



A Review on the Deposit Geology and Mineralization Mechanism of Tsumeb Polymetallic Deposit, Namibia

Regean Pumulo Pitiya^{1,2*}, Lubang Jacob Peter^{1,2}

¹School of Geoscience and Info-Physics, Central South University, Changsha, China

²The Key Laboratory of Nonferrous Metal Mineralization Prediction and Geological Environment Detection of Ministry of Education (Central South University), Changsha, China

Email: *regeanpitiya@yahoo.com

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Abstract

The Tsumeb polymetallic deposit of Otavi Mountain Land (OML), Namibia, is a prominent deposit of remarkable and complex mineral species with the accreditation of about 337 valid minerals. A total of 72 species of these minerals are of Tsumeb as the type of locality. The deposit was first prospected in 1893 by the South West Africa Company and it was mined from the year 1897 to 1996, yielding a total of about 30 Mt of ore with the grade of 10% Pb, 4.3% Cu, and 3.5% Zn along with ore minerals of As, Sb, Ag, Cd, and Au. The orebody also typifies the largest renowned single sulfidic accumulation of germanium (Ge). However, like many other deposits, the Tsumeb copper deposit has been exhausted. Hence, re-assessment of ore reserve and exploration is a crucial practice in the discovery of new mineral resources and occurrences. This practice requires extensive understanding of the geological characteristics and metallogenic mechanisms of the parent/exhausted ore deposit as a reference model. In this paper, we presented a summary description of the Tsumeb deposit (polymetallic Copper deposit) of the Otavi Mountain Land (OML), Namibia, with the main focus on the regional geological background, deposit geology and ore mineralization mechanism.

Subject Areas

Geology

Keywords

Tsumeb, Otavi Mountain Land (OML), Mineralization, Damara Orogen, Neoproterozoic

1. Introduction

Tsumeb is a town of about 19,000 residents and one of the big towns in Oshikoto region, located in northeast Namibia, on the South West side of Africa, roughly 500 km to the North of the capital city, Windhoek (**Figure 1**) [1] [2]. The town is characterized by a hot semi-arid climate, with hot summers and mild winters with average annual precipitation of 528 mm. The Tsumeb polymetallic Copper deposit is one of the critical carbonate-hosted manifestations of Cu, Pb, Zn mineralization within the Otavi Mountain Land (OML) [3]. This deposit is a prominent deposit of remarkable and complex elements with the accreditation of about 337 valid minerals of which 72 of these minerals are of Tsumeb type-locality [4] [5] [6] [7]. The deposit was first prospected in 1893 by the South West Africa Company, commercially mined from the year 1897 to 1996, yielding a total of about 30 Mt of ore with the grade of 10% Pb, 4.3% Cu, and 3.5% Zn along with minerals of As, Sb, Ag, Cd, Ge and Au [8]. Extraction of minerals from the Tsumeb deposit, copper minerals in particular has a history prior to the year 1897. The extraction activities were done by ancient people smelting copper, locally in the vicinity of Tsumeb. The smelting of copper was a common exercise in the Bergdama tribe, the Herero and Ovambo people [9] [10] [11]. For indigenous miners, the green tint of malachite identified copper-bearing deposits



Figure 1. Map showing Tsumeb in Namibia (modified from Cairncross, 2017).

from other rocks and they used it for a variety of purposes including making jewelry, weapons, and trading it in exchange for livestock. Still, present-day evidence shows that ancient smelting activities are widespread all over the Otavi Mountain Land, with the pattern and methods employed being alike to those used prior to 500 AD in Central Africa [12] [13] [14]. The ore deposit is well-known and was one of the major producers of base metal in Africa [15], in particular due to its profound high quality ore throughout its production lifespan [16] [17]. The high grade ore at the time meant that a greater proportion of the ore was sent directly to the smelter without undergoing mineral enrichment stage. The deposit output was moderate until 1990 when the price of copper declined, along with eventuality of strikes at the mine. The labour strikes halted operations at the mine which lead to flooding of major equipment thus its closure in 1996 [18]. In this paper, we present a summary of the Tsumeb deposit (polymetallic Copper deposit) of the Otavi Mountain Land (OML), Namibia, based on selected literature sources, with the main focus on the regional geological background, deposit geology and ore mineralization. The primary objectives of this study are to ascertain the nature of geological and tectonic events, and the origin of ore-forming elements, as well as to better understand the ore-forming process and mineral precipitation mechanism of the Tsumeb deposit.

2. Regional Geology and Tectonic Evolution

The Tsumeb deposit is located within the Otavi Mountain land (OML), a mineral zone spanning about 10,000 km² of northern Namibia, forming part of the Northern Carbonate Platform of the Pan African Damara Orogen [19] [20] [21]. There are more than 600 Cu-Pb-Zn-V deposits and occurrences reported in OML [22]. The Damara Orogen is a late-Proterozoic orogenic belt of Pan African age, situated between the ancient landforms of the Congo and Kalahari cratons [23] [24] [25] [26] [27]. It accommodates various species of sulphide (Pb-Cu-Zn ore deposit dominated by “oxidized” Pb, Cu and Zn ore minerals) and non-sulphide occurrences [28] [29]. The formation of the Damara Orogen is characterized by multifarious geotectonic episodes which can be broadly summarized into earlier deposition of a geosynclinal sequence estimated at 900 to 650 Ma, triggered by the separation of the Kalahari, Congo and proto-South American cratons [30] [31]. The rifting allowed the deposition that lead to formation of the Damara Orogen, which was then tailed by episodes of compression [32] [33] [34].

The Damara orogeny sedimentary rocks’ texture and composition indicate that they formed in a cold to temperate climate. Two global ice periods, the so called “Snowball Earth”, disrupted regular sedimentation hundreds of millions of years ago, when massive glaciers covered the land. When the glaciers eventually retreated and temperatures rose again, characteristic deposits of glacial debris accumulated, allowing rock units to be associated between different regions of the Damara Orogen. However, Eyles & Januszczak (2007) [35] argue

based on sedimentological analyses of specific outcrops in Namibia that there is no distinct indication of catastrophic Snowball Earth-type glaciations. In addition, the findings of Eyles and Januszczak (2007) [35] support the idea of tectonic dominance over sedimentation, which is linked to recurring occurrences of faulting and slope failure. In the Damara Orogen, mineralization regions formed all the way through and post orogenic processes due to multifarious interactions between magma, hydrothermal solutions, and sediments [36]. The northern part (arm) of the Damara Orogen is identified as the Kaoko Belt, whereas the southern part overlying the Namaqua Metamorphic Complex, which consists of meta-sediments in southern Namibia, is identified as the Gariiep Belt (**Figure 2**) [37] [38]. Detailed descriptions about the Damara Orogen are documented by Joseph, Richard, Ben, & Rudolph (2008) [30] and Haack & Martin (1983) [39].

3. Regional Stratigraphy and Structure

Within the OML, the Neoproterozoic siliciclastic and carbonate successions of the Damara Supergroup of the Damara Belt are separated into three groups. Lithologically, the groups from bottom to top are: 1) Nosib Group, which are volcanic and clastic sediments, reaches up to 1200 m in thickness [40]; 2) Otavi Group, 4800 m in thickness with predominance of carbonates, estimated to be deposited between 750 and 545 Ma and; 3) Mulden Group, deposition or age constrained between 580 and 541 Ma, which are clastic molasse-type sediments [41].

The Otavi group is subdivided into the Tsumeb and Abenab sub-groups. The three groups of sedimentary strata are supported by basement rocks made up of granite, gneiss, and a mafic complex that is poorly exposed. The Otavi Mountain Land's regional structure is made up of east-west-trending folds that are overprinted by a second folding phase that produces northward veering recumbent folds. Furthermore, lower green-schist to prehnite-pumpellyite facies metamorphisms have occurred in the Otavi mountain land layers.

4. Geology and Mineralization of the Tsumeb Deposit

Stratigraphically, the Tsumeb deposit rests in the upper section of the Otavi group, (**Figure 3** and **Figure 4**). The ore deposit is a polymetallic pipe-like body (**Figure 5** and **Figure 6**) emplaced at 530 ± 11 Ma [42] [43]. The dolomite and limestone of the Neoproterozoic age (a period between 1 billion years to 542 million years ago) are the major lithology. The host rocks of the Tsumeb pipe are similar to that of northern Arizona breccia pipe deposit [44]. The development mechanism of the pipe-like body structure of the ore was a result of solution pipe and karst activities [45] [46]. The action of karst formation driven by meteoric water can be simply described as follow: meteoric water picks up carbon dioxide from the atmosphere and soil respiration (produced by soil organisms), the combination result is a weak carbonic acid solution which then dissolves the carbonaceous rocks along the flow path to a certain extent, thus the creating cleavages, cavities and sinkholes [47].

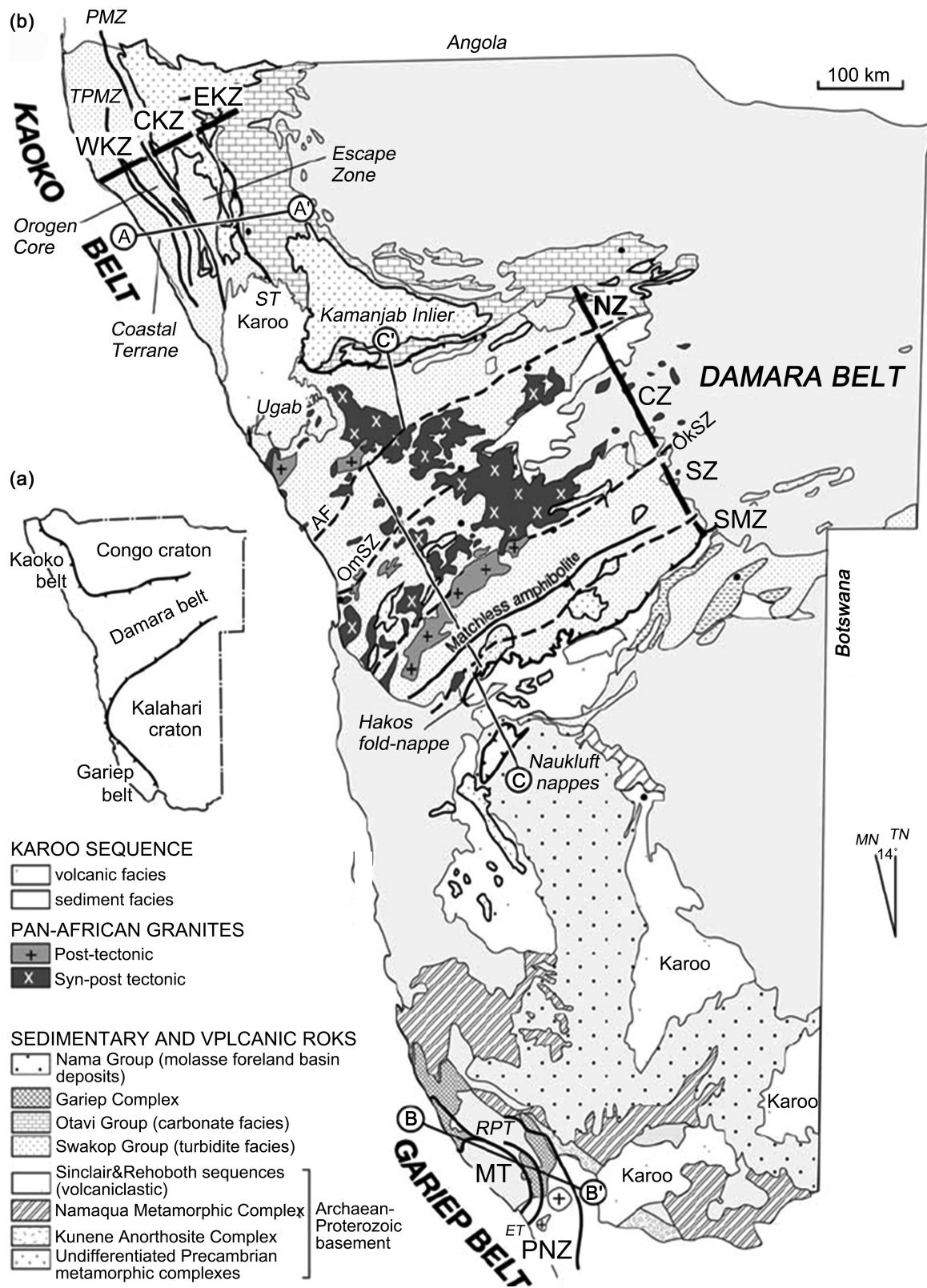


Figure 2. Geological map of the Damara Orogen: (a) Sections of the Damara Orogen with Damara belt located between the Congo and Kalahari cratons, northern arm identified as the Kaoko belt and the southern arm as the Gariep belt, (b) Depiction of the distribution of the Karoo sequence, Pan-African granites, sedimentary and volcanic rocks (adapted from Joseph, Richard, Ben, & Rudolph, 2008).

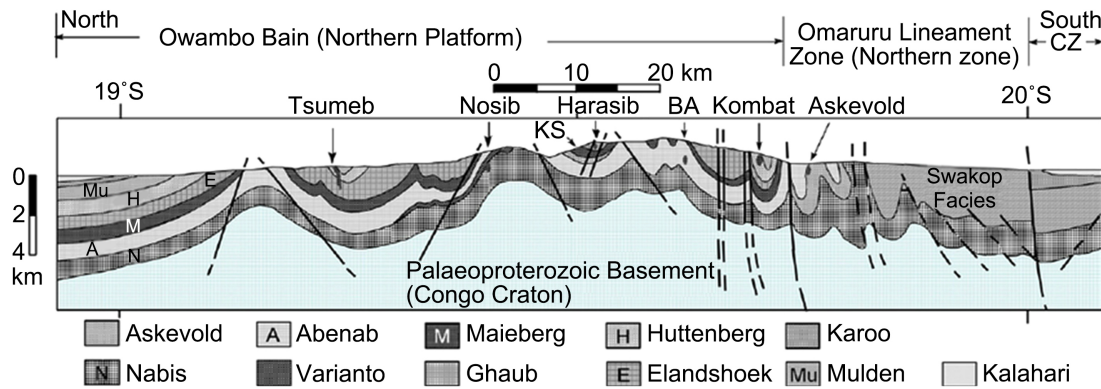
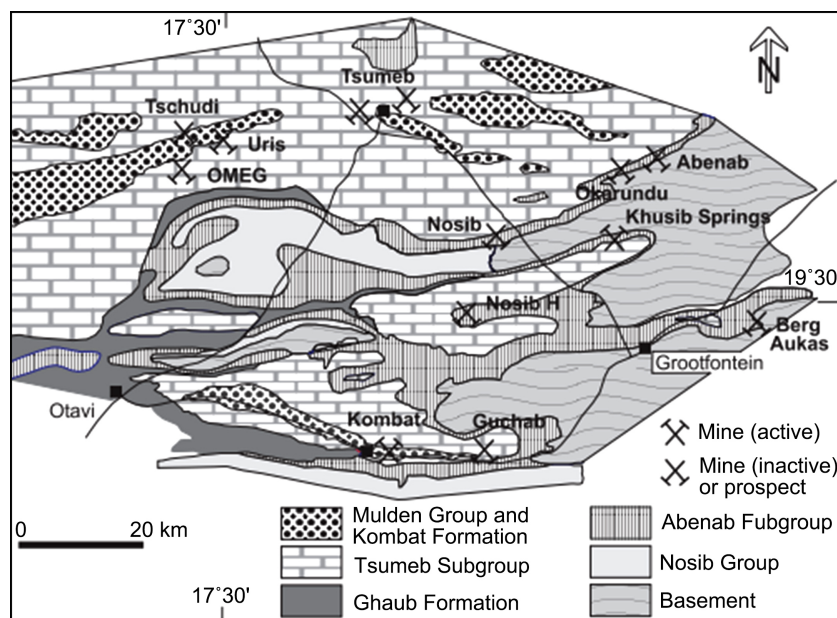


Figure 3. The north-south section across the OML depicting major structures, deposits and prospects (adapted from Kamona & Günze, 2007).



Group	Subgroup	Formation	Lithology
Mumulden		Owambo	Pelite, marl, carbonate
		Kombat	Shale
		Tschudi	Arenite
Otavi 580 Ma	Tsumeb	Hüttenberg	T8 T7 T6 Dolomite, Pelite
		Elandshoek	T5 T4 Dolomite, Chert
		Maieberg	T3 T2 Dolomite
		Ghaub	T1 Limestone
	Auro	Carbonate, Pelite	
750 Ma	Abenab	Gauss	Dolomite
		Berg Aukas	Dolomite
		Chuoso	Diamictite
Nosib		Askeveld	Volcanics
		Nabis	Clastics
Grootfontein Basement Complex			

Figure 4. Geological map of the Otavi Mountain Land, with major mines and prospects (upper part of the figure), as well as table of Groups of OML (lower part of the figure) (modified from Melcher, 2003): Note, the OML is divided into three groups with distinct Formations and Lithology.

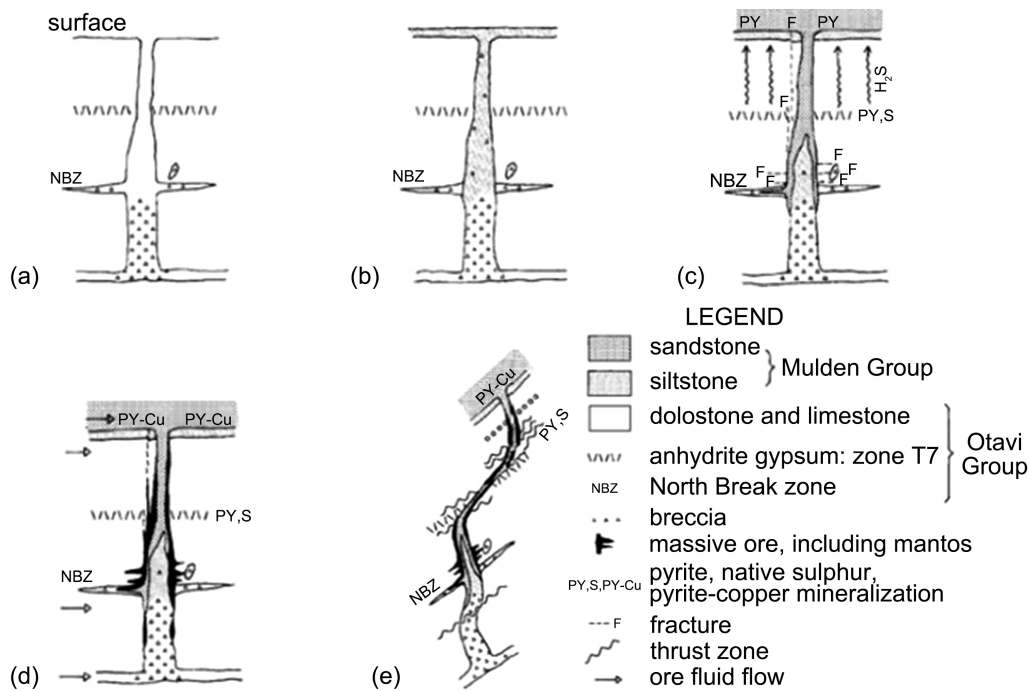


Figure 5. Tsumeb deposit development sequence (modified from Maiden & Hughes, 2000). (a) Development of a solution pipe partially infused with sedimentary and strata-bound breccia. (b) Infilling of karstic cavities and solution pipe with sandstone from the overlying Mulden group. (c) Subsidence of the pipe's sedimentary column. (d) Flow of fluids released from the Pan-African Damara's belt orogeny and deposition of primary minerals (Pb-Cu-Zn sulphide minerals) into the pipe. (e) Episodes of folding and thrusting of the pipe mineralization.

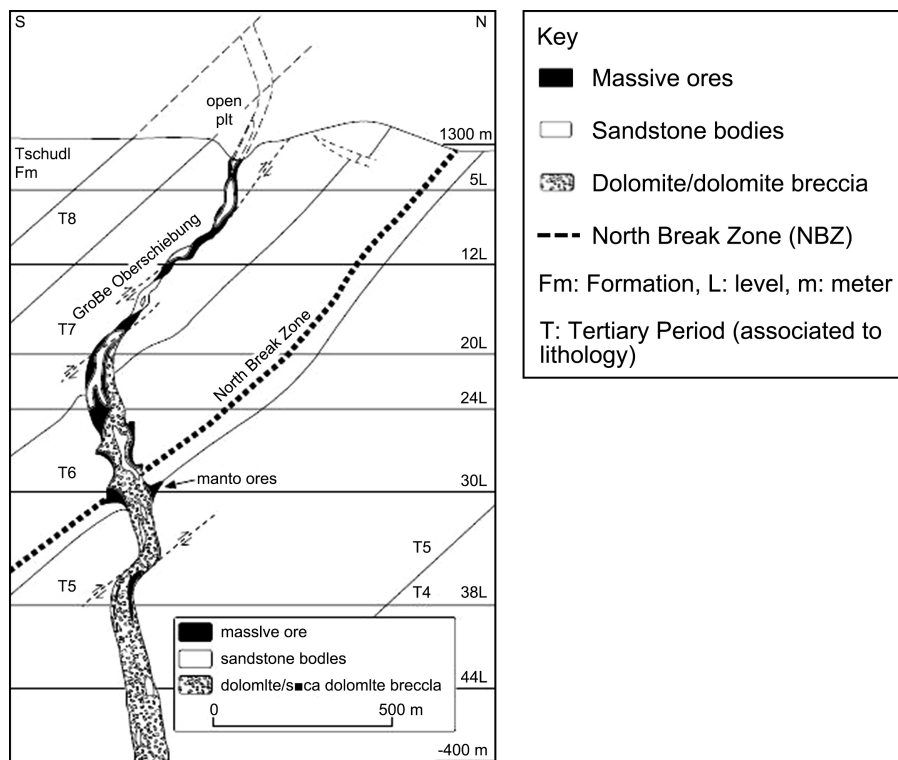


Figure 6. Geological cross-sectional view of the Tsumeb pipe deposit (adapted from Laukamp, 2006): **Note** T5-T8 signifies Dolomite units; **white areas** signify sandstone and the **dark structure** being the high grade oxide and sulphide ore.

Another rare situation is when surface water rich in oxygen or underground water reacts with sulfides such as pyrite and hydrogen sulfide to form sulfuric acid solution which also dissolves the carbonatites, leaving behind a cavity. The pipe-like cavity of the Tsumeb is believed to have been infilled with the sandstone from the overlying Mulden group, thus forming the host of the mineralization [48]. According to Chetty & Frimmel (2000) [49], fluids released during Pan-African orogeny in the Damara Belt's more severely deformed interior zones are thought to be the source of Tsumeb mineralization. Base metal sulphide precipitation took place in regions of relatively increased porosity afforded by karst features in the carbonaceous structure (cavities and cleavages) when fluids of high salinity reached the carbonate platform after incorporating great amounts of base metals [50] [51]. Large scale alteration such as silicification, calcification and host rock argillization as well as the presence of hydrothermal carbonate-veins are some of the noticed features of the pipe mineralization [52] [53]. A diverse species of minerals such as Copper, Lead, Zinc, Silver, Antimony, Cadmium, Cobalt, Germanium, Gallium, Gold, Iron, Mercury, Molybdenum, Nickel, Tin, Tungsten and Vanadium were compositional elements of the pipe mineralization [54] [55] [56].

The recognized ore emplacement controls comprise the core breccia, interrupted circular fracture, and feldspathic sandstone internal mass [57] [58]. The ore body bound to the pipe was estimated to having dimensions of 15 by 120 m cross-section [58]. It was a steeply dipping ore body that extended from the surface to a depth of approximately 1700 meters. The Tsumeb pipe deposit contained high mineralized pods, large lenses (Manto Ore) and small veins predominantly emplaced in arcuate and marginal fractures. It is also established that minerals forming low grade ore with large tonnage were disseminated in altered rock formations. According to *Bowell & Mocke (2018) [1]*, the Tsumeb orebody's large marginal ores held up to 40% total metal (Pb+Cu+Zn) concentration. There was a noticeable fracture zone extending from the surface intersecting the sulfide ore pipe at a depth of approximately 900 m [59] [60]. This fracture was a conduit for meteoric water, which created a lower oxidized zone in the sulfide ore [61] [62] [63]. Within the pipe deposit, three oxidation zones had been identified containing secondary minerals derived from the alteration of primary sulfides minerals. These oxidation zones occurred from surface down to level 12 (360 m below surface) [64], from level 25 (750 m) to 35 (1150 m), and below level 42 (1380 m). At the level 25, the primary sulfide orebody was slightly altered. The second oxidation zone below level 25 was characterized by perfectly developed secondary minerals. At the intersection (Level 28 and 29) of pipe and North Break Zone "NBZ", there was a development of rich sulfides (secondary minerals) [52] [65]. The third oxidation zone, which was only observed in the last stage of mining, was typified by a mixed sulfide-oxide mineralization and it only hosted partially oxidized arsenites (leiteite) [1] [66].

5. Concluding Remarks

The ore formation of the Tsumeb polymetallic deposit with its diverse mineral-

ogy composition was a result of the Pan-African Damara orogenic process. The orogenic process was essential for mineralization in OML as it activated various interactions between magma, hydrothermal solutions, and sediments. In particular, the fluids liberated during orogenic processes in the Damara Belt's more severely deformed inner zones were the principal source of Tsumeb mineralization. Base metal sulphide precipitation occurred in karst structures of the carbonate rocks that provided considerably enhanced porosity. The Tsumeb mineralization is classified into four types, 1) The Oxide ores, which are supergene ores within the pipe's upper part, as well as in the oxidation zones; 2) Disseminated ores, which are hosted in unaltered to altered bedded dolomite and dolomite breccias as well as by feldspathic sandstone; 3) Manto ores, which are wing like extensions attached to the pipe; and 4) Massive peripheral ore, marginal ores which held up to 40% total metal (Pb+Cu+Zn) concentration. In general, according to the climatic setting, geological nature, and history of mineral extractions of OML as well as the documented mineralization mechanism of Tsumeb orebody as a representative of the OML, there is potential for high-value mineralization and underground water resources in the OML. The potential high-value mineralization is also associated with tectonic events including rifts, and thrust and folds belt systems, characteristic of OML. These resources or potential reserves can in the future be delineated by deployment of extensive integrated geophysical prospecting and exploration techniques.

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Conflicts of Interest

The authors declare no conflicts of interest.

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