The Zinnwald Lithium Project: Transferring legacy exploration data into new mineral resources

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The Erzgebirge represents one of the most important metallogenic provinces in Europe and was mined for various metals (i.e. Ag, Sn, U) over centuries. All mining activities were abandoned in the early 1990s, but recent technological and geopolitical developments have brought the Erzgebirge back into the focus of the raw material sector. The leucogranite hosted greisen deposit Zinnwald, historically mined for Sn and W, was systematically explored between 1945 and 1989. Despite the massive presence of the lithium mica Zinnwaldite, its raw material potential remained unused. The combination of legacy data and results of recent exploration (2012-2019) demonstrates that the deposit hosts significant Li resources (35.5 Mt averaging 3,500 ppm Li) and thus has the potential to contribute substantially to the domestic production of Germany.

La région d'Erzgebirge qui représente l'une des provinces métallogéniques les plus importantes d'Europe a fait l'objet de travaux miniers pendant des siècles, pour l'exploration de différentes substances métalliques (i.e. l'Argent, l'étain, l'uranium). Toutes les activités minières ont cessé au début des années 1990 mais de récents développements technologiques et géo-politiques ont réactivé le secteur des matières premières. Le leucogranite qui hébergeait l'ancien gisement de Zinnwald, historiquement exploité pour l'étain et le tungstène, fut alors exploré systématiquement entre les années 1945 et 1989. Malgré la présence massive du mica à lithium (Zinnwaldite), son potentiel en matières premières est resté inutilisé. La mise en commun des données d'exploration, historiques et récentes (2012-2019), montre que le gisement renferme des ressources de lithium significatives (35.5 MT avec en moyenne une concentration de 3 500 ppm de lithium) et donc capables de contribuer de manière substantielle à la production nationale allemande.

El Erzgebirge representa una de las provincias metalogénicas más importantes de Europa en la cual se extrajeron varios metales (Ag, Sn, U) durante siglos. Todas las actividades mineras fueron abandonadas a principios de la década de 1990, pero los recientes desarrollos tecnológicos y geopolíticos han llevado al Erzgebirge nuevamente al foco del sector de las materias primas. El leucogranito greisen alojado en el depósito Zinnwald, históricamente extraído para la obtención de Sn y W, fue explorado sistemáticamente entre 1945 y 1989. A pesar de la presencia masiva de la beta de litio Zinnwaldite, su potencial como materia prima no llego a ser explotada. La combinación de los datos heredados y los resultados de la exploración reciente (2012-2019) demuestra que el depósito alberga importantes reservas de Li (35,5 Mt con un promedio de 3.500 ppm de Li) y, por lo tanto, tiene el potencial de contribuir sustancialmente a la producción nacional de Alemania.

Introduction

Mining in the Erzgebirge has a long tradition and can be traced back to the Bronze Age (Tolksdorf *et al.* 2019). The region hosts numerous ore deposits that were important raw material sources for Fe, Sn, Ag, Cu, Co and later also Zn, Pb, and U in Saxony and the entire Central German region for several centuries (Baumann *et al.* 2000). During this time span the mining industry went through six main mining periods, whose new technological developments led to a change in the demand for individual commodities and thus to greenfield and brownfield exploration with the discovery of new deposits or the reactivation of existing ones. This was also the case in the Eastern Erzgebirge. Historically, the known greisen ore deposits of this region (e.g. Zinnwald/Cínovec, Altenberg, Sadisdorf) were initially an important source for Sn (1300-1800) (Schilka 1991). In the course of the development of the steel industry (19th century), W became increasingly important. Both metals remained the principal mining targets until the beginning of the 1990s, when economic conditions led to the shut down and closure of all ore mines within the region (Schilka 1991; Baumann *et al.* 2000).

However, recent trends show unequivocally that usage of renewable energy is an energy-, climate- and socio-political necessity. The resulting demand for battery storage capacity triggered by the growth of electromobility was the key driver for a very strong increase in demand of lithium (***Figure 1***) (SignumBox 2019). Lithium supply is currently dominated by the four

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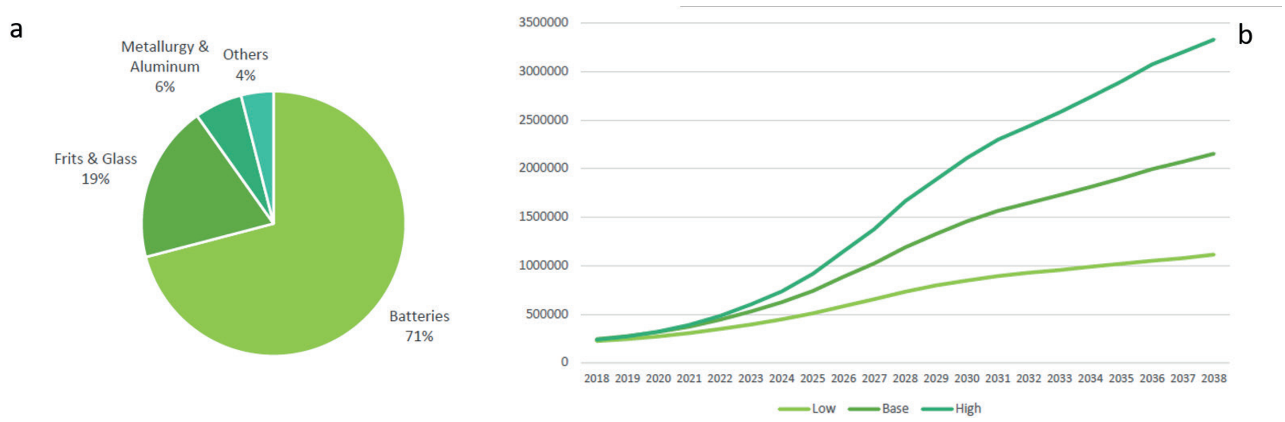

Figure 1: Lithium market. a: Lithium consumption by application in 2018. b: Estimation of total lithium demand, t/LCE (SignumBox 2019).

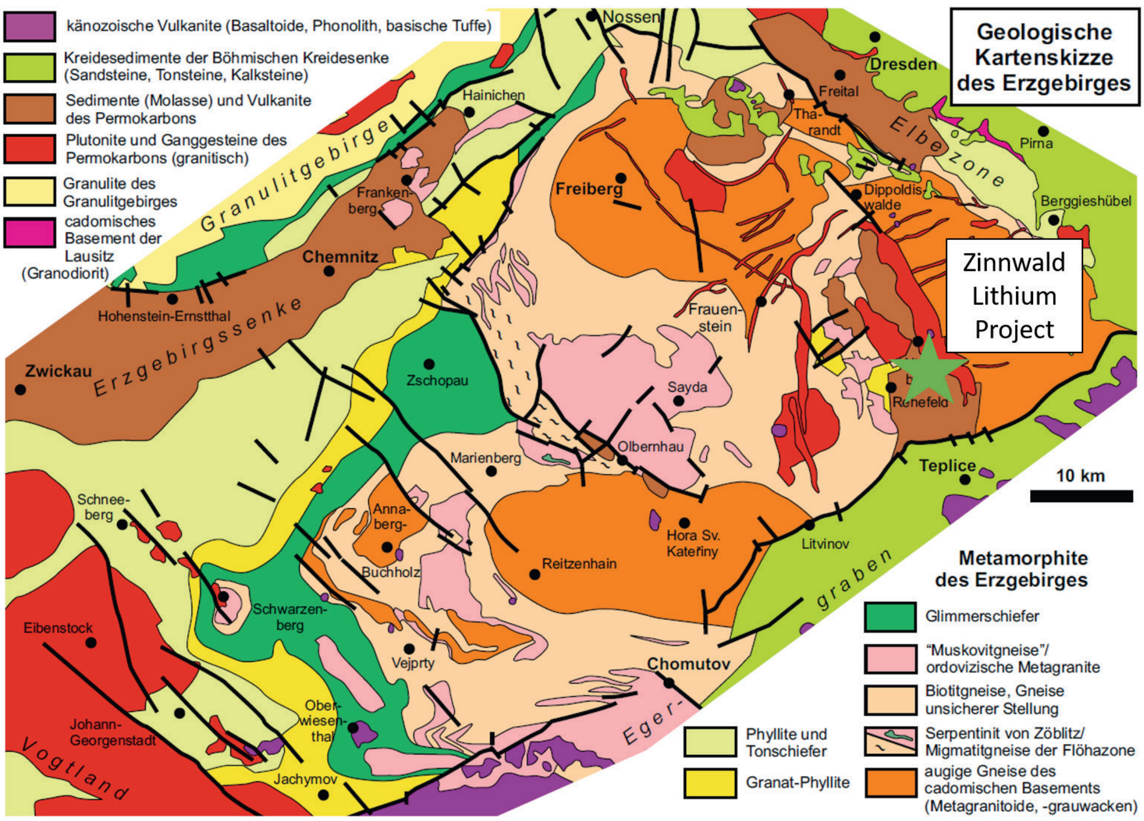

Figure 2: Schematic geological map of the Erzgebirge (modified after Sebastian 2013).

producers Tianqi, SQM, Albermale and FMC, who jointly account for an estimated 56 % of forecast global lithium production in 2019. Due to the current oligopolistic market and the simultaneous rapidly increasing demand for lithium compounds, a stable and secure supply from the free market cannot be guaranteed.

This possible supply shortfall can be filled either by expanding existing capacities or by commissioning new deposits. However, with regard to other unforeseen influences, such as the breakdown of supply chains due to political crises (e.g. trade disputes, wars) or the spread of unknown infectious diseases (e.g. coronavirus), closing this supply gap poses major challenges for a country's industry. In order to mitigate the latter effects, it can be an advantage if a part of the demand can be met by local raw materials that are accessible at all times.

The Eastern Erzgebirge is a region with well-developed infrastructure, services, facilities and access roads. Beside cassiterite and wolframite, as major sources of Sn and W, lithium mica minerals like zinnwaldite as the principal host of Li are essential components of the leucogranitic greisen ore deposits within the Eastern Erzgebirge. Consequently, the region has again become a focus of exploration.

Intensive exploration work in the second half of the 20th century was primarily focused on the economically important Sn; lithium mica mineralisations were discovered as by-product. Neither a final assessment of the exploration data in order to estimate the overall lithium potential of the region nor the estimation of Li mineral resources and reserves were undertaken at that time. However, although the area of the Eastern Erzgebirge must be considered as

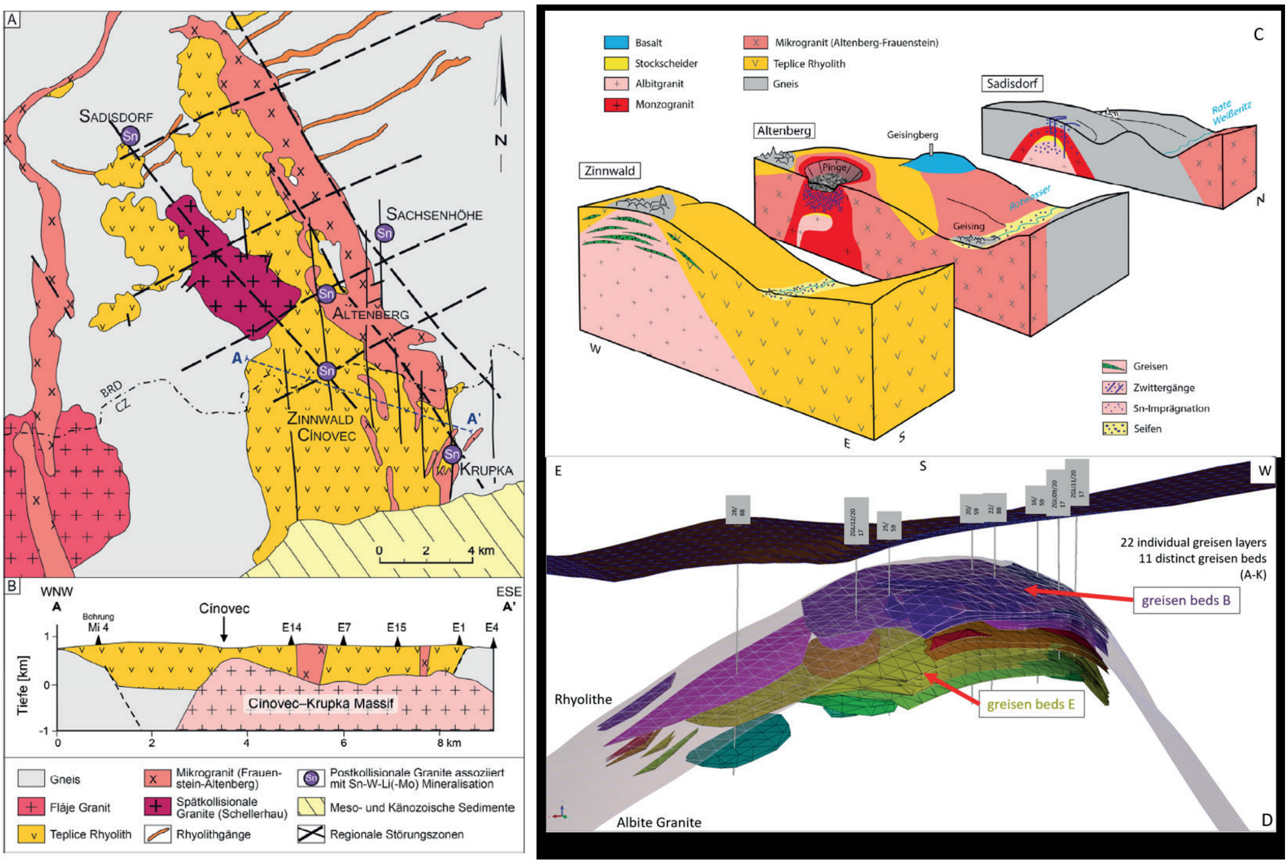

Figure 3: Geology and structures of the Li-Sn-W deposit Zinnwald. A) Schematic geological map of the south-eastern Eastern Erzgebirge (Altenberg-Teplice-Caldera, modified from Neßler et al. 2017 according to Seifert and Kempe 1994). B) Geological section along the line A-A' (modified by Neßler et al. 2017). C) Schematic E-W sections through the tin deposits of the Eastern Erzgebirge (modified after Sebastian 2013). D) Spatial location of the individual greisen ore bodies (Bock et al. 2020).

underexplored with regard to Li and needs to be re-evaluated, it shows considerable potential to serve as a domestic source for Li.

Among the known sites, the border crossing albite granite dome of Zinnwald/Cínovec is one of the most promising Li-Sn-W greisen ore deposits. Historic underground mining activities on Sn have been reported since the second half of the 15th century.

Based on a Li research network project at the TU Bergakademie Freiberg (Seifert and Gutzmer 2010) in 2010 Solarworld Solicium GmbH (SWS) and from 2017 its legal successor Deutsche Lithium GmbH (DL) carried out an in-depth exploration of Li in the German part of the deposit Zinnwald/Cínovec. The aim of the exploration was the estimation of mineral resources that meet the requirements of modern internationally accepted standards such as the Canadian NI43-101 standard. This paper addresses the evaluation of legacy data sets and their combination with new exploration data with a view to present a resource estimate that meets the required standards of resource reporting.

The Eastern Erzgebirge lithium province

The Li-Sn-W greisen deposit Zinnwald/Cínovec is located in the Eastern Erzgebirge/Krušné hory. This crustal unit represents the northernmost extension of the Bohemian Massif, which was formed as a result of the collision of Gondwana and Laurussia during the Variscan Orogeny (***Figure 2***) (Sebastian 2013). Its geological structure is characterised by a crystalline basement comprising Proterozoic and Palaeozoic lithologies which were intruded by various pulses of post-kinematic magmatites belonging to the Erzgebirge/Krušné hory Bath！oliths. This late Variscan magmatism was accompanied by widespread volcanic activity, of which the formation of the Altenberg-Teplice Caldera is one of the most important events. The Altenberg Teplice Caldera is a large elliptical collapse structure (approx. 35 by 22 km wide) that hosts a thick volcanic succession and several phases of granitic intrusions. The model of deep fault zone-related small intrusions of Li-F granites and associated Sn-W-Mo-Li ore deposition in the (eastern) Erzgebirge (see ***Fig. 3a***) discusses also the influence of mantle-derived magmatic pulses (Seifert and Kempe 1994; Seifert 2008).

At or near intersections of these tectonic zones the crystalline basement in the Eastern Erzgebirge is intruded by different late-Variscan acidic melts. The first major magmatic pulse (330-324 Ma) formed a stock-like intrusion with steep flanks (e.g. Niederbobritzsch Granite, Flajé Granite) and immediately was followed by a second major pulse at 324–318 Ma. However, as these melts represent low temperature melts (Helbig *et al.* 2019) they are not highly differentiated, as is evident from a geochemistry exhibiting only low contents of Sn, W, and Li.

In contrast, high temperature melts that were not able to penetrate the gneissic basement could fractionate and thus were enriched in Sn, W and Li and other granitophile elements. Those melts were trapped below the basement until its collapse at 320–318 Ma and the formation of the Altenberg-Teplice Caldera. The highly fractionated melts then could ascend along the resulting fault network into the overlying crust, where they formed small dome or pipe-like intrusions (e.g., Schellerhau

Table 1: Summary of bore holes from exploration campaigns in the German part of the deposit.

Campaign	Number of drill holes	Total length
1917-1918	2	345 m
1930-1945	75	1,903 m
1951-1960	27	5,973 m
1977-1978	2	1,216 m
1988-2989	8	3,148 m
2012-2013	10	2,564 m
2017	15	4,455 m
Total	139	19,604 m

Table 2: Resource estimate of historic Lithium exploration (summarised by Neßler et al. 2017)

Resource Estimation	Resource Classification	Ore Volume [m^3]	Ore Tonnage [t]	Mean Grade [ppm]		
				Li	Sn	W
1960	C_1	4,000,000	10,700,000	3,100		
	C_2	1,000,000	2,800,000	3,200		
	Δ	200,000	500,000			
		Total C_1 +C_2	Total C_1 +C_2		prognostic	prognostic
		5,000,000	13,500,000	3,000	500	200
1978	none	5,980,000	16,100,000	3,000	not calcu-lated	

Granite). These late-stage granites show monzo- to syeno- and alkali feldspar granitic compositions and are usually formed in this order (e.g. Altenberg, Sadisorf). The major Sn and W mineralisation phase is related to the monzogranitic stage, whereas the final alkali feldspar stage is accompanied by major Li and minor Sn and W mineralisation (Helbig *et al.* 2019).

Pneumatolitc fluids enriched in HF, CO_2, HCI, and H_2S accompanied the emplacement of highly fractionated melts and led to autometasomatic processes within the crystallising and consolidating granite or the post-magmatic metasomatic alteration of the crystallised granite and host rocks (e.g. Teplice Rhyolite, gneiss). The first process is typical for Li-mica bearing leucogranites (e.g.Zinnwald/Cínovec, Schenkenshöhe), where massive greisen bodies up to 44 metres in thickness were formed.

The second mechanism caused stockwork-like greisen or greisen veins. Examples for this metasomatic alteration type are sub-horizontal greisen veins and accompanying greisen at Zinnwald/Cínovec, the Morgengänge (sub-vertical veins) at Zinnwald / Cínovec and the greisen stockworks at Altenberg and Sadisdorf (outer granite).

In addition, the metasomatic lithium-mica (zinnwaldite, polylithionite etc.), cassiterite and wolframite mineralisation is accompanied by subordinate to minor topaz, fluorite, arsenopyrite, molybdenite, native bismuth and bismuthine mineralisations.

The Li-Sn-W Greisen deposit of Zinnwald/Cínovec

With regard to Li, Zinnwald is the most explored and richest among the known greisen ore deposits in the Erzgebirge. The deposit is located about 3 km south of Altenberg and is divided into a smaller German (Zinnwald, containing about one third of the deposit) and a larger Czech part (Cínovec) along the German-Czech border. The geological structure of the deposit is relatively simple and is mainly determined by the rocks of the Zinnwald albite granite intrusion that is hosted by the Teplice Rhyolite (***Figure 3***) (Neßler *et al.* 2017).

The major part of Li-Sn-W mineralisation occurs as greisen beds and veins within the granite (endocontact) and only to a lesser extent in the surrounding Teplice Rhyolite (exocontact). The albite granite (***Figure 3***) is a small-scale granitic intrusion that forms an ellipsoidal surface outcrop of about 1,300 m in length (N-S) and about 300 m in width (E-W; Baumann *et al.* 2000). It exhibits a pale yellow to greenish colour, has a weakly porphyritic to poikilitic texture and consists essentially of plagioclase, quartz, orthoclase, Li-Fe-F mica (zinnwaldite) and sericite (Neßler *et al.* 2017). In addition to progressive evidences of greisenisation (in particular decomposition of feldspar, quartz and zinnwaldite metablastesis), albite granite is also affected by argilitisation and hematitisation.

Based on style, orientation, extent and mineral inventory, the greisen- and vein-type mineralisations are divided into different ore types (e.g., Neßler *et al.* 2017).

- Massive greisen beds, that follow with subparallel dip the morphology of the granites' surface
- Massive greisen stockworks, associated with NW-SE striking faults
- Sub-horizontal dipping quartz-greisen veins (called "Flöze")
- Sub-vertical dipping veins (called "Morgengänge").

Among those, the massive greisen beds represent the volumetrically dominant mineralisation type and the largest resource for Li in Germany (Bock *et al.*, 2020) The mineralogical composition of the massive greisen beds is relatively simple and consists predominantly of quartz (70-80 %), zinnwaldite (20-30 %) and also contains minor topaz and remnants of feldspar. These mineralisations form flat, lenticular, irregular ore bodies and are developed in the upper part of the granite dome as well as along its flanks. Individual greisen bodies have a lateral extent of up to several hundred metres at thicknesses of <1 m to 30 m and at several locations of up to 50 m. Their frequency and thicknesses decrease with increasing depth (Neßler *et al.* 2017).

The sub-horizontally dipping quartz greisen veins are the host for the major part of the Sn-W mineralisation in the upper part of the intrusion and therefore were the basis of historic mining activities. These greisen veins also follow with subparallel dip the morphology of the granite' surface. In contrast to the massive greisen beds they can extend in the exocontact. Due to their flat packing and high lateral continuity they were referred as "seams" ("Flöze") as this appearance resembles a stratiform mineralisation. The most common type of veins is represented by quartz-zinnwaldite-veins, where the zinnwaldite rests as irregular nests or bands within the quartz gangue (Nessler *et al.* 2017). Cassiterite typically forms small nests, which consist of many small single grains that are intergrown with large (up to 15 cm) wolframite crystals and massive white to milky quartz.

Sub-vertically dipping veins are only a subordinate mineralisation in the deposit. Their mineralogical composition is similar to that of shallow dipping veins. Their thickness is usually around 10 to 20 cm and does not exceed 1 m (Neßler *et al.* 2017).

Zinnwaldite is only a minor constituent of this mineralisation style and occurs as disseminated crystals or rosettes in a compact core of quartz.

In addition to the Li mineralisation, the deposit also contains subordinate to minor mineralisations of Sn(-W)-mineralised albite granite, feldspatites, Sn-(In)-Zn-Cu-Pb sulphide ores as well as barite(-fluorite) mineralisation (Neßler *et al.* 2017).

Historic mining and exploration

The Zinnwald/Cínovec deposit is one of the most important greisen-type ore deposits of the Central European Variscan Orogen. It is not possible to reconstruct the exact date of the first mining activities, but it is estimated to be the end of the 13th century (Schilka 1991). Starting from the first discovery, the main focus for around 400 years was the extraction of tin ore (cassiterite). It was not until 1880 that the tungsten mineral wolframite became the main product of ore extraction. The first production of lithium-mica is reported from 1890 (Schilka 1991). After the end of the Second World War mining in the Saxon part of the deposit was abandoned.

The first core drillings were performed in 1917-18, with further drillings following between 1936 and 1945. Systematic exploration of the Sn and Li reserves began in 1930. The deposit was explored in detail by surface and underground bore holes during several campaigns (***Table 1***). In addition, the accessible parts of the underground mine were sampled. The results of the Li reserve estimations in the German part of the deposit for historic exploration campaigns prior to 1990 are summarised in ***Table 2***.

In the course of economic and political developments, the exploration was stopped at the beginning of the 1990s.

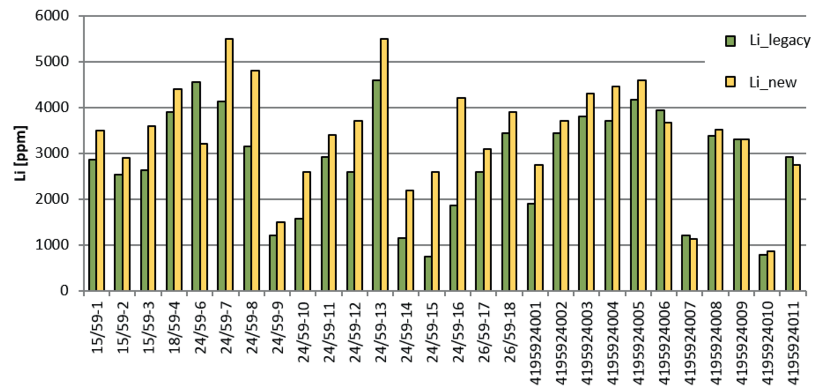

Figure 4: Comparison of Li-grades from legacy and new analysis (Neumann et al. 2014).

Table 3: Lithium resource estimation of the 2011-2014 exploration campaign (Neumann et al. 2014).

Resource classification “Ore Type 1” - greisen beds, vertical thickness ≥ 2 m, cut-off Li = 2,500 ppm	***Ore Volume [m³]***	***Ore Tonnage [t]***	***Mean Li Grade [ppm]***
Demonstrated *(Measured+Indicated)*	*9,840,000*	*26,570,000*	*3,620*
Total *(Measured+Indicated+Inferred)*	***13,495,000***	***36,437,000***	***3,643***

Table 4: Mineral inventory of the Zinnwald Lithium Deposit, German part below 740 m a.s.l. (Bock et al. 2020).

Mineral inventory “Ore Type 1”	***Volume [m³]***	***Tonnage [t]***	***Mean Li Grade [ppm]***
Total	*19,900,000*	*53,800,000*	*3,100*

5. 2011-2014 Exploration

In 2011 and 2012 SWS acquired two exploration licenses in the Zinnwald area. SWS initially focused its exploration activities in the central Zinnwald area as well as underground in the accessible parts of the abandoned mine. Exploration consisted of 10 surface drill holes (9 DDH and 1 RC DH) completed during the years 2012 to 2014 with a total length of 2,484 m. An underground sampling campaign was conducted in the year 2012, which provided a series of 88 greisen channel samples from the sidewalls of the adits (Neßler *et al.* 2017). In addition, a 20 t bulk ore sample was taken for processing test works.

Another important information source consisted of various kinds of datasets from prior exploration campaigns. These include exploration reports and assay tables in printed form, but also drill cores and retained sample materials from old geochemical analyses (Neßler *et al.* 2017).

Table 5: Lithium resource of the Zinnwald Lithium Deposit, German part below 740 m a.s.l. – Base Case “Ore Type1” Summary (Bock et al. 2020).

Resource Classification “Ore Type 1” Greisen Beds	***Ore Volume [m³]***	***Ore Tonnage [t]***	***Mean Li Grade [ppm]***	***Ore Volume [m³]***	***Ore Tonnage [t]***	***Mean Li Grade [ppm]***
	Vertical Thickness ≥ 2 m, cut-off Li =2,500 ppm			*Vertical Thickness ≥ 2 m, cut-off Li = 0 ppm*		
Measured	*6,855,000*	*18,510,000*	*3,630*	*8,954,000*	*24,176,000*	*3,246*
Indicated	*6,296,000*	*17,000,000*	*3,399*	*8,046,000*	*21,725,000*	*3,114*
Inferred	*1,802,000*	*4,865,000*	*3,549*	*2,675,000*	*7,224,000*	*2,995*
Demonstrated (Measured+Indicated)	*13,152,000*	*35,510,000*	*3,519*	*17,000,000*	*45,901,000*	*3,183*
	Internal Dilution					
Total (Measured+Indicated+Inferred)	*4,722,000*	*12,749,000*	*2,001*			

To check the accuracy of the geological data, the first two drill holes in 2012 were executed as twin holes of historic drillings. Results demonstrated a good match in both geology and geochemistry. In order to further validate the results from chemical analysis of these former campaigns, a reassessment of the assayed values was conducted (***Figure 4***). This work included the geochemical analysis and comparison of about 53 historic samples from drill cores at certified analytical labs. After thorough and careful evaluation and interpretation, a large part of the legacy data sets could be implemented and used for geological modelling and reserve estimations.

Thus, a potential lithium resource (***Table 3***) was confirmed applying the European PERC reporting standard and published in a prefeasibility study (Neumann *et al.* 2014).

6. 2017-2019 exploration

In February 2017, Bacanora Lithium plc. acquired 50 % of SWS and the 50:50 joint venture company was renamed Deutsche Lithium GmbH. Consequently, the further exploration work had to be conducted according to the Canadian NI43-101 reporting standard.

Infill and verification drilling was resumed and completed in 2017 by Deutsche Lithium consisting of 15 surface DDH with a total length of 4,458.9 m. In addition, another 100 t bulk ore sample was taken for pilot plant scale processing test works.

The geological and geochemical results were fully integrated in the database and used to update the geological model and resource estimation. QA/QC procedures were carried out for due diligence purposes during both exploration campaigns (2011–2014 and 2017–2019) and were verified by external qualified persons. The results confirmed the careful sampling and reasonable accuracy and precision of the assays.

Thus, exploration within the Zinnwald property has confirmed the presence of several lithium bearing greisen ore bodies with dimensions of around 1 km from north to south and of around 1 km in east-west direction. Intersected thicknesses range between a minimum of 0.1 m and a maximum of 43.7 m. The deepest exposure of greisen ore was encountered at a depth of 416 m below surface.

The general mineral inventory of lithium (***Table 4***) estimated from the block model on the basis of a zero cut-off and without a constraint of minimum thickness of the ore bodies accounts to 53.8 Mt ("Ore Type 1") with a rounded average grade of 3,100 ppm Li.

Modifying factors for eventual economic extraction (vertical thickness ≥ 2 m, cut-off = 2,500 ppm Li) applied to the mineral inventory result in a demonstrated (measured and indicated) lithium resource of 35.51 Mt of greisen ore with an average lithium grade of 3,519 ppm Li (***Table 5***).

The potential of Sn, W and K_2O have been estimated for the greisen beds as mean grades for "Ore Type 1" of the deposit and below 740 m a.s.l. at a total volume of rounded 15 Mm^3 and a tonnage of 40 Mt, the overall mean grades for Sn, W and K_2O account to 500 ppm, 100 ppm and 3.1 wt.%, respectively.

8. Summary and outlook

The Zinnwald Li mineral resources have been established on a solid data basement and with the use of modern estimation methodology. Through careful and accurate treatment, it was possible to combine legacy and new data, which led to a robust resource estimation in accordance with internationally recognised standards.

In summary, the resources (***Table 5***) were found to double those estimated in the prior 1990 results (see ***Table 2***). In addition, it was demonstrated that due to the particular tectonic situation along the western flank of the intrusion, the mineralisation remains open beyond the expected limits of the deposit towards the northwest.

Another result of metallogenetic and possibly economic importance is the discovery of a continuous mineralised zone with disseminated Sn-W mine ralisation along the eastern flank at the footwall section of the main greisen ore bodies. A corresponding core interval of 20 m in length resulted in average grades of 0.26 wt.% Sn and 0.06 wt.% W (Neßler *et al.* 2015, 2017).

Both commodities need to be investigated in more detail by further field exploration during mining of the deposit.

In April 2017, a mining permit was applied for by Deutsche Lithium GmbH (DL), which was approved for the field "Zinnwald" in October 2017. The mining permit covers 2,564,800 m^2 and is valid up to the end of 2047. In addition, DL holds two other exploration licenses (Falkenhain, Altenberg-DL) within the area that have the potential to significantly increase the lifetime of the project.

Following mine development and construction of the processing and chemical plant, which will take a period of 18-20 months, DL plans to mine around 500,000 to 600,000 tonnes of ore per year to produce 5,000 tonnes of battery grade LiF or other Li-salts (e.g. $LiOH \cdot H_2O$, Li_2CO_3).

The results of the exploration campaigns were published by DL in a feasibility study in April 2020 (Bock *et al.* 2020). Based on this, a financing package is currently under way. In parallel, the higher-level approval procedures (i.e. optional framework operating plan) are underway. Depending on positive results of both, the project can be executed.

Due to the still weak demand for lithium as a result of a generally weakening lithium market, the acquisition of capital for the implementation of the project has become significantly more complex. However, it is assumed that in the coming years (2020-2022) the demand for lithium compounds will continue to increase sharply due to the expansion plans for electromobility.

In addition to its location in a region with well-developed infrastructure, services, facilities, and access roads, the short distances to the end-users of the lithium compounds are another essential advantage of the project. Furthermore, all social and economic standards are met. The Zinnwald deposit thus has the potential to cover part of the domestic lithium demand.

References

Baumann, L., Kuschka, E., Seifert, T. 2000: Lagerstätten des Erzgebirges (Mineral deposits of the Erzgebirge Mountains). Stuttgart: Enke im Thieme-Verlag.

Bock, W-D., Kühn, K., Gowans, R. 2020. Zinnwald Lithium Project, Technical Report on the Feasibility Study for the Zinnwald Lithium Project, Germany, NI 43-101 Technical Report, effective date 15.04.2020, prepared for Deutsche Lithium GmbH, Freiberg, G.E.O.S Ingenieurgesellschaft mbH, Halsbrücke, Germany, Micon International Ltd., Toronto.

Grunewald, V. 1978. Neueinschätzung Rohstoffführung Erzgebirge, Gebiet Osterzgebirge – Metallogenie und Prognose Zinnwald, Teil 1: Metallogenie (Reassessment of resource base of the Erzgebirge Mountains, Eastern Erzgebirge Mountains District - metallogeny and forecast for Zinnwald, part 1: Metallogeny). Unpublished report, Zentrales Geologisches Institut der DDR, Berlin.

Helbig, M., Kahnt, R., Becker, L., Gabriel, A. 2019. Verbundprojekt GEM Granitgebundene Erze strategischer Metalle – Bildungsbedingungen und Ableitung innovativer Suchkriterien für verborgene Erzkörper. Arbeitspaket 4 – Wärmetransportmodellierung und geochemische Modellierung (Joint project GEM, granite-bound ores of strategic metals: conditions of formations and derivation of innovative search criteria for hidden ore bodies. Work package 4 - heat transport modeling and geochemical modelling). Unpublished report. G.E.O.S. Ingenieurgesellschaft mbH Halsbrücke / Germany, 31.12.2018.

Neßler, J., Seifert, T., Gutzmer, J. 2015. New Sn-W potential at the Zinnwald/Cínovec deposit, eastern Erzgebirge, Germany. "Mineral Resources in a Sustainable World", 13th SGA Biennial Meeting 2015, Nancy. Proceedings, Volume 2, 2819-2822.

Neßler, J., Seifert, T., Gutzmer, J., Müller, A. 2017. Beitrag zur Erkundung und metallogenetischen Charakteristik der Li-Sn-W-Greisenlagerstätte Zinnwald, Osterzgebirge, Deutschland (Contribution to the exploration and metallogenetic characteristics of the Li-Sn-W Greisen deposits Zinnwald, Eastern Erzgebirge Mountains, Germany). *Freiberger Forschungshefte* C 552. Freiberg: TU Bergakademie Freiberg.

Neumann, M., Bachmann, T., Hartsch, J., Henker, J., Helbig, M., Kahnt, R., Kühn, K., Morgenstern, S., Müller, A., Neßler, J., Zernke, B. 2014. Zinnwald Lithium Project, Report according to PERC Standard on behalf of SolarWorld Solicium GmbH. G.E.O.S. Ingenieurgesellschaft mbH, Halsbrücke, Germany in collaboration with TU Bergakademie Freiberg, 01.10.2014.

Schilka, W. 1991. Zinnwald. Die Geschichte eines osterzgebirgischen Bergbauortes (Zinnwald: The history of a mining site in the Eastern Erzgebirge Mountains). Gemeindeverwaltung Zinnwald-Georgenfeld.

Schilka, W., Baumann, L. 1996. Metasomatische Prozesse im Schellerhauer Granitmassiv (Osterzgebirge) (Metasomatic processes in the Schellerhauer granite massif) . *Freiberger Forschungshefte*, C467. 151-176.

Sebastian, U. 2013. *Die Geologie des Erzgebirges (The geology of the Erzgebirge Mountains)*, Berlin: Springer Spektrum. DOI: 10.1007/978-3-8274-2977-3

Seifert, T. 2008. *Metallogeny and Petrogenesis of Lamprophyres in the Mid-European Variscides – Post-Collisional Magmatism and Its Relationship to Late-Variscan Ore Forming Processes (Bohemian Massif)*. Amsterdam: IOS Press BV.

Seifert, T., Gutzmer, J. 2010. Li-reiche Sn(-W-Polymetall)-Greisenlagerstätten im Freistaat Sachsen (Li-rich Sn(-W-polymetallic) deposits in Saxony). In: Voigt, W. (ed), Freiberger Forschungsforum: 61. Berg- und Hüttenmännischer Tag, FK 3: "Lithium for Li-Ion Batteries - Resources and Recovery", abstracts volume.

Seifert, T., Kempe, U. 1994. Zinn-Wolfram-Lagerstätten und spätvariszische Magmatite des Erzgebirges (Tin-tungsten deposits and late Variscan magmatites from the Erzgebirge Mountains). *Beihefte zum European Journal of Mineralogy*, 6(2). 125–172.

Signumbox 2019. Lithium Fluoride Market Study – Final. signumBox, Santiago, Chile, 11.03.2019.

Tolksdorf, J. F., Schröder, F., Petr, L., Herbig, C. 2019. Evidence for Bronze Age and Medieval tin placer mining in the Erzgebirge mountains, Saxony (Germany). *Geoarchaeology* 35. 198–216. DOI: 10.1002/gea.21763