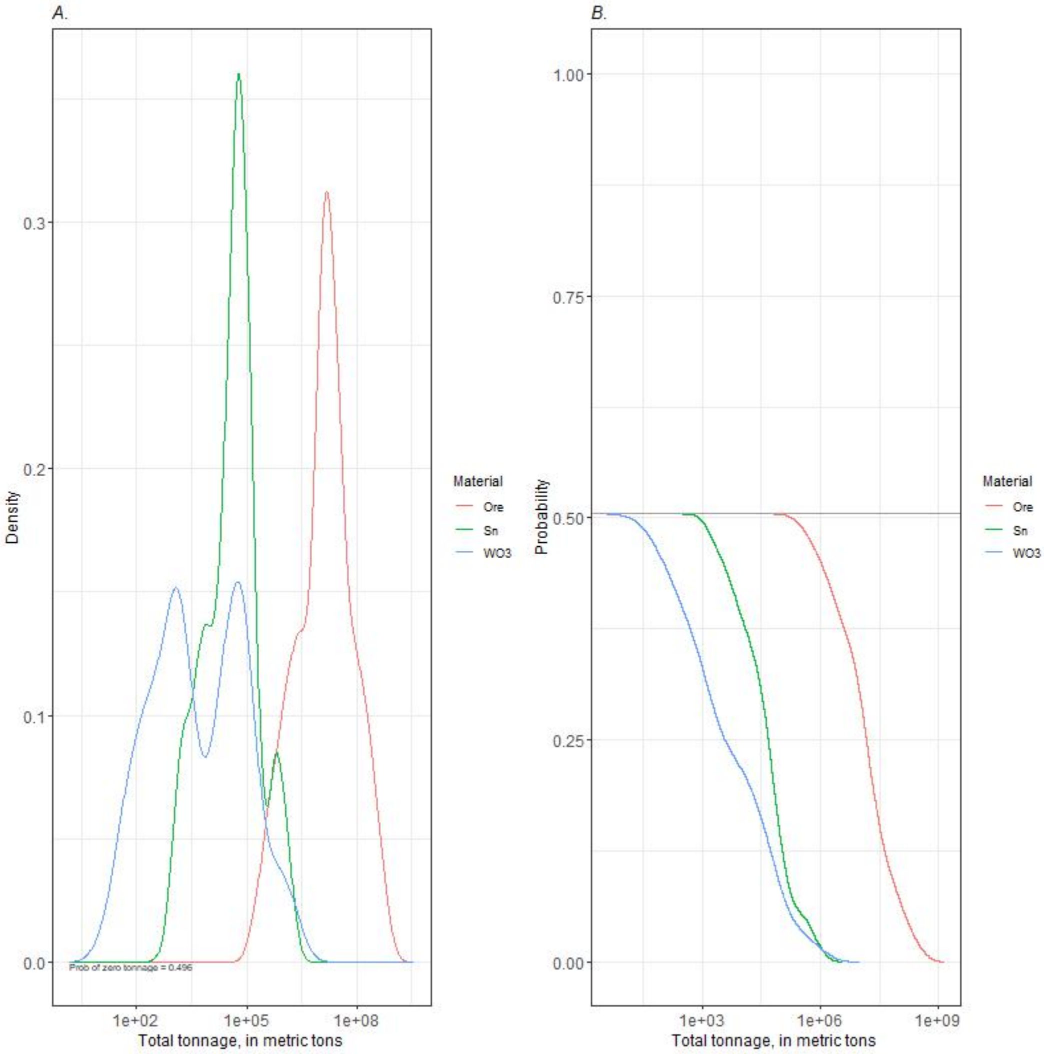

Figure 13 Probability distribution of the tonnages of ore, Sn and WO_3 in undiscovered deposits within permissive tract 1

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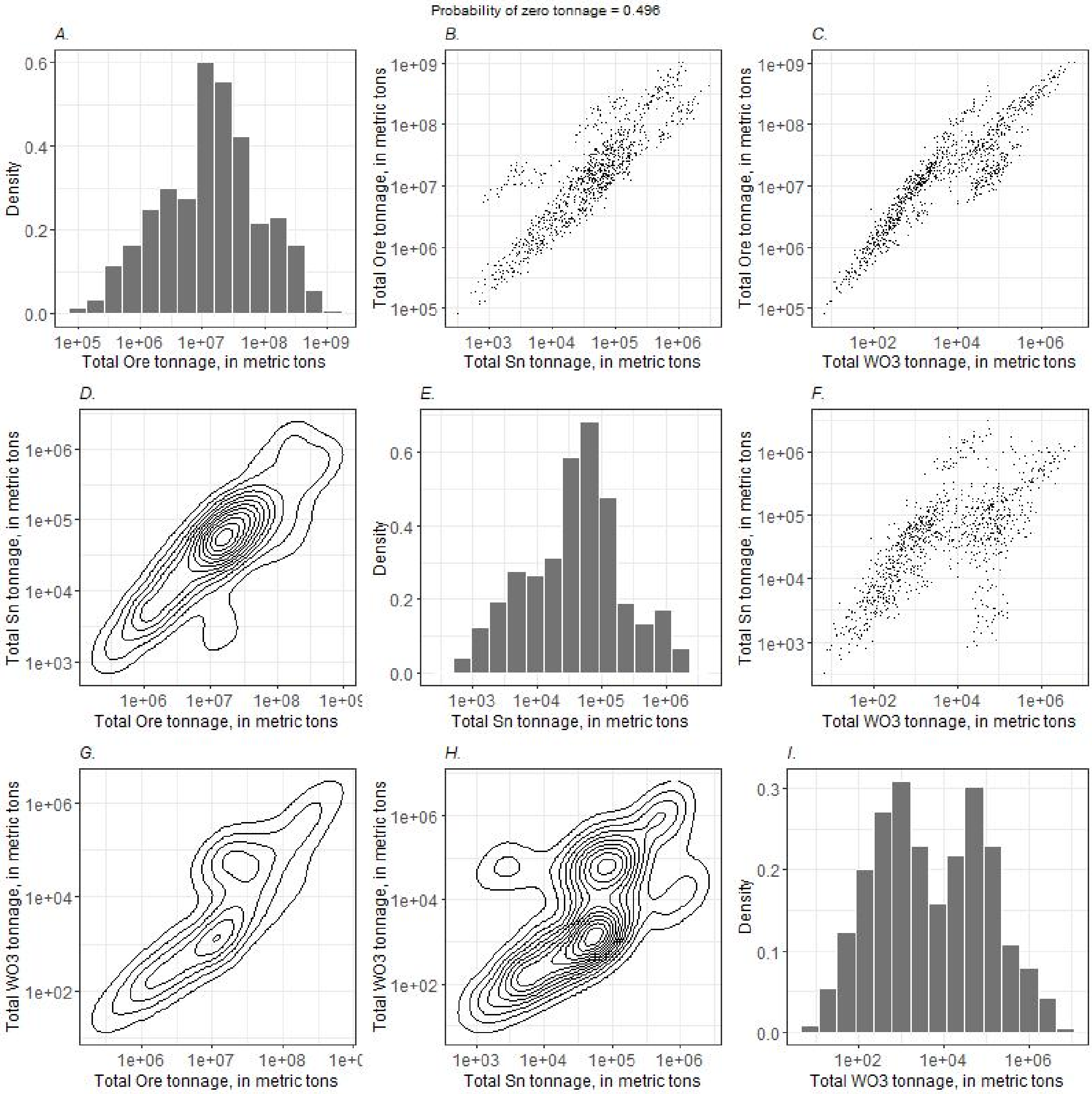

Figure 14 Histograms and cross plots for the tonnages of ore, Sn and WO_3 in undiscovered deposits within permissive tract 1

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3.2. Assessment results for tract 2 (Westerzgebirge)

Delineation of permissive tract

Permissive tract 2 is located above the extensive concealed tin-specialised Variscan granites of the Western/Central Erzgebirge. The cover rocks are low to intermediate-grade metamorphites (phyllite and micaschist) with several levels of calcareous layers and lenses which are partly metasomatized to magnetite and garnet-pyroxene skarns. The granite surface is constrained by numerous drill holes and located between 0 and 1,500 m below the land surface.

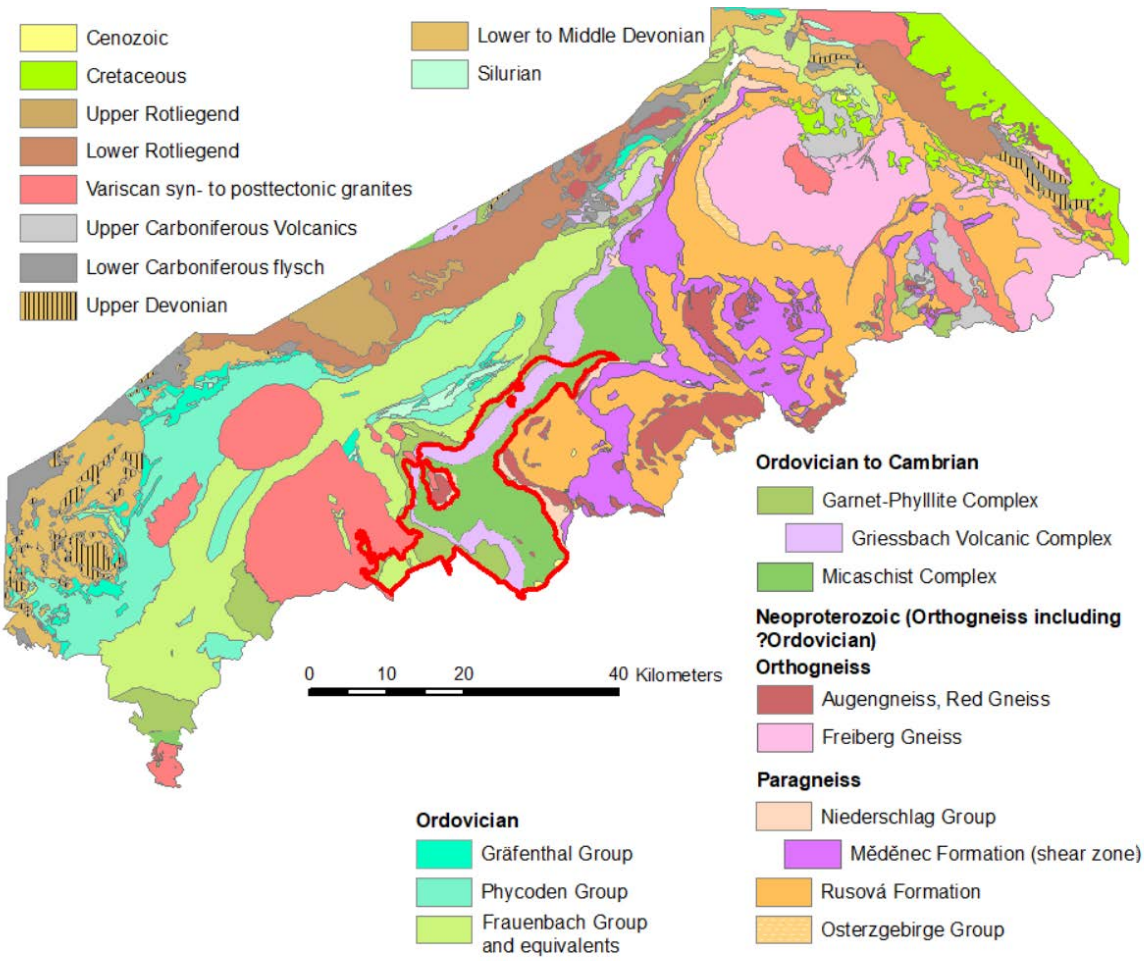

Figure 15 Location of permissive tract 2 on a geologic map of the assessment area

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Location and resource summary

This tract covers an area of 342 km² between Johanngeorgenstadt and Ehrenfriedersdorf in the Western/Central Erzgebirge. The permissive area continues in the southwest outside of the assessment area in the Czech part of the Erzgebirge. This tract contains all of the deposits with known tonnages and grades that are located in the assessment area. In the southwest, straddling the Czech boundary are the Tellerhäuser deposit with 13.058 Mt ore @ 0.71% Sn, the Hämmerlein deposit with 13.77 Mt ore @ 0.4% Sn (Schuppan & Hiller, 2012) and the Pöhla-Globenstein deposit with 14.645 Mt ore @ 0.57% Sn and 0.45% WO_3 (Hösel, 2003). Further to the north, several deposits were discovered on the margin of the Schwarzenberg gneiss cupola (which is itself not permissive): The Breitenbrunn deposit with 22 Mt ore @ 0.25% Sn, the Antonsthal deposit with 14.7 Mt ore @ 0.19% Sn and 0.47% WO_3 and the large but poor grade Bernsbach SE deposit with 126 Mt ore @ 0.04% Sn and 0.125% WO_3 (SMWA, 2008). In the northeast of the tract a number of smaller deposits was explored in the vicinity of Geyer and Ehrenfriedersdorf: The Geyer SW deposit with 8.219 Mt ore @ 0.56% Sn, the small Geyer NE deposit with 0.273 Mt ore @ 0.52% Sn and the Ehrenfriedersdorf-Hahnrück deposit with 0.79 Mt ore @ 0.4% Sn and 0.012% WO_3 (Hösel, 1996). The combined resources amount to 213 Mt ore with 415,000 tons Sn and close to 300,000 tons WO_3. Until recently the processing of the complex ore was an unsolved problem and only a few thousand tons have been mined experimentally at the Hämmerlein deposit. Small parts of some of the other deposits were mined historically for their iron content but most of the ore is still in the ground.

Estimation of the number of undiscovered deposits

From the expert estimates presented in Table 3 the probability distribution of the number of undiscovered deposits was modelled with the MAP software. The experts agreed in ranking this tract as the most favourable, with everyone confident at the 90% level that at least one undiscovered deposit exists. The modelled probability distribution shows only a 6.4% probability of zero undiscovered deposits. Between one and four undiscovered deposits are modelled as the most likely number, but even the existence of five or more deposits has a probability of about 15%.

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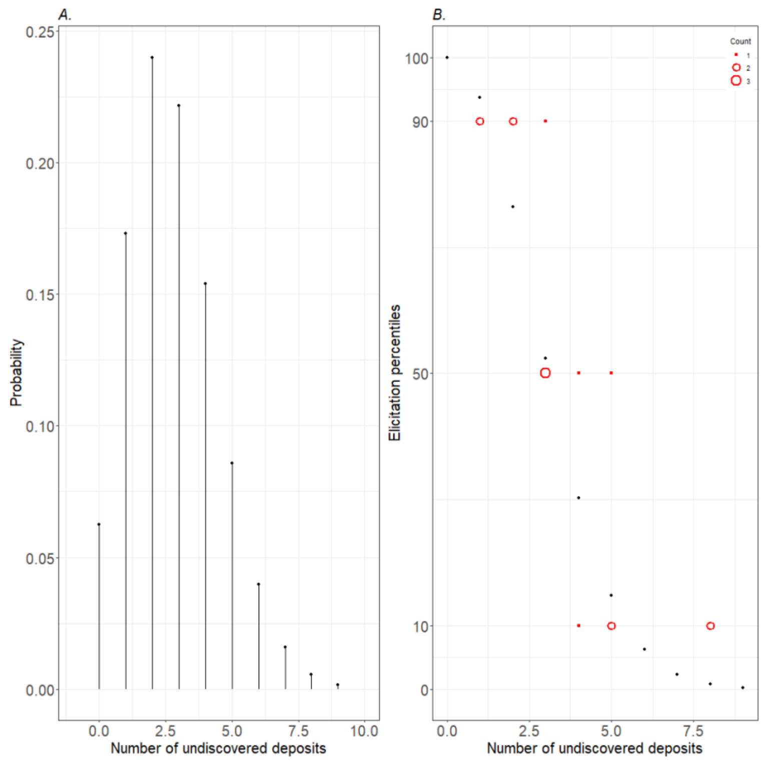

Figure 16 Modelled probability distribution of the number of undiscovered deposits in permissive tract 2

Assessment of metal tonnages

The modelled tonnages of ore, tin and tungsten contained in undiscovered deposits within the permissive tract are shown in Figure 17 and Figure 18. The most likely value for the tonnage of ore contained in undiscovered deposits within this tract is slightly below 10^8 tons, with most likely tin and tungsten contents a little above 100,000 tons each. The arithmetic mean is 110 Million tons of ore, 289,000 tons of Sn and 250,000 tons of WO_3, the median values are 40.6 Million tons of ore, 114,000 tons of Sn and 36,100 tons of WO_3. This is clearly less than the discovered amount and the probability of doubling the known resources even if all undiscovered deposits are found is only about 15%. This agrees with the expert assessment that this tract is well explored, but also shows the perspective of finding economically interesting undiscovered resources that could equal the richest of the known deposits in the assessment area.

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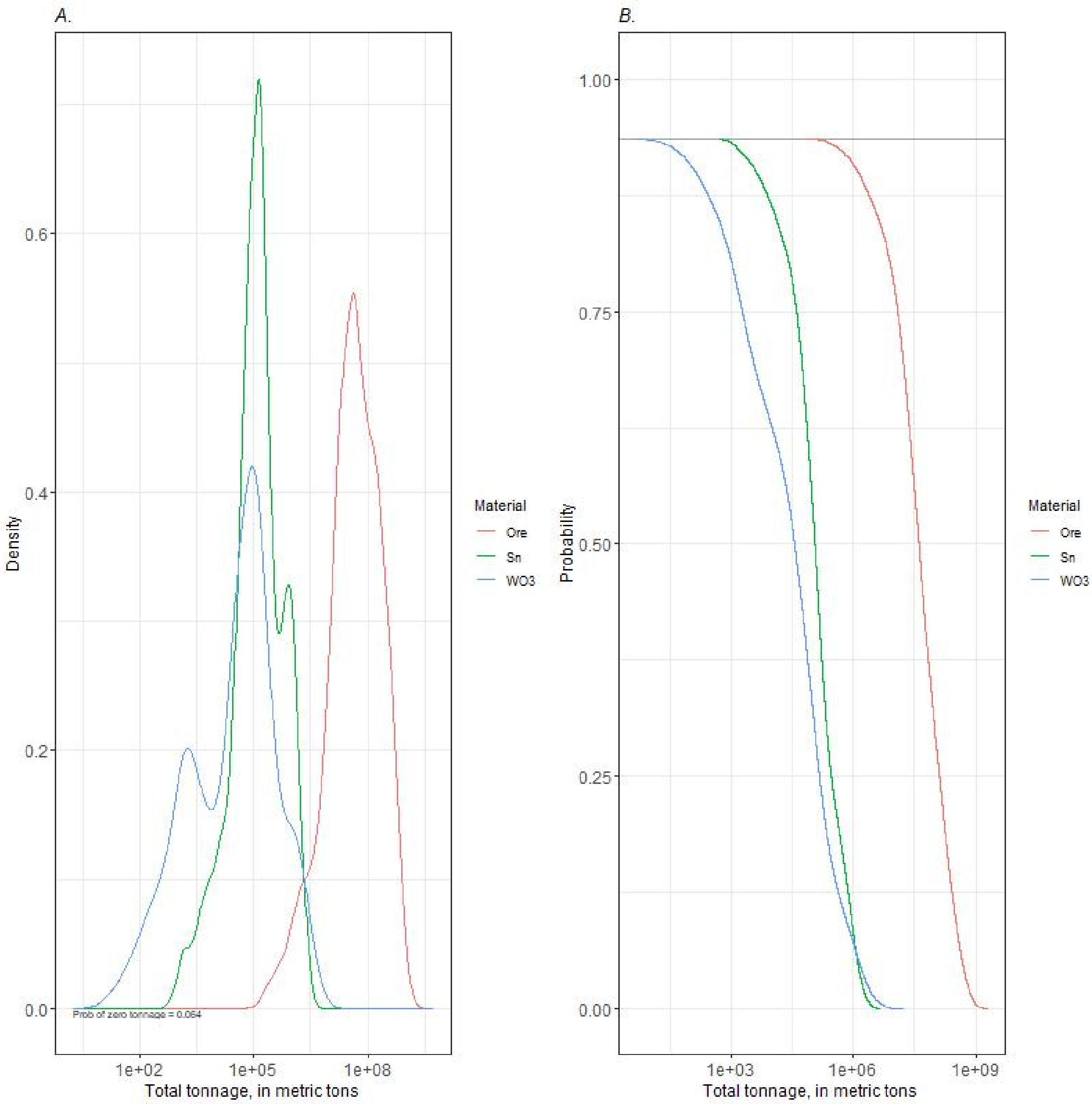

Figure 17 Probability distribution of the tonnages of ore, Sn and WO_3 in undiscovered deposits within permissive tract 2

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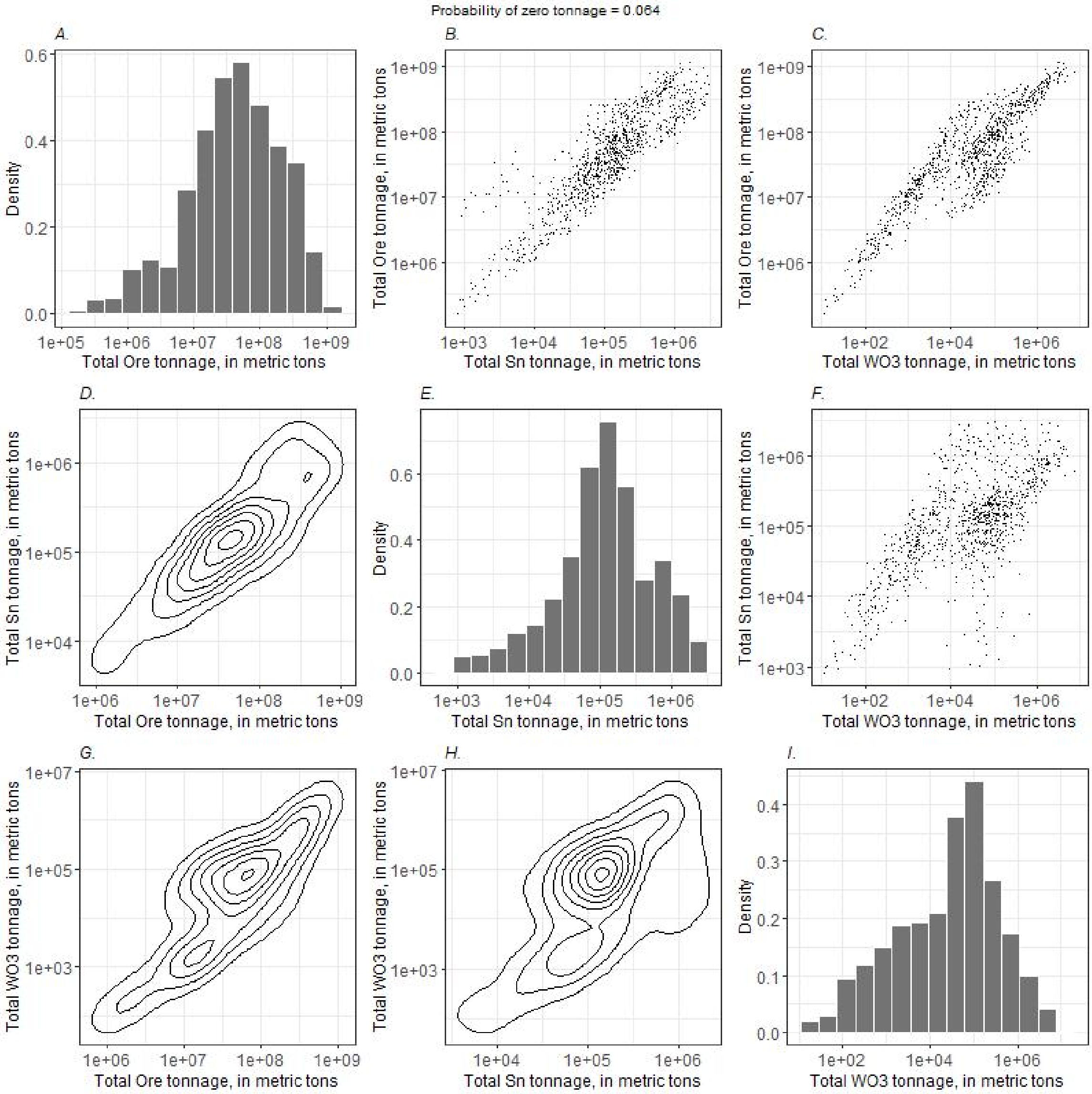

Figure 18 Histograms and cross plots for the tonnages of ore, Sn and WO_3 in undiscovered deposits within permissive tract 2

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3.3. Assessment results for tract 3 (Zschopau)

Delineation of permissive tract

Permissive tract 3 is located in the Central Erzgebirge and consists low to intermediate-grade metamorphic rocks (phyllite and micaschist) with several levels of intercalated calcareous layers and lenses. The rocks are contiguous with tracts 2 and 4. Geophysical data indicate that in this area no large granite bodies exist at shallow depths (less than about 5 km). No skarns are known from the area, but in the western part some tin stream sediment anomalies and occurrences of tin-enriched phyllites are known. The area is ranked as permissive because it cannot be excluded that small granite stocks or apophyses of the neighbouring granites exist in the area.

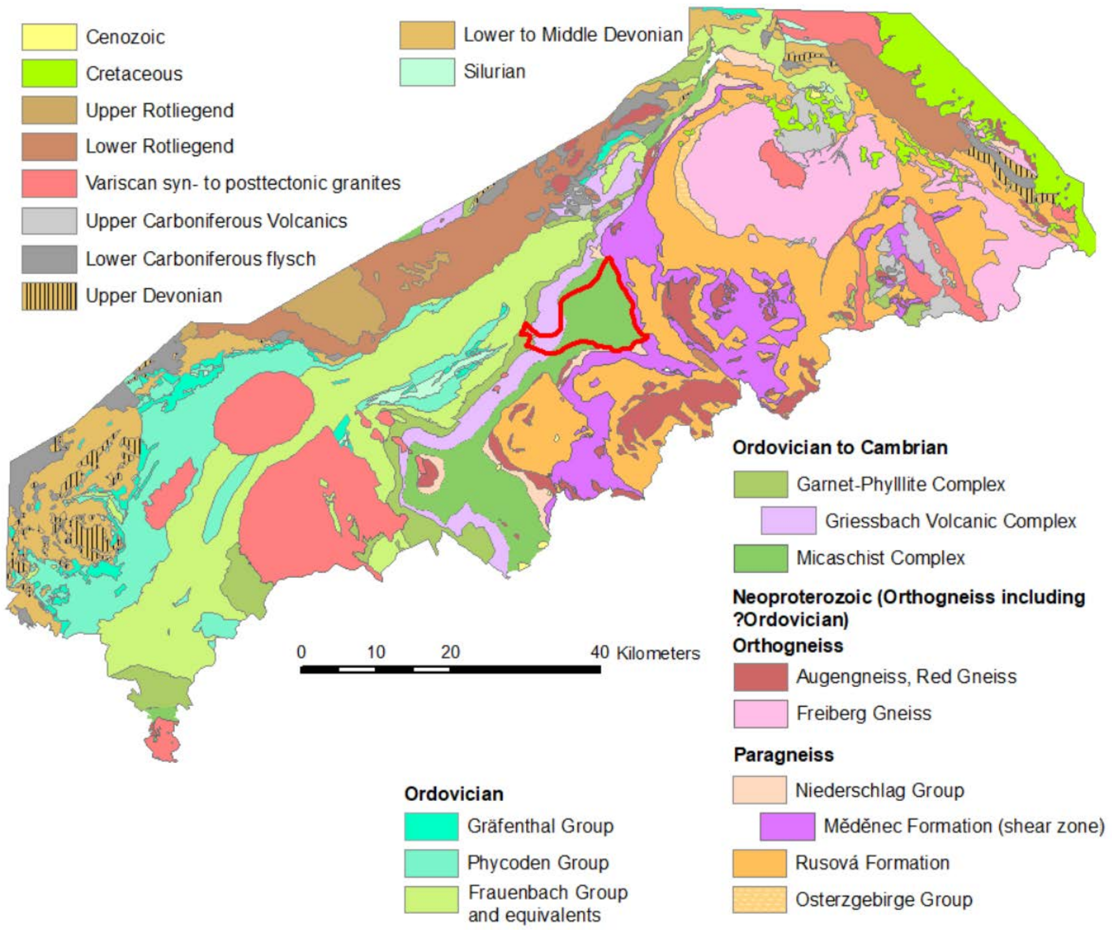

Figure 19 Location of permissive tract 3 on a geologic map of the assessment area

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Location and resource summary

The permissive tract is a compact area of 95 km² surrounding the town of Zschopau. So far no skarn occurrences are known in the tract.

Estimation of the number of undiscovered deposits

From the expert estimates presented in Table 3 the probability distribution of the number of undiscovered deposits was modelled with the MAP software. While the occurrence of tin skarns is not excluded it is regarded as unlikely by the experts that even one undiscovered deposit exists in the area. The modelled probability distribution of undiscovered deposits shows a 89% probability of zero deposits. The probability of one undiscovered deposit is around 10% and the existence of more than one deposit is very unlikely.

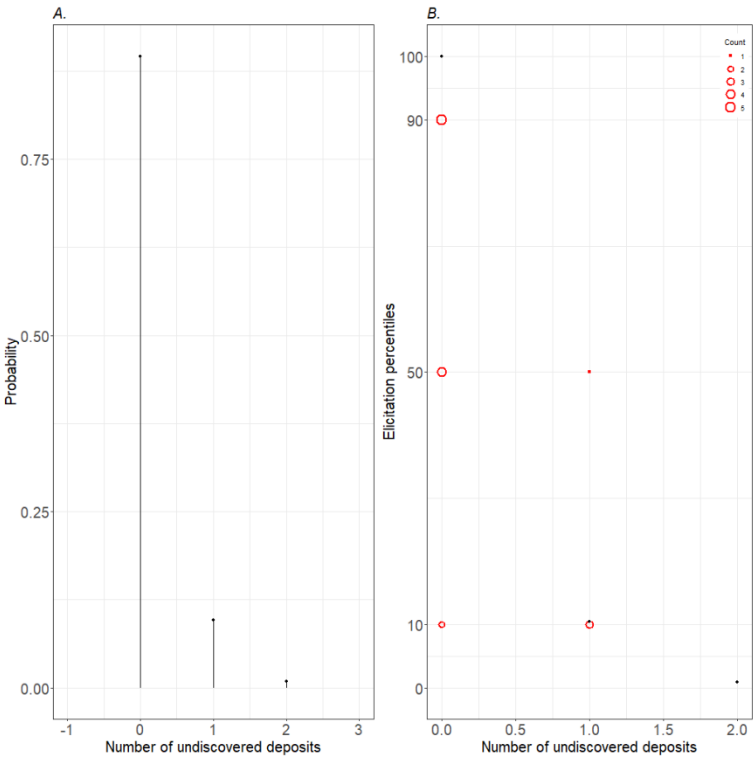

Figure 20 Modelled probability distribution of the number of undiscovered deposits in permissive tract 3

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Assessment of metal tonnages

The modelled tonnages of ore, tin and tungsten contained in undiscovered deposits within the permissive tract are shown in Figure 21 and Figure 22. For the ore tonnage the most likely values are about 10^7 tons with between 30,000 and 100,000 tons of tin content. For tungsten (calculated as WO_3) a double-peaked distribution is observed with the most likely values around 1,000 tons and around 50,000 tons. The arithmetic mean is 4.68 Million tons of ore with 12,700 tons of Sn and 9,930 tons of WO_3. However, by far the most likely scenario (at 89% probability) is that zero undiscovered deposits exits in this tract and the median values of ore and metal content are therefore zero.

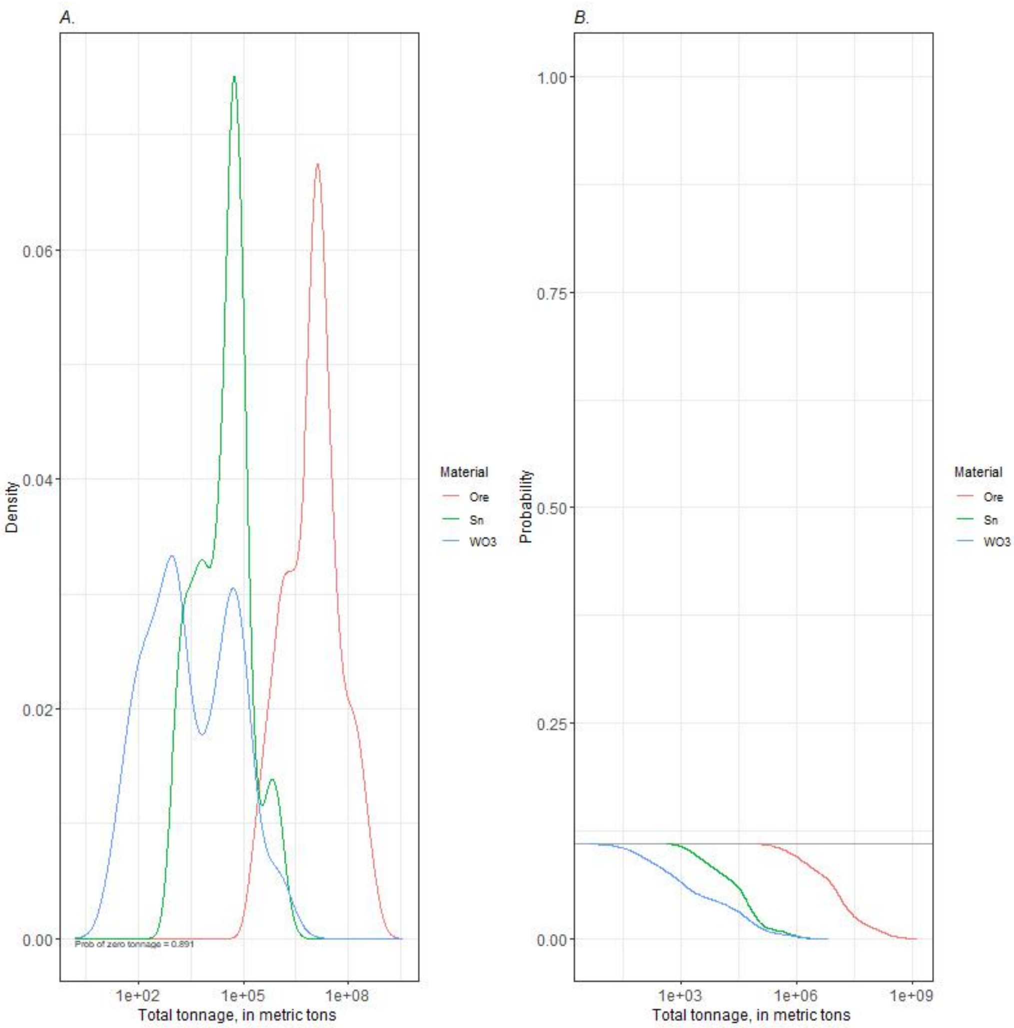

Figure 21 Probability distribution of the tonnages of ore, Sn and WO_3 in undiscovered deposits within permissive tract 3

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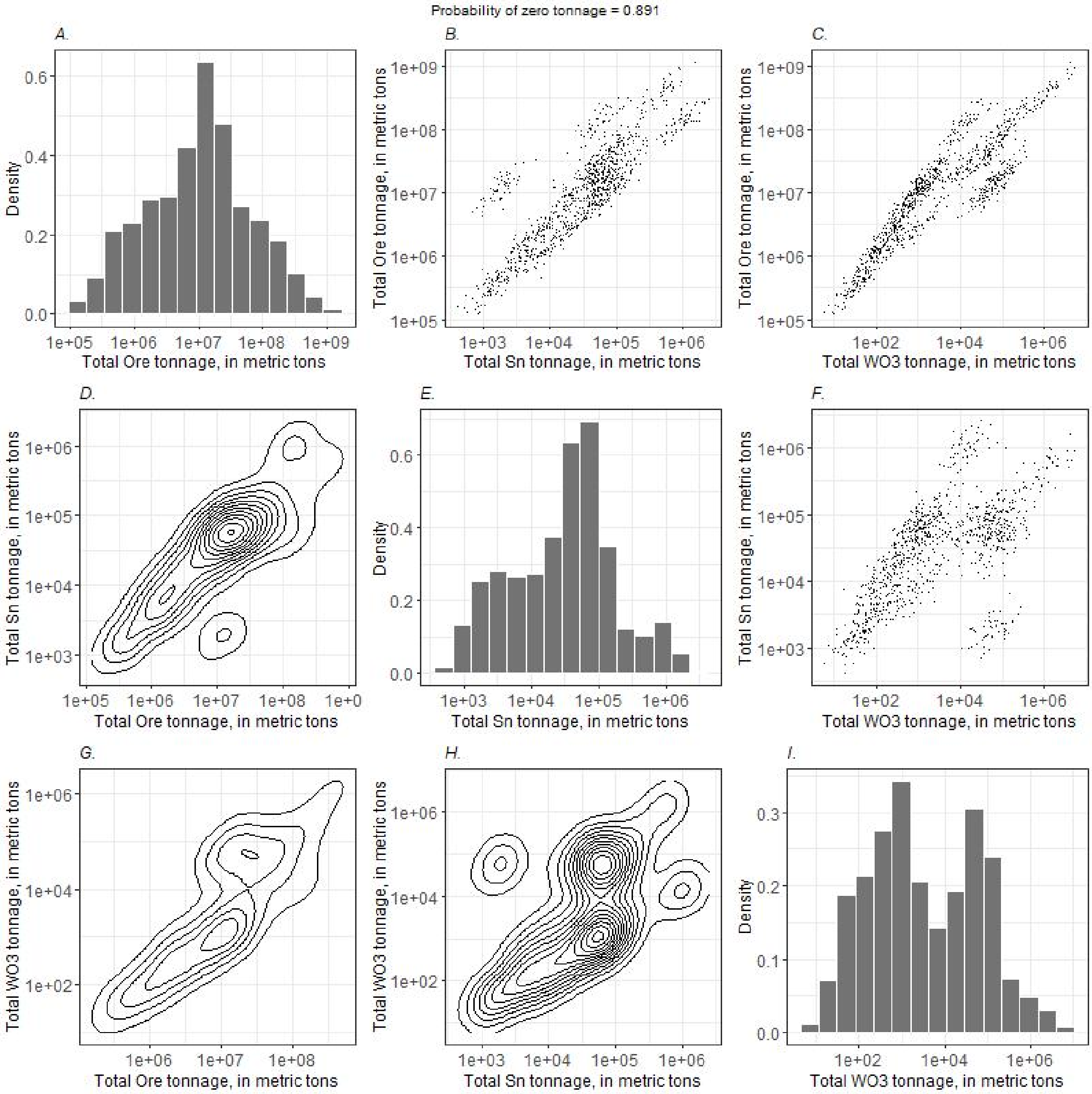

Figure 22 Histograms and cross plots for the tonnages of ore, Sn and WO_3 in undiscovered deposits within permissive tract 3

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3.4. Assessment results for tract 4 (Nordrand)

Delineation of permissive tract

Permissive tract 4 is located above a concealed Variscan granite inferred from geophysical data. Inversion modelling of gravimetric data suggests the granite surface is 500 to 1,500 m below the land surface. The cover rocks are low to intermediate-grade metamorphitic rocks (phyllite and micaschist) with several levels of calcareous layers and locally strong tin anomalies.

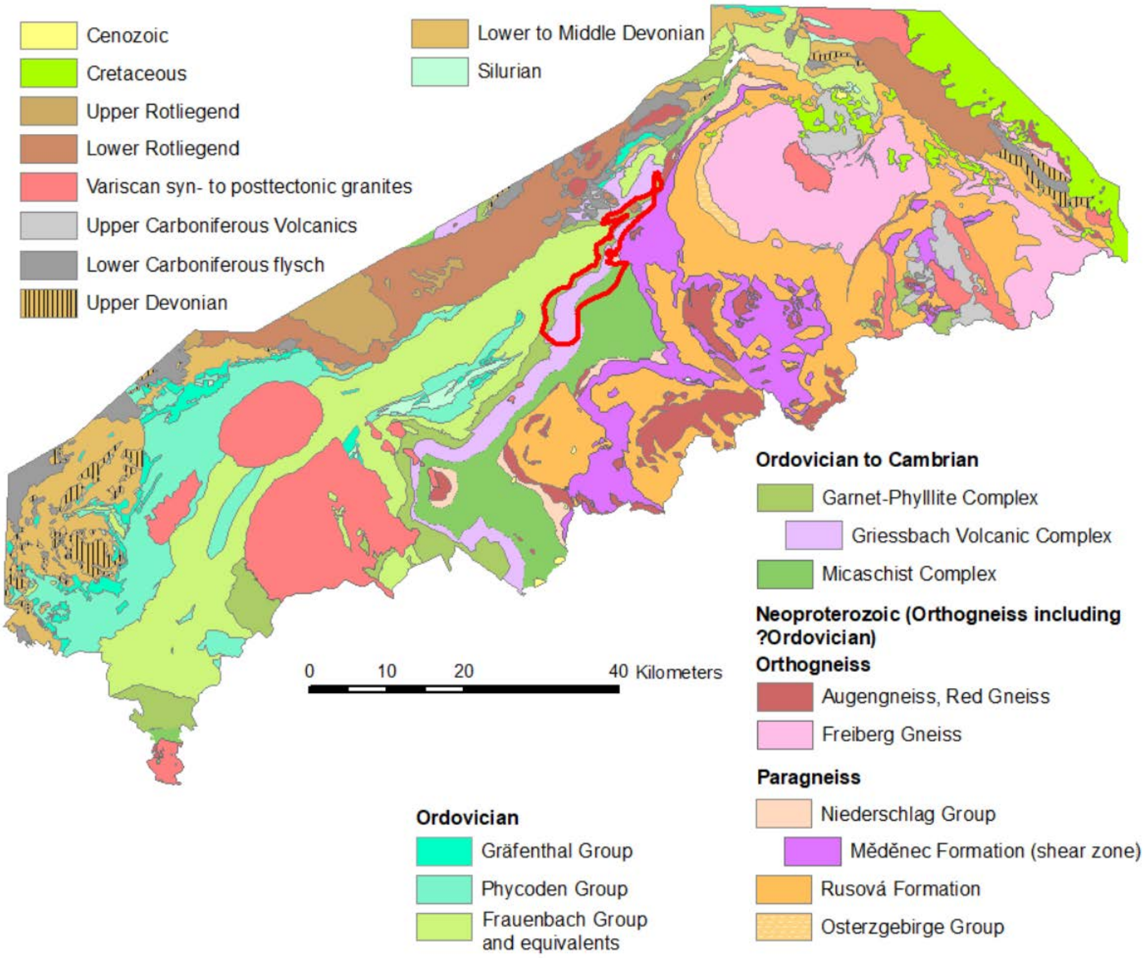

Figure 23 Location of permissive tract 4 on a geologic map of the assessment area

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Location and resource summary

The tract is a 25 km long strip with an area of 76 km² that follows the crest line of the elongated concealed granite pluton. The tract is located to the southeast of Chemnitz, near the towns of Zschopau and Flöha. No tin skarns are known from this area, but statiform disseminated tin mineralisation is widespread in phyllites and quartzites. The descriptive model for this type of stratiform mineralisation is currently incomplete and a genetic connection with tin skarns is not demonstrated.

Estimation of the number of undiscovered deposits

From the expert estimates presented in Table 3 the probability distribution of the number of undiscovered deposits was modelled with the MAP software. The opinions of the experts differ more strongly than in the other tracts but are still of the same order of magnitude. The disagreement is rooted in the interpretation of the stratiform tin mineralisation and whether it is genetically related to skarns or not. As this question is currently unsolved, all expert assessments are weighted equally despite the disagreement.

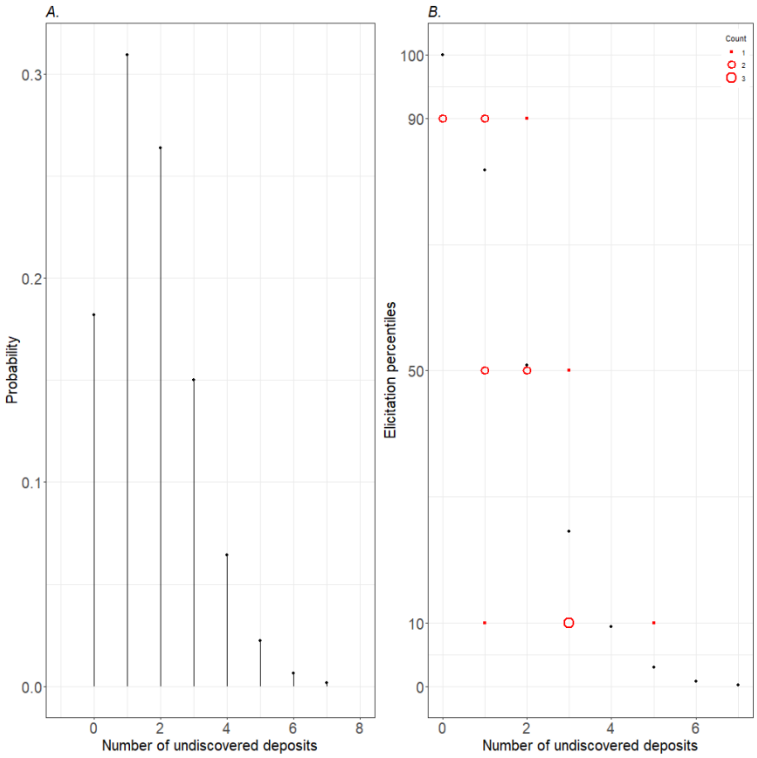

Figure 24 Modelled probability distribution of the number of undiscovered deposits in permissive tract 4

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Assessment of metal tonnages

The modelled tonnages of ore, tin and tungsten contained in undiscovered deposits within the permissive tract are shown in Figure 25 and Figure 26. For the ore tonnage the most likely values are in the range of a few 10^7 tons with a about 100,000 tons of Sn and WO_3 content. The arithmetic means are 66.7 Million tons of ore with 174,000 tons of Sn and 148,000 tons of WO_3. The median values are substantially lower at 16.6 million tons of ore, 52,100 tons of Sn and only 3,880 tons of WO_3.

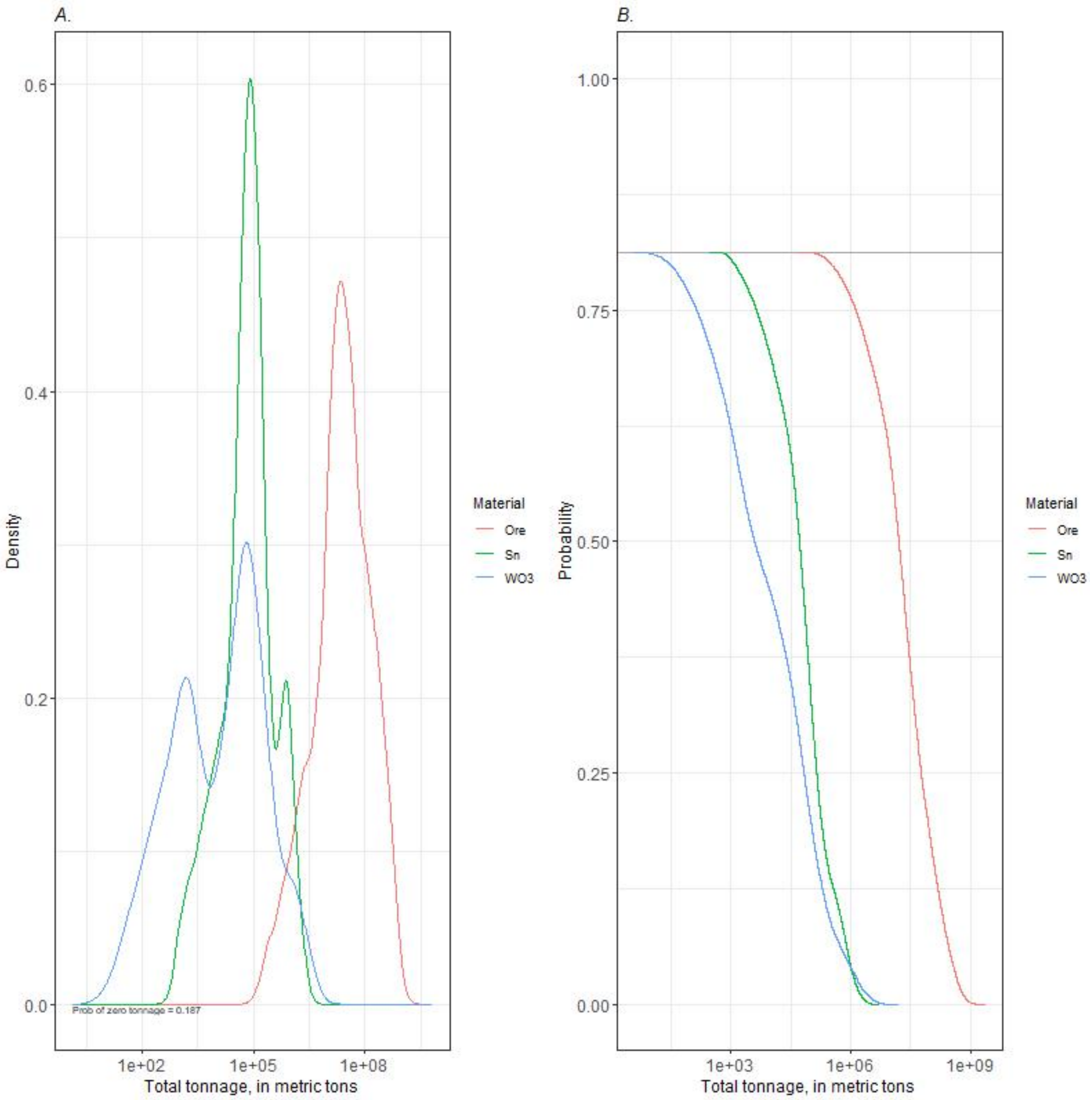

Figure 25 Probability distribution of the tonnages of ore, Sn and WO_3 in undiscovered deposits within permissive tract 4

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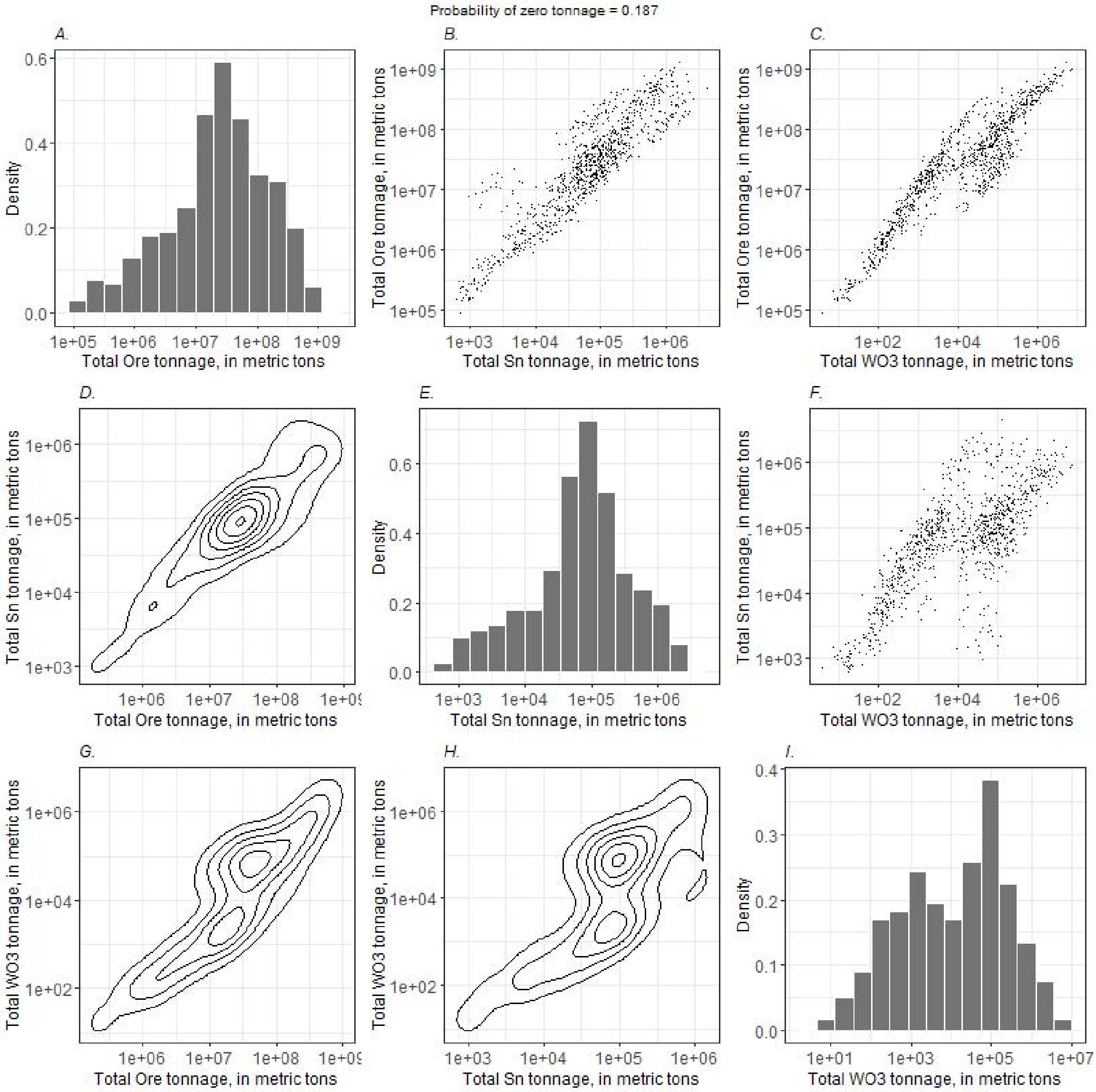

Figure 26 Histograms and cross plots for the tonnages of ore, Sn and WO_3 in undiscovered deposits within permissive tract 4

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3.5. Assessment results for tract 5 (Jöhstadt-Großschirma)

Delineation of permissive tract

Permissive tract 5 is composed of the occurrences of the Měděnec Formation on the northwest margin of the eastern Erzgebirge. This gneiss and migmatite unit is interpreted as a shear zone within the nappe stack of the Variscan orogen. It contains fragments of neighbouring and also of exotic lithologies. The existence of small carbonate lenses and the presence of tin-specialised Variscan granites under part of this tract make the area permissive for tin skarns. Furthermore, a stratiform shear zone hosted type of disseminated tin mineralisation (Großschirma Felsite horizon) exists at the northern tip of the tract. The magnetite skarns close to the Czech boundary and in the Czech part of this unit are genetically not related to the tin skarns and do not show appreciable tin or tungsten content. They are the product of and earlier metasomatic phase caused by the intrusion of Cadomian (and possibly Ordovician) granites to granodiorites.

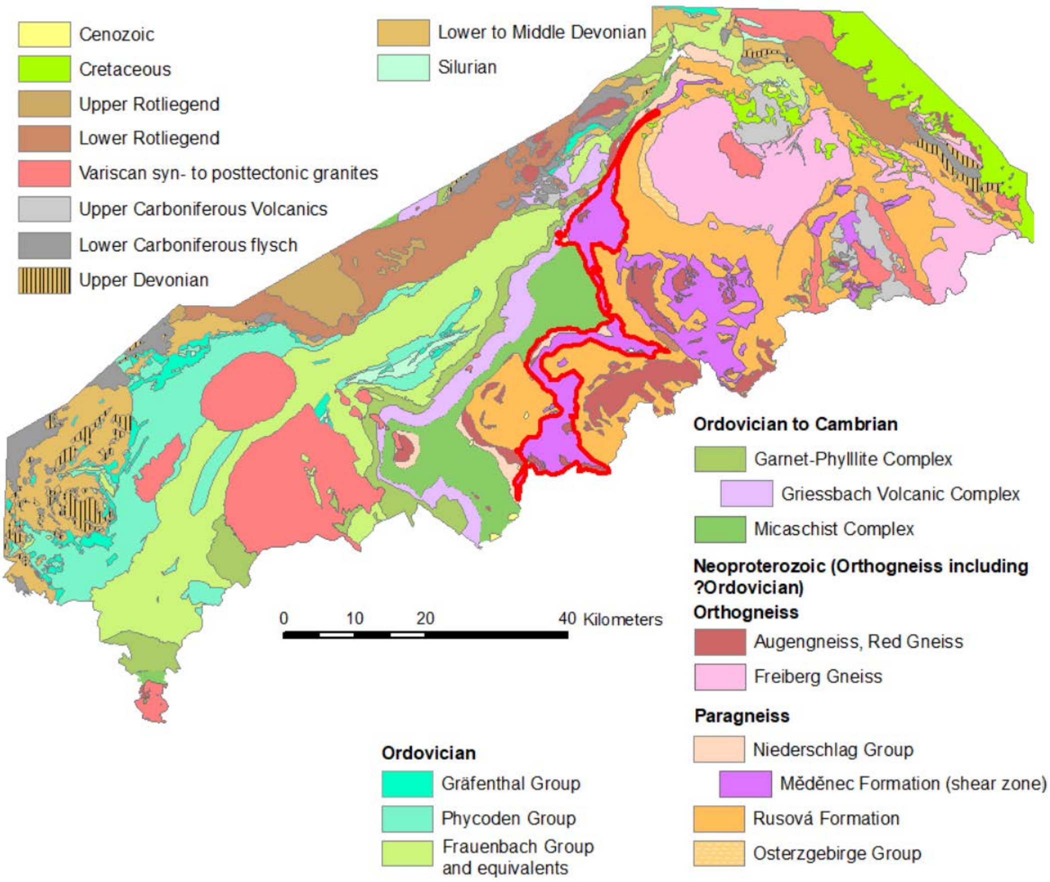

Figure 27 Location of permissive tract 5 on a geologic map of the assessment area

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Location and resource summary

The permissive tract forms a narrow strip with an area of 205 km² between the town Jöhstadt on the Czech border and the town Großschirma north of Freiberg. No tin skarn resources are known from this area, but the stratiform “Felsit” tin deposit at Großschirma was explored in the 1960ies and rated at a prospective content of 70,000 tons of tin (SMWA, 2008).

Estimation of the number of undiscovered deposits

From the expert estimates presented in Table 3 the probability distribution of the number of undiscovered deposits was modelled with the MAP software. The experts are sceptical of the existence of tin skarns in this tract and exclude them at the 90% and 50% confidence levels. At the 10% confidence level, three out of five experts consider at least one undiscovered deposit possible within the tract. In consequence, the modelled probability distribution of undiscovered deposits shows a 82% probability of zero deposits. The probability of one undiscovered deposit is around 16% and the existence of more than one deposit is very unlikely.

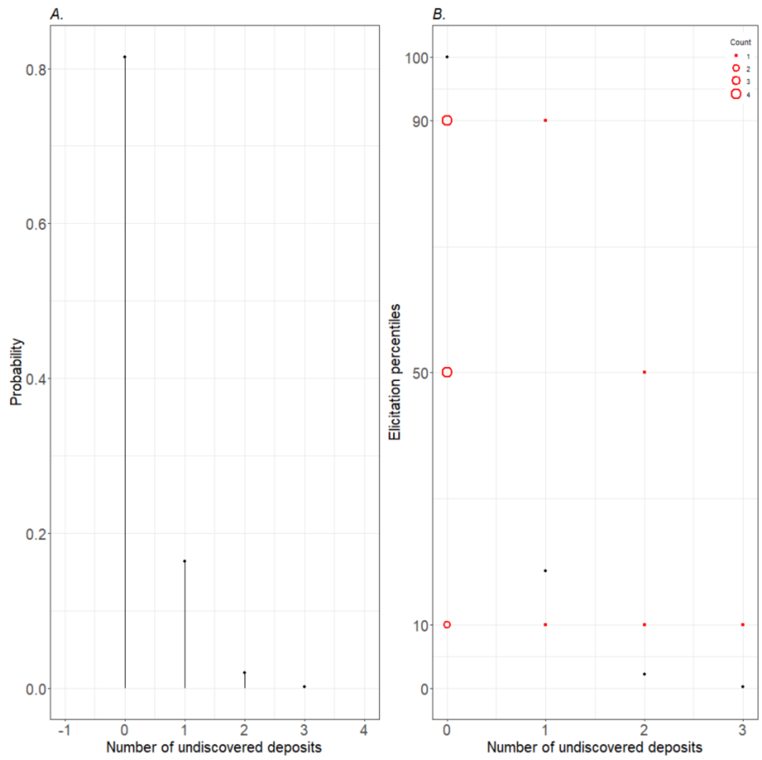

Figure 28 Modelled probability distribution of the number of undiscovered deposits in permissive tract 5

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Assessment of metal tonnages

The modelled tonnages of ore, tin and tungsten contained in undiscovered deposits within the permissive tract are shown in Figure 29 and Figure 30. For the ore tonnage the most likely values are in the range of a few 10^7 tons with a bit less than 100,000 tons of tin content. For tungsten (calculated as WO_3) a double-peaked distribution is observed with the most likely values around 1,000 tons and around 50,000 tons. The arithmetic means are 7.96 Million tons of ore with 20,400 tons of Sn and 17,400 tons of WO_3. Because of the 82% percent probability of zero deposits, the median values for the ore and metal tonnages are zero.

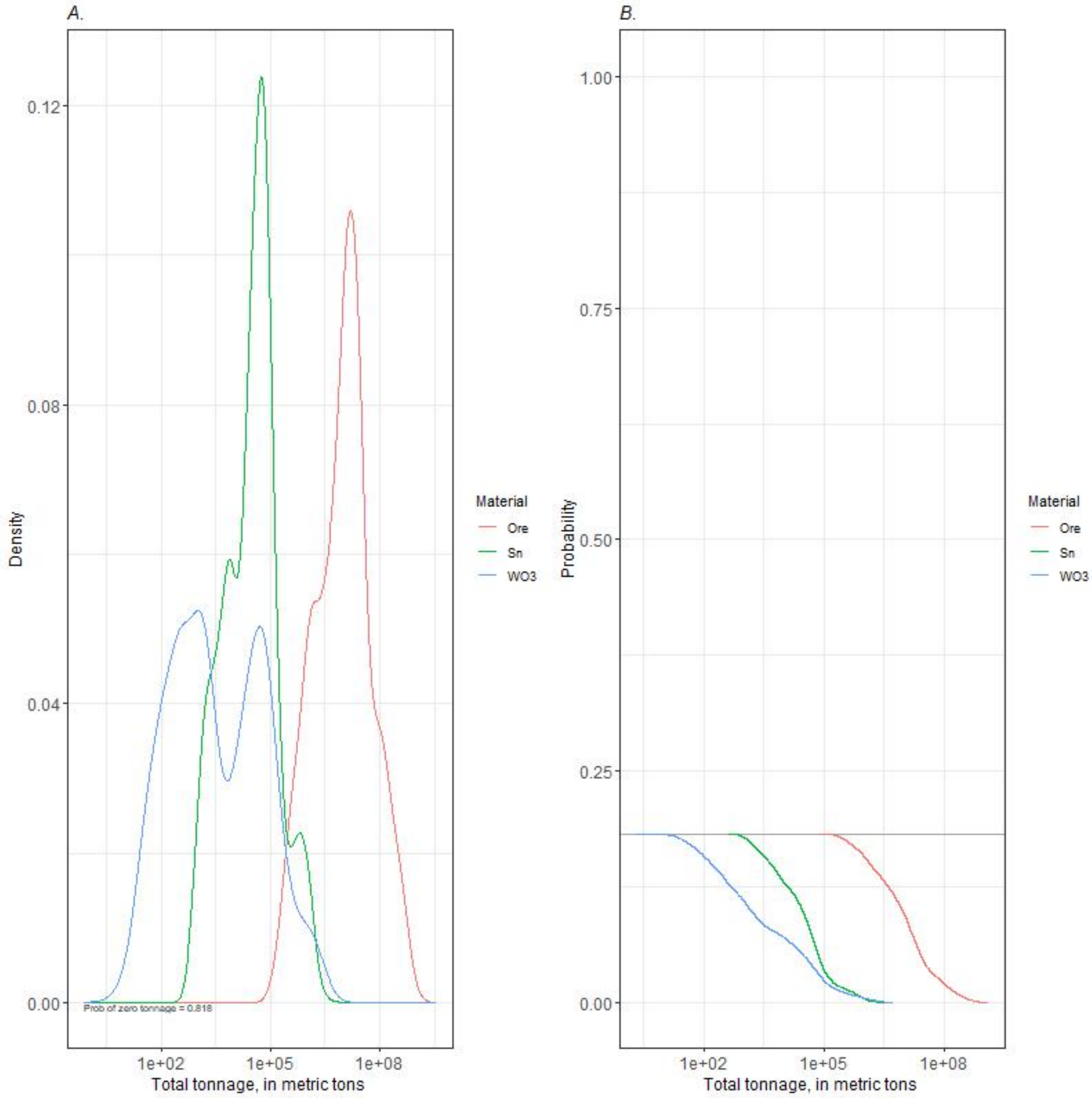

Figure 29 Probability distribution of the tonnages of ore, Sn and WO_3 in undiscovered deposits within permissive tract 5

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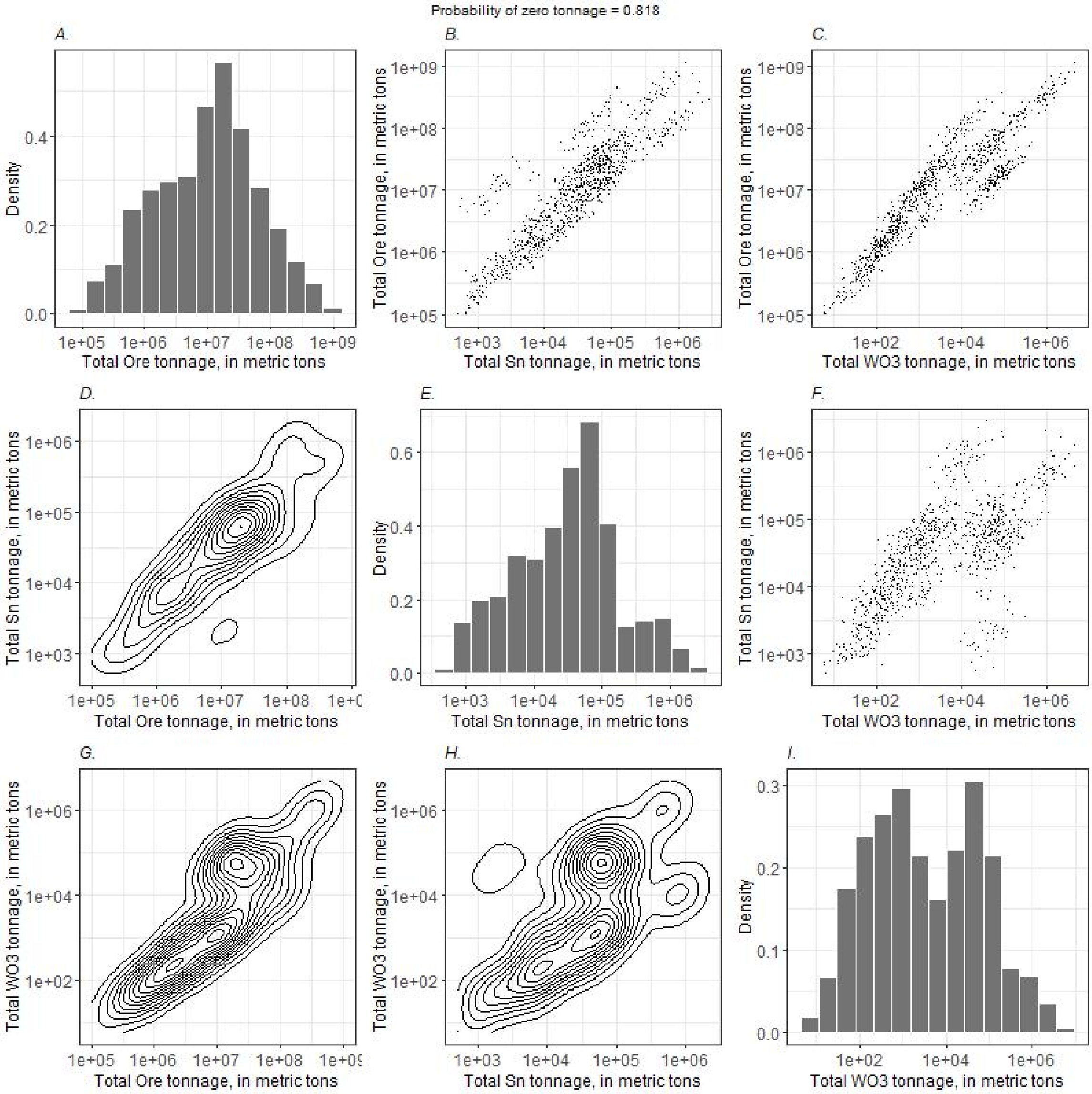

Figure 30 Histograms and cross plots for the tonnages of ore, Sn and WO_3 in undiscovered deposits within permissive tract 5

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3.6. Assessment results for tract 6 (Hermsdorf)

Delineation of permissive tract

The tract consists of two isolated blocks of phyllite with a tectonic contact to the underlying gneisses. The existence of intercalated marble layers in the phyllites and the proximity to the Variscan tin-specialised Schellerhau granite suggest permissive conditions for the formation of tin skarns.

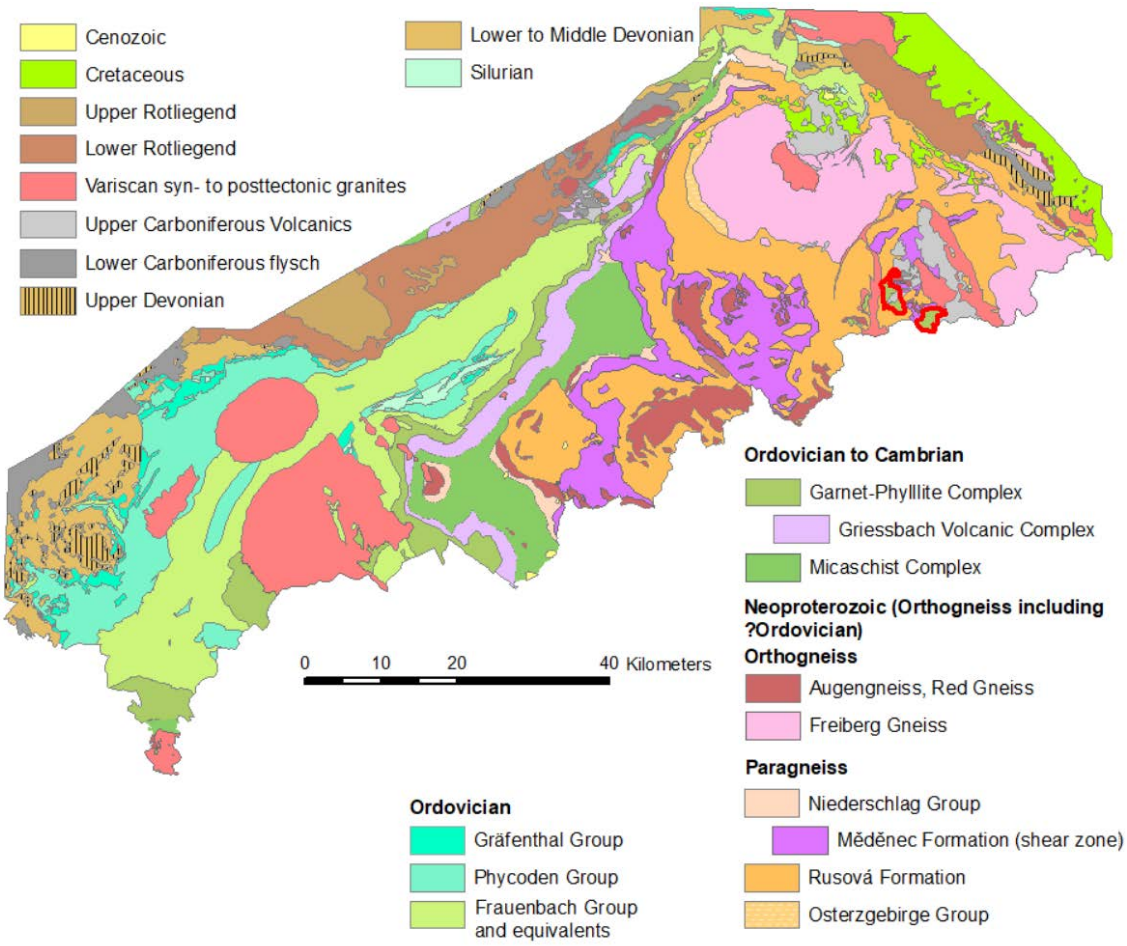

Figure 31 Location of permissive tract 6 on a geologic map of the assessment area

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Location and resource summary

The combined area of the Hermsdorf and the Rehefeld-Zaunhaus blocks is 16 km². Within the Hermsdorf block, marble layers were mined until 2016. The marbles contain stratiform lead-zinc mineralisation which never reached economic significance. No tin skarn deposits are known in the tract.

Estimation of the number of undiscovered deposits

From the expert estimates presented in Table 3 the probability distribution of the number of undiscovered deposits was modelled with the MAP software. The experts are highly sceptical of the existence of any undiscovered deposits due to the small size of the tract, the high level of exploration in the course of the marble mining and the lack of any geochemical tin anomalies in the phyllites. One expert considers the possibility of one undiscovered deposit at the 50% confidence level and two more experts consider one deposit possible at the 10% confidence level. Thus the modelled probability for zero undiscovered deposits is 89.6 % and the probability for one deposit is only 8%, while more than one deposit is very unlikely.

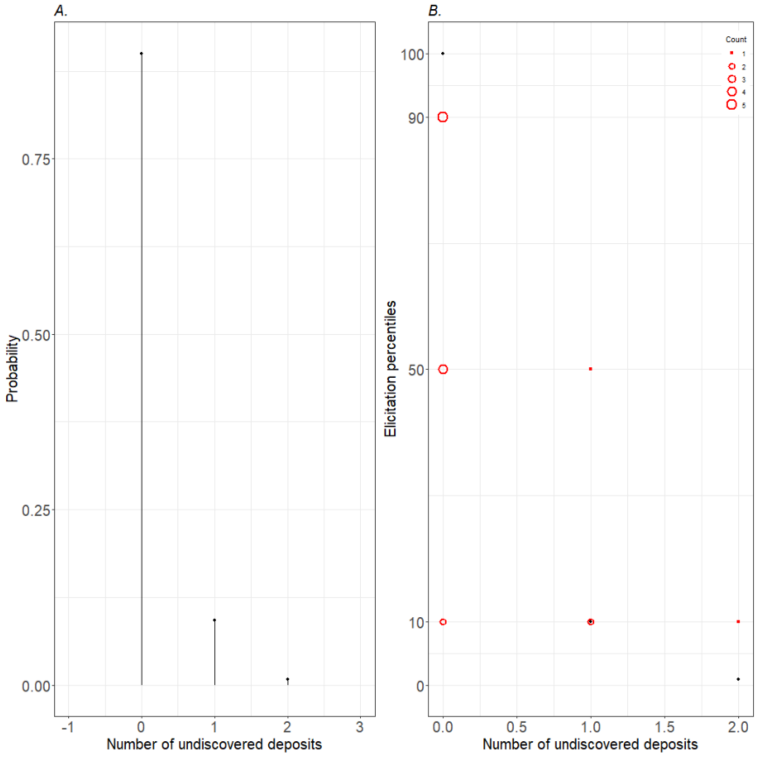

Figure 32 Modelled probability distribution of the number of undiscovered deposits in permissive tract 6

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Assessment of metal tonnages

The modelled tonnages of ore, tin and tungsten contained in undiscovered deposits within the permissive tract are shown in Figure 33 and Figure 34. For the ore tonnage the most likely values are in the range of 10^7 tons with a bit less than 100,000 tons of tin content. For tungsten (calculated as WO_3) a double-peaked distribution is observed with the most likely values around 1,000 tons and around 50,000 tons. The arithmetic means are 4.22 Million tons of ore with 107,00 tons of Sn and 9,940 tons of WO_3. Because of the 89.6% percent probability of zero deposits, the median values for the ore and metal tonnages are zero.

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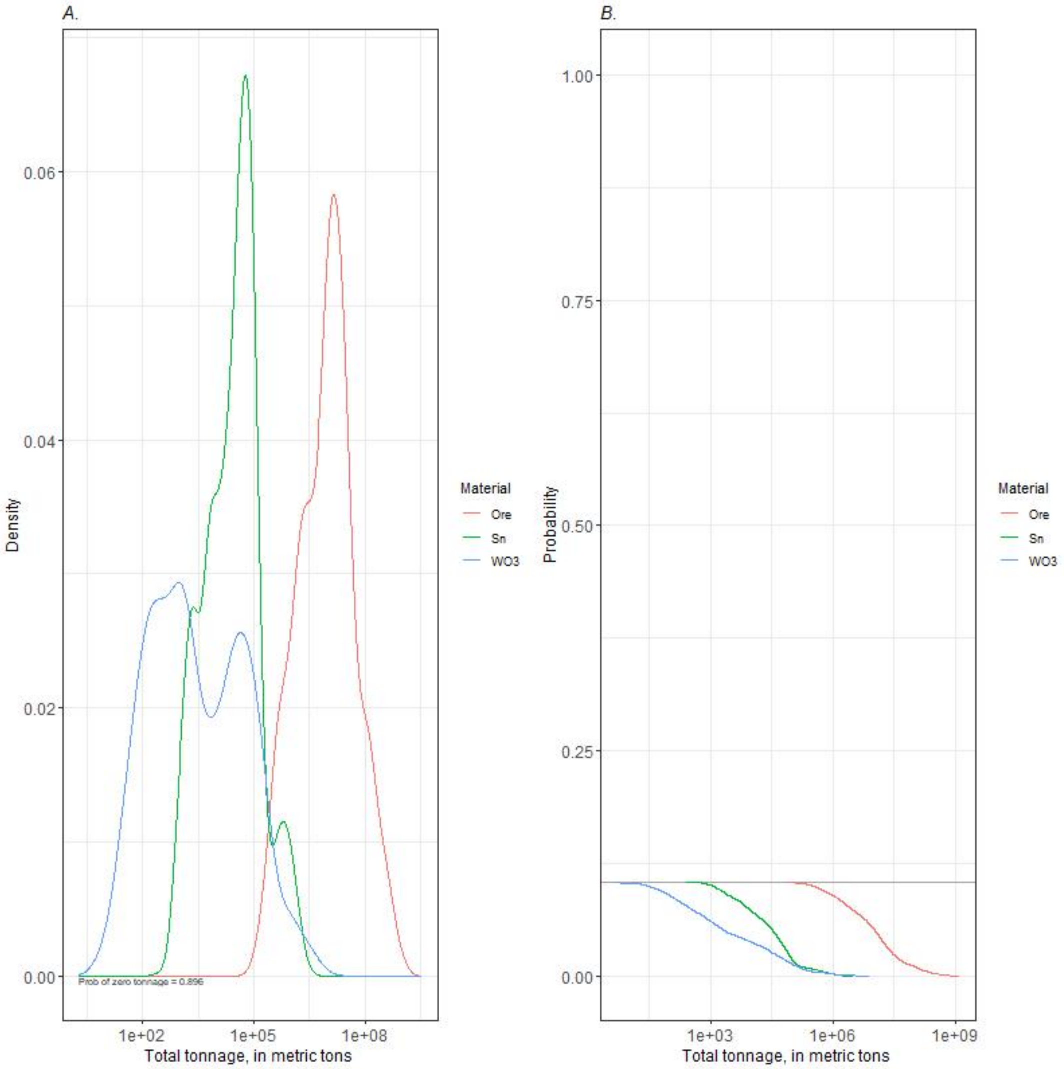

Figure 33 Probability distribution of the tonnages of ore, Sn and WO_3 in undiscovered deposits within permissive tract 6

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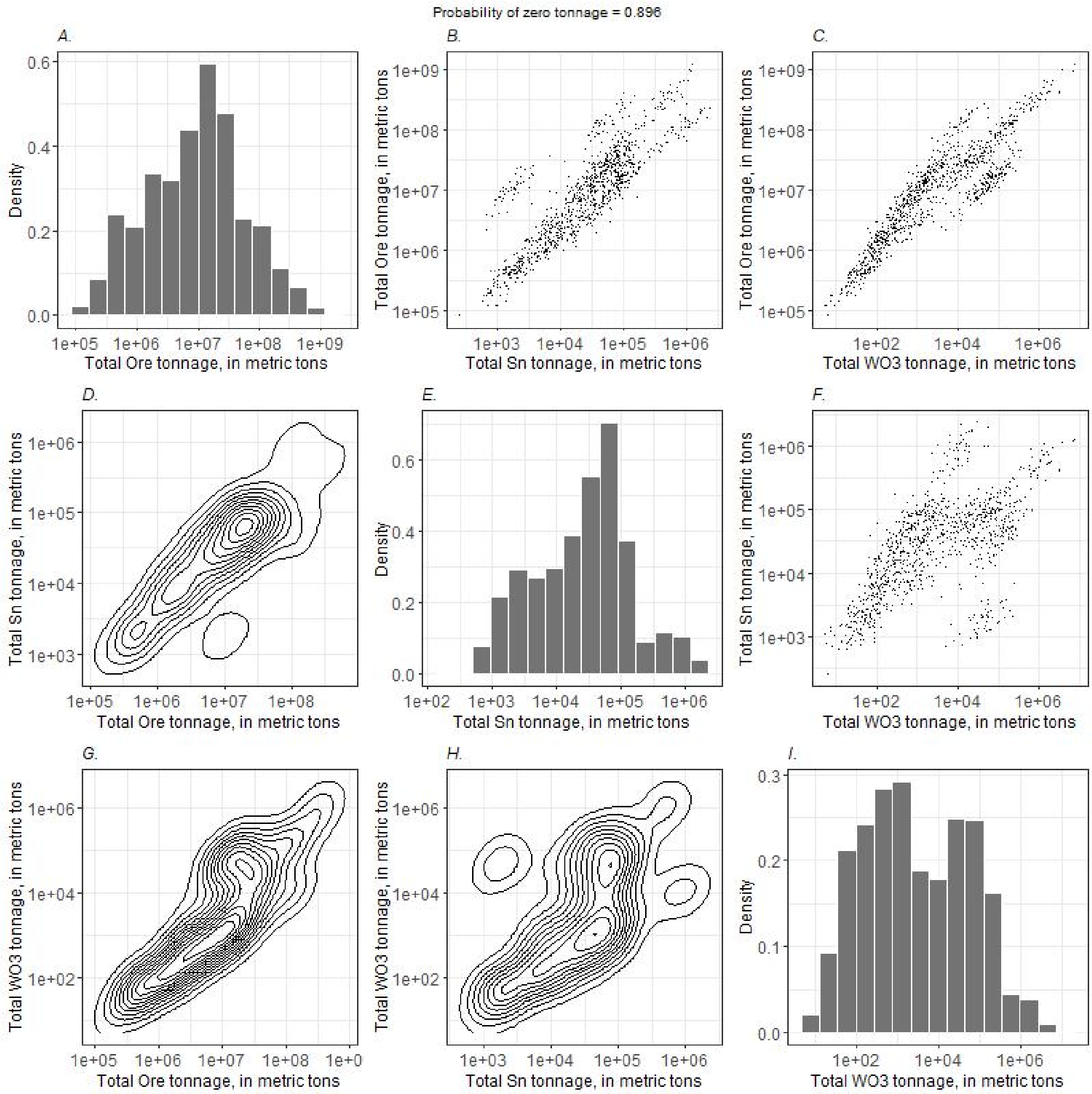

Figure 34 Histograms and cross plots for the tonnages of ore, Sn and WO_3 in undiscovered deposits within permissive tract 6

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3.7. Assessment results for tract 7 (Elbtal)

Delineation of permissive tract

The permissive tract is located in Devonian shallow marine sediments with carbonate intercalations that exist in two tectonically separated narrow strips in the Elbtalschiefergebirge. At Berggießhübel near the southern end of the tract 13 individual layers of magnetite skarns were mined in the past (SMWA, 2008). In this area the tin-specialised Markersbach granite is in contact with carbonate-bearing horizons. An elongated Bouguer minimum suggests that the granite continues as a concealed intrusion for several kilometres into the tract. A part of the tract near the contact with the granite is covered by Cretaceous sediments of the Elbtal Group.

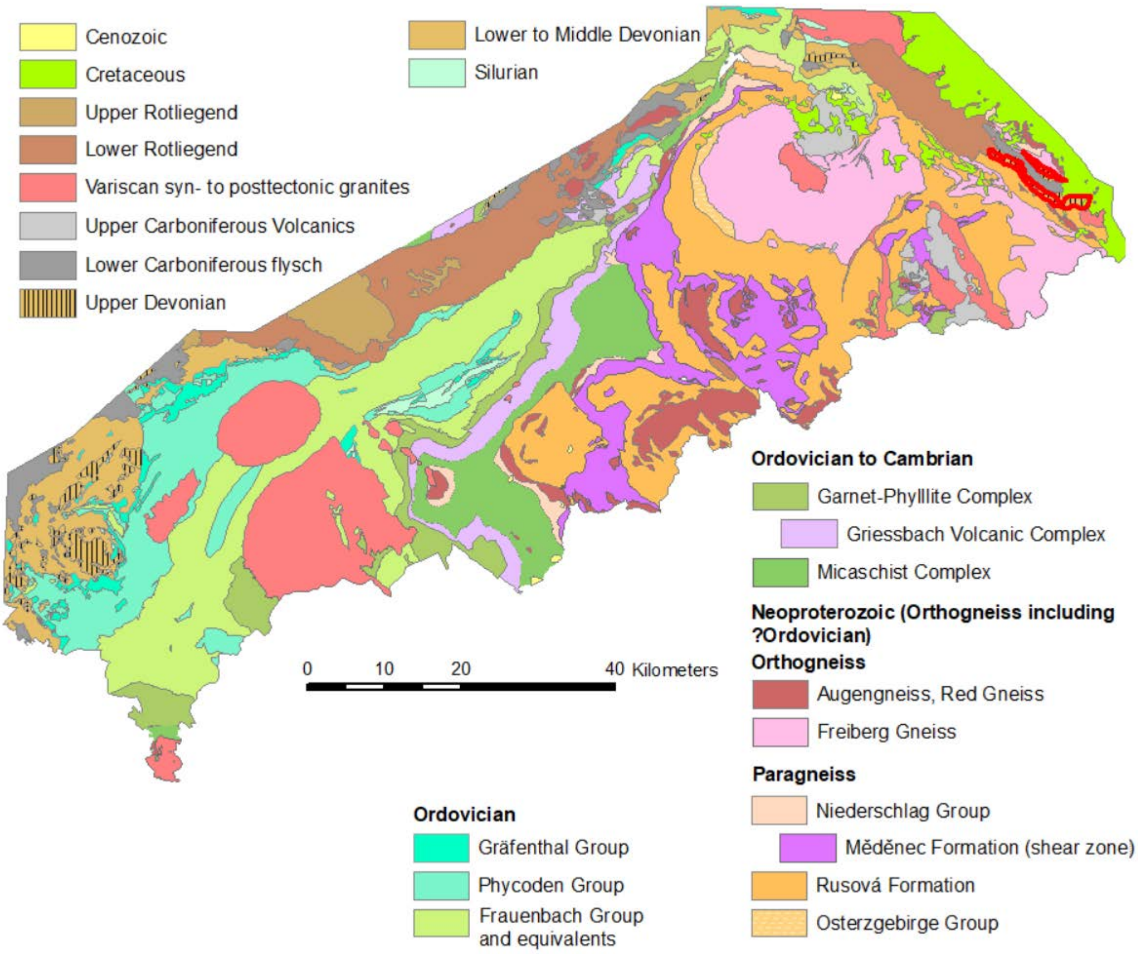

Figure 35 Location of permissive tract 7 on a geologic map of the assessment area

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Location and resource summary

The tract consists of two narrow strips with a combined area of 17 km² to the south of Dresden. The area is part of the Elbtalschiefergebirge, a highly tectonized unit at the margin of the Elbe Lineament. Magnetite skarns have been mined in the past, and particularly in the southern part of the tract near the Markersbach granite they are known to contain tin. However, the tin content has never reached the level of an economically viable deposit.

Estimation of the number of undiscovered deposits

From the expert estimates presented in Table 3 the probability distribution of the number of undiscovered deposits was modelled with the MAP software. The existence of tin-bearing (although subeconomic) skarns and the presence of the Markersbach granite suggest to the experts the possibility of concealed tin skarns in the southern part of the tract. Because of the small area, the number of expected deposits is still low. At the 10 % confidence level the experts expect between one and five undiscovered deposits and between zero and three deposits at the 50% confidence level. Only one expert considers the existence of at least one undiscovered deposit to be probable at the 90% confidence level.

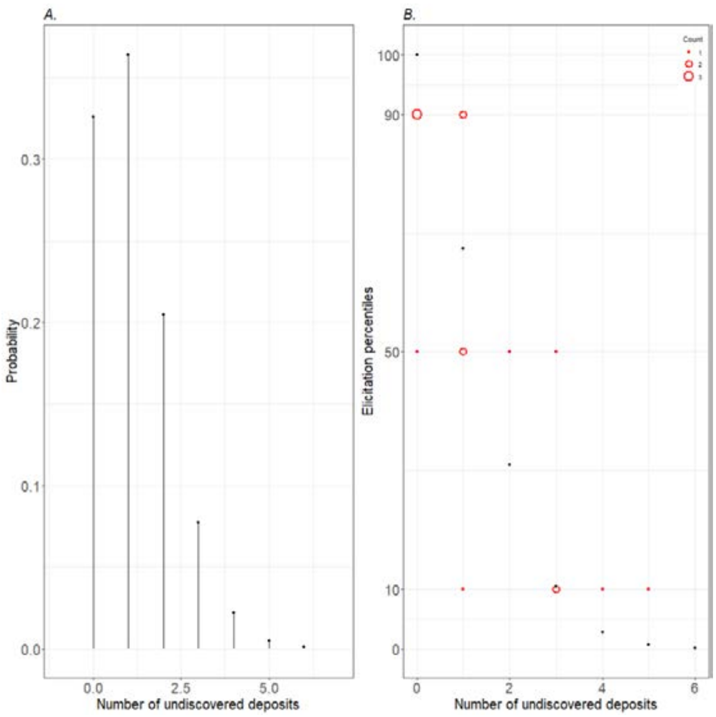

Figure 36 Modelled probability distribution of the number of undiscovered deposits in permissive tract 7

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Assessment of metal tonnages

The modelled tonnages of ore, tin and tungsten contained in undiscovered deposits within the permissive tract are shown in Figure 37 and Figure 38. For the ore tonnage the most likely values are in the range of a few 10^7 tons with about 80,000 tons of tin content. For tungsten (calculated as WO_3) a double-peaked distribution is observed with the most likely values around 1,000 tons and a bit below 100,000 tons. The arithmetic means are 45.3 Million tons of ore with 116,000 tons of Sn and 104,000 tons of WO_3. However, due to the 33% probability that no deposit exists at all, the median values are quite low at 5.82 million tons of ore with 18,900 tons of tin and only 698 tons of WO_3.

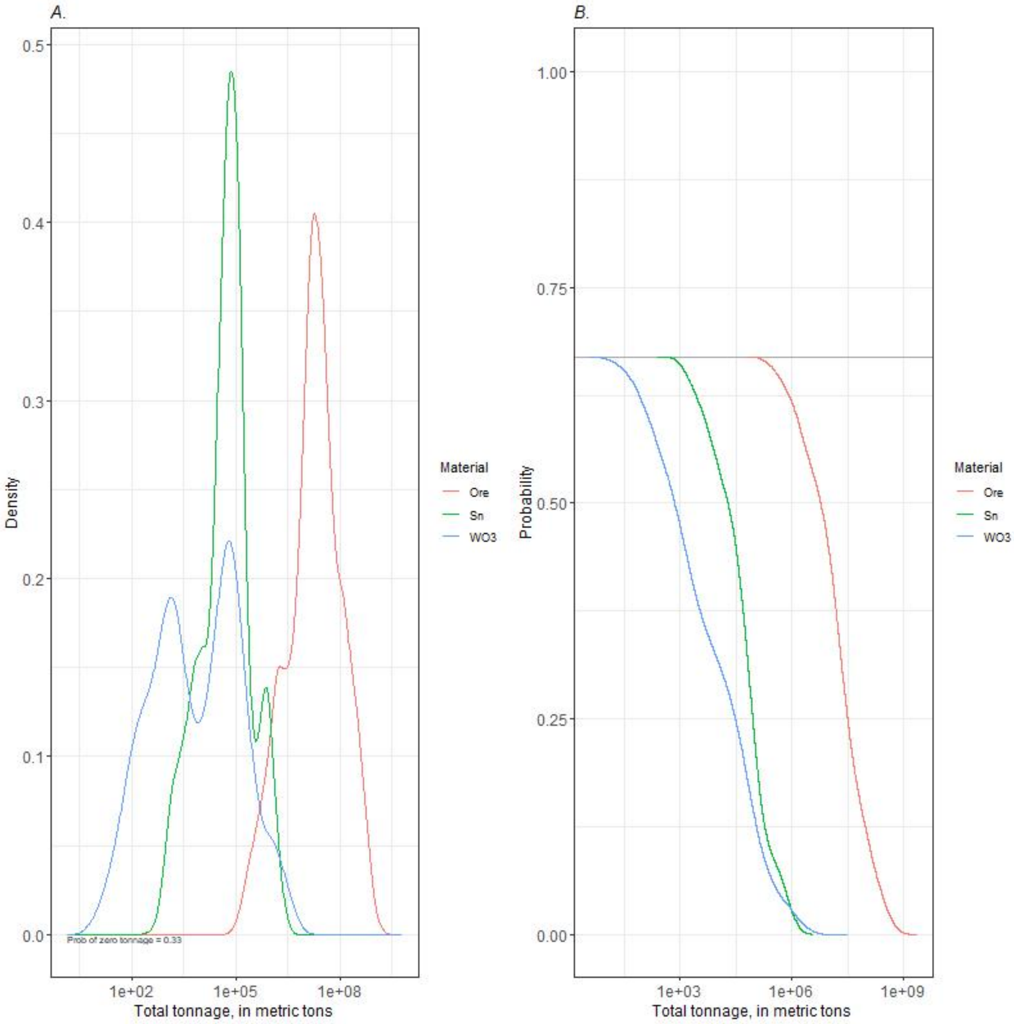

Figure 37 Probability distribution of the tonnages of ore, Sn and WO_3 in undiscovered deposits within permissive tract 7

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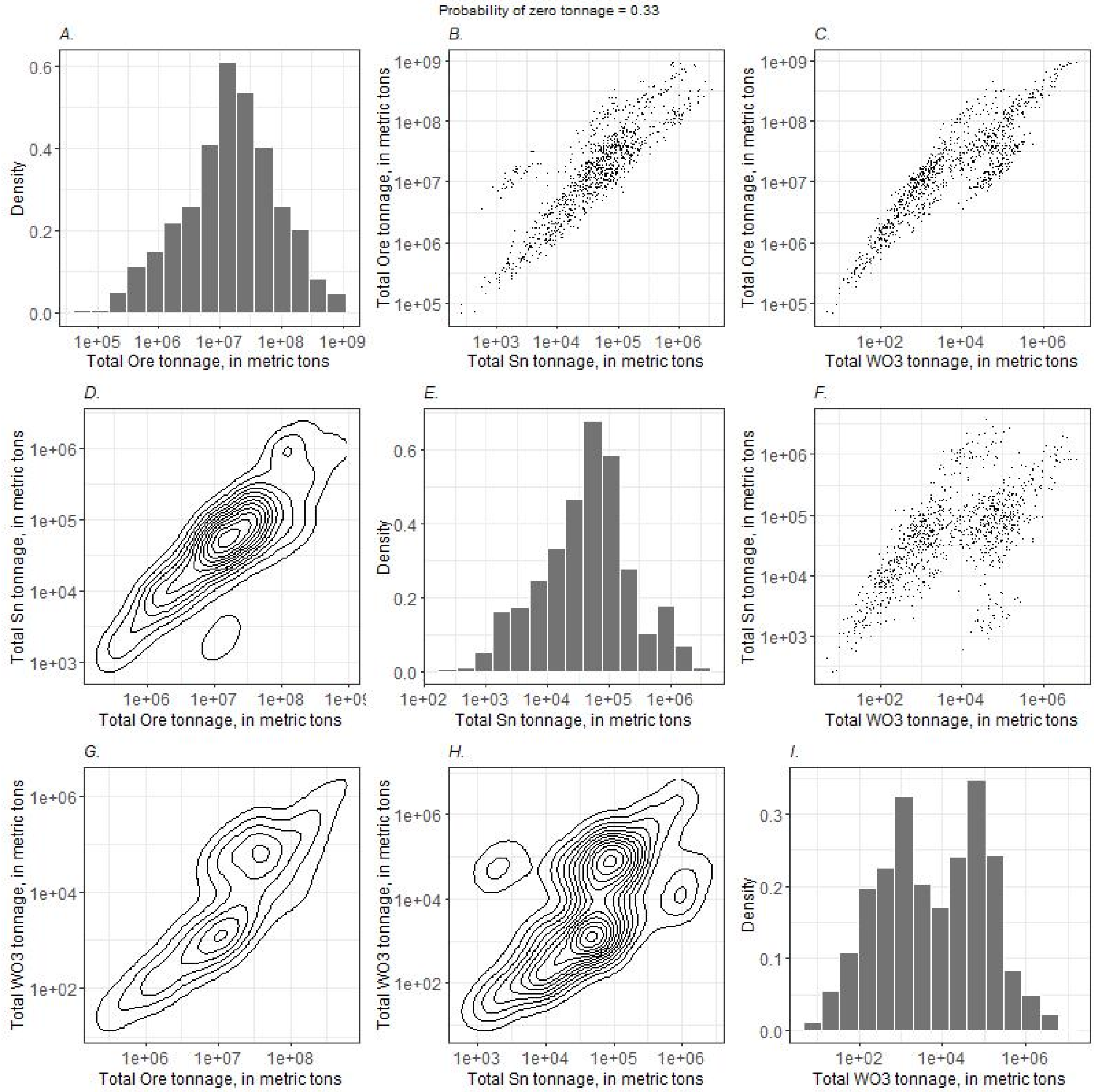

Figure 38 Histograms and cross plots for the tonnages of ore, Sn and WO_3 in undiscovered deposits within permissive tract 7

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3.8. Aggregation of undiscovered deposits

The aggregation of undiscovered deposits was performed over all seven tracts with three different assumptions: perfect statistical independence, statistical dependence and with a best-estimate correlation table (Table 4). For the correlation table three levels of correlation are distinguished and set at correlation coefficients of 0.25, 0.5 and 0.75 respectively. A low level of correlation is expected between all tracts because the geology of the melting and ascent areas of the Variscan granites is somewhat similar and because metasediments with significant tin enrichment are widespread in the shallow crust of the project area. Thus abundant tin-bearing fluids could have been generated in all of the tracts. The next higher level of correlation is set for tracts 3, 4 and 5 which contain known tin deposits or are adjacent to tracts with known tin deposits and large tin-specialised concealed granite bodies. The highest level of correlation is assumed for tracts 2 and 4 which, in addition to the aforementioned similarities, both contain extensive carbonatic layers or lenses above the apical portions of known or inferred granite bodies.

Table 4: Best estimate of pairwise correlation between tracts for the aggregation of undiscovered deposits

	Tract 7	Tract 6	Tract 5	Tract 4	Tract 3	Tract 2	Tract 1
Tract 7	1	---	---	---	---	---	---
Tract 6	0,5	1	---	---	---	---	---
Tract 5	0,25	0,25	1	---	---	---	---
Tract 4	0,25	0,25	0,5	1	---	---	---
Tract 3	0,25	0,25	0,25	0,25	1	---	---
Tract 2	0,25	0,25	0,5	0,75	0,25	1	---
Tract 1	0,25	0,25	0,25	0,25	0,25	0,25	1

The three assumptions produce different aggregate results (Table 5). At the 90% confidence level, the number of deposits decreases from four to one with increasing levels of dependence. At the lower levels of confidence the opposite effect is observed with the number of undiscovered deposits increasing from 14 to 25 at the 1% confidence level. If the assumptions concerning the correlation of tracts detailed above are accepted it is highly likely (90%) that at least two undiscovered deposits exist in the assessment area and moderately likely (50%) that at least six undiscovered deposits exist.

Table 5: Results of the aggregation of undiscovered deposits from all permissive tracts in the project area for three different assumptions regarding correlation.

Association	P90	P50	P10	P05	P01	Mean	Sigma

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Independent	4	7	10	11	14	2.56	0.38
Correlated	2	6	12	13	18	3.87	0.58
Dependent	1	6	15	18	25	5.59	0.84

4. Summary

An assessment of tin-skarn resources in the Erzgebirge, Germany, was conducted with the 3-Part Method. For this purpose a Grade-Tonnage Model for this deposit type was established. A literature review produced grade and tonnage data for 23 skarn deposits, of which 9 are in the assessment area. Based on an existing predictive map created with an AI algorithm, seven permissive tracts with a total area of 776 km² were defined. To estimate the number of undiscovered deposits a panel of five experts in the economic geology of the Erzgebirge was assembled. From the expert estimates and the newly developed Grade-Tonnage Model the undiscovered ore and metal tonnages in each permissive tract were evaluated. In four of the seven tracts the probability of the existence of at least one undiscovered deposit is estimated to be greater than 50%, in permissive tract 2 it is even greater than 90%. In each of these tracts, the median assessed undiscovered ore tonnages are several million tons and the tin resources exceed 10,000 tons. For the most perspective tract (Permissive tract 2) the median estimates are 40.6 Million tons of ore with a tin content of 114,000 tons. For tungsten (tonnages calculated as WO_3) the numbers are slightly lower.

The results verify the high resource potential of tin skarns in the Erzgebirge and can be used to guide future exploration activities to the most economically promising permissive tracts.

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