GEOPERSIA

Accepted Manuscript

A review on Afghanistan pegmatite belt: lithium resources, challenges and prospects

Hamidullah Arian, Zahra Alaminia, Mohammad Arif Nero, Azizullah Haydari, Akram Shirzad

DOI: 10.22059/GEOPE.2024.380316.648766

Receive Date: 03 August 2024
Revise Date: 07 September 2024
Accept Date: 19 September 2024

A review on Afghanistan pegmatite belt: lithium resources, challenges and prospects

Hamidullah Arian 1, Zahra Alaminia [1,2] *, Mohammad Arif Nero [3], Azizullah Haydari [4], Akram Shirzad [5]

[1] Department of Geology, University of Isfahan, P.O. Box: 81746-73441, Isfahan, Iran
[2] Department of Geology, Faculty of Science, Ferdowsi University of Mashhad, Iran
[3] Department of Geological Engineering and Exploration of Mines, Kabul Polytechnic University, Kabul, 1001, Afghanistan
[4] Daikundi Mines Department, Daikundi, Afghanistan
[5] Afghanistan Atomic Energy Agency, Kabul, Afghanistan

Received: 03 August 2024, Revised: 07 September 2024, Accepted: 19 September 2024

Abstract

Abstract – The Afghanistan pegmatite belt, renowned for its vast resources of rare-metals, has emerged as a crucial focal point for geological exploration and resource assessment since 1960. This study delves into the existing literature, offering insights into the lithium resources, challenges and prospects within this belt while pinpointing areas that require further studies. Spanning a considerable expanse of approximately 900 kilometers by 200 kilometers in a SW-NE orientation, the Afghanistan pegmatite belt stands out for its rich deposits of rare metals such as Li, Cs, Ta, Nb, Rb, Be, Sn, and W, alongside industrial minerals (mica, quartz and feldspar) as well as gem-quality minerals (gem quality spodumene, tourmaline, garnet, beryl, etc.). With average grades of 1.7% Li_2O, 9% Cs_2O, around 0.025% Ta_2O_5 and over 0.03% Nb_2O_5, these pegmatites represent a valuable resource. These pegmatite bodies, which can reach kilometers in length and meters in width, are associated both spatially and genetically with the third phase of Oligocene granites (S-Type) and have intruded surrounding metamorphic rocks, granites, diorites, and gabbro of different ages. The future prospects of the Afghanistan pegmatite belt are promising, with the potential to play a pivotal role in meeting the escalating global demand for lithium and other rare-metal elements. As ongoing research continues to unveil the untapped potential of this region, the Afghanistan pegmatite belt is offering valuable opportunities for sustainable resource development and economic growth.

Keywords: Pegmatite, Oligocene, Rare-metals, Lithium

Introduction

Pegmatites are holocrystalline igneous rocks, texturally complex and marked by a composition of coarse and different sizes of crystals, spatial zonation of mineral assemblages, eminent anisotropy of crystal orientations from the margins inward, and skeletal, radial and graphic intergrowth forms of crystals (London, 2018). Pegmatites typically develop as segregations near the uppermost layers of their source plutons, often within the top tens of meters. Additionally, they frequently occur as clusters of dikes extending from the upper regions of the pluton's roof (London, 2018). Although it can be considered that pegmatites are not economically and industrially valuable on their owns but they house valuable commodities of

---

* Corresponding author e-mail: z.alaminia@sci.ui.ac.ir

strategic and valuable elements and minerals such as lithium, tantalum, niobium, cesium, rubidium, muscovite and gem-quality minerals that can meet the growing demand for green technology, and high field strength elements in future. More recently, hard rock supplies have increasingly dominated the lithium production sector, referred to as the ‘rise of the pegmatites’ for three main reasons: a) high quality of Li_2CO_3 with fewer deleterious elements; b) direct production of LiOH from pegmatites, which is preferred for battery feedstock; and c) a general rise in lithium prices that have changed the economic calculations of some lithium pegmatite operations (Sun et al. 2017; Azevedo et al., 2018; Gardiner, 2024). Initially, lithium was sourced from pegmatite districts and related magmatic deposits that contain Li_2CO_3. These geological resources are more abundant than brines, yet pegmatites with rare metals like tin and tantalum are rare and previously mined, and despite lithium's presence in over 145 minerals, it is extractable from only five: spodumene, lepidolite, petalite, amblygonite, and eucryptite (Baudino et al., 2021).

Although granitic pegmatites are abundant and widely distributed, rare-metal pegmatites constitute only a small portion, about 0.1% of the total, with lithium-bearing pegmatites representing an even smaller fraction (Laznicka, 2006). Granitic pegmatites have been identified in various regions globally (Kesler et al., 2012; Gourcerol et al., 2019), and the Afghanistan pegmatite belt (APB) is also notable among them for its significant potential in rare metals, industrial minerals, and gemstones. Fenogenov and Mosazai established the APB in 1989 as a distinct geological feature. This belt spans approximately 900 kilometers, originating in the southwest Sistan depression, encompassing significant portions of the Helmand River watershed and Hazarajat regions. It extends northeastward through Maidan Wardak and Kabul provinces, traversing Panjshir, Kapisa, Laghman, Jalalabad, Kunar, Nuristan, and Badakhshan provinces before reaching the northeast border of Afghanistan. From there, it extends into the territories of Pakistan, China, and Tajikistan. The width of the belt varies from 100 to 250 kilometers, as indicated by Figure 1. This extensive geological formation is known for its mineralization of rare metals (Li, Rb, Cs, Be, Sn, Ta and Nb) resources, as detailed by Abdullah et al. (1977), ESCAP (1995) Mosazai et al. (2017), Abdullah et al. (2008) and Tarin (2022).

The global transition from fossil fuels to vehicle electrification has sparked a surge in demand for lithium due to its unique chemical and physical characteristics, as noted by Gruber et al. (2011) and Cardoso-Fernandes et al. (2019). This shift has elevated lithium to a critical element and intensified exploration efforts worldwide for lithium minerals, as emphasized by Gardiner et al. (2024). Consequently, regions such as APB holding significant lithium resources have emerged as crucial areas for exploration and investment. Early instances of pegmatite mining in Afghanistan date back to the mid-20th century, with Dara-e-Nur in Konar province being the pioneering site where approximately 130 tons of beryl were extracted through open-cast mining between 1950 and 1960. Subsequently, exploration efforts expanded to include Dara-e-Pech during 1963 to 1964, as documented by (Yousaf, 2009; Safi, 2021). Exploring and investing in the lithium resources within the APB can thus be seen as imperative in meeting the escalating global demand for this essential element. Since the 1960s, significant exploration efforts have been undertaken on Afghanistan's pegmatites, particularly in the eastern regions such as Nuristan, Kunar, Laghman, and Badakhshan. These investigations, led initially by the USSR in collaboration with Afghan geologists, and later by USGS (United States Geological Survey), TFBSO (the U.S. Department of Defense Task Force for Business and Stability Operations), BGS (British Geological Survey), AGS (Afghanistan Geological Survey), and independent researchers, have yielded valuable insights.

Despite sporadic investigations focusing more on mineralogical composition of these pegmatites, their genetic relationship with their parent granites, estimation of resources in some deposits, introduction of gem quality minerals, and petrological studies of APB, dating back to the early 20th century, including contributions from researchers such as Ehsan (1934), Abdullah (1940), Khan (1949), Chmyriov and Mirzad (1972), Rossovskiy (1974, 1976, 1980), Abdullah and Chmyriov (1977), Rossovskiy and Chmyriov (1977), Bogatskiy et al. (1978), ESCAP (1995), Bowersox and Chamberlin (1995), Peters et al. (2007), Abdullah et al. (2008), Cocker (2011), Peters (2011), Mashkoor et al. (2022) and Arian et al. (2024), a comprehensive study that systematically maps the pegmatite belt and its thousands of dikes is still lacking. This study aims to address existing gaps in the understanding of the APB by offering a comprehensive and cohesive overview of the entire belt. While several authors have made valuable contributions to the field, a consolidation of information is lacking to provide a more unified introduction to the APB. Additionally, this research focuses on assessing the lithium resources across 12 key deposits within the belt, based on an extensive review of published literature. The objective is to align this assessment with the broader goal of advancing our knowledge of the APB's resource potential, challenges and prospects. This study can contribute in guiding exploration efforts and informing sustainable resource management in the region.

Geological Setting

The overall geologic setting of Afghanistan is marked by a complex mosaic of lithostatic domains from Gondwanan terranes, sutured into block terranes along the southern Eurasian plate through tectonic events from the Proterozoic to the Phanerozoic era, with three distinct zones: the Afghan-Tajik Block in the north, the southeast Katawaz Basin, and the central terranes (Treloar & Izatt, 1993; Shroder et al., 2021).

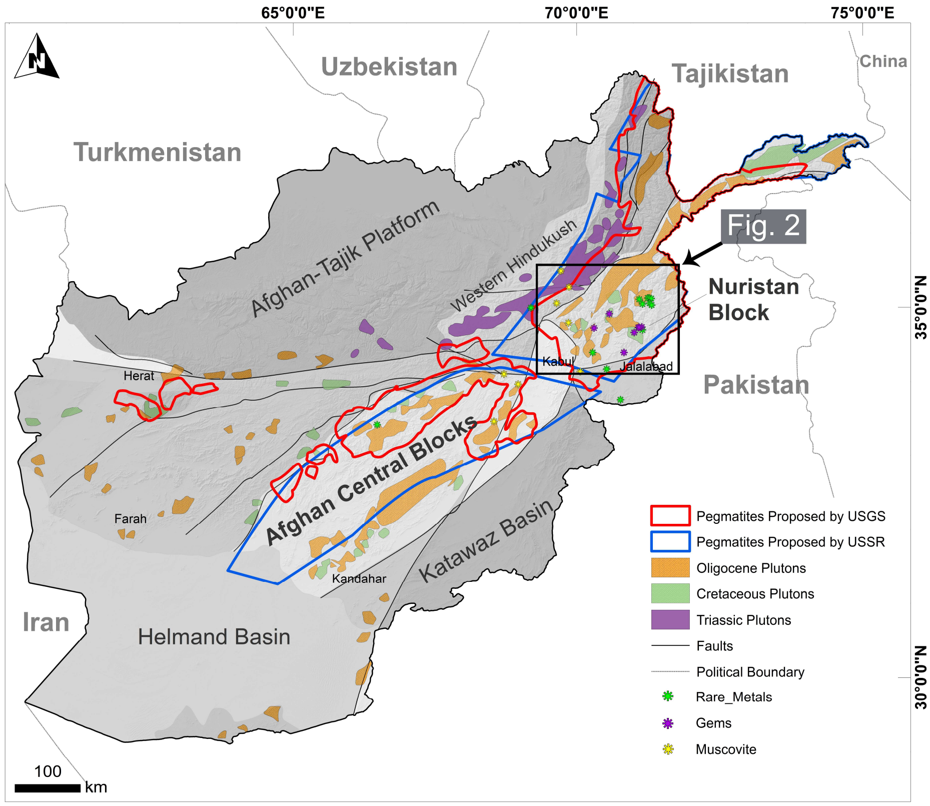

Figure 1. Simplified tectonic map of Afghanistan showing tectonic blocks and major faults outline, magmatic belt, pegmatite belt and location of important pegmatitic deposits and occurrences of Afghanistan. As is shown most rare-metals and gem-quality minerals resources located in NE part of the country

APB, mostly located on median masses of Afghanistan (The region bordered by the Middle Cimmeride to the north and the Alpides to the east, south, and west is known as the South Afghanistan Median Mass). In the northeastern part of Afghanistan, including Nuristan, South Badakhshan, and Wakhan, the area is referred to as the Nuristan-Pamir Median Mass), is an important geological feature and is surrounded by a significant presence of igneous rocks, constituting around 40% of the area (Abdullah et al., 2008; Mosazai et al., 2017). Pegmatite dikes within the APB are found in formations ranging from the Archean to the Mesozoic. APB is characterized by numerous faults and folds across formations of varying ages, reflecting the area's complex tectonic structures (Figure 1). This belt is delineated by significant faults: the Kunar and Gardiz faults in the northeast, east, and southwest, and the Muqur-Chaman and Hazrat-e-Sultan faults in the northwest, west, and southwest. Predominantly, the entire structural framework trends towards the northeast, with both the fold axes and the orientation of numerous tectonic faults following this same northeast direction. Abdullah et al. (1977, 2008) have suggested 24 pegmatite fields (Table 1) in APB within four smaller belts (Nuristan, Badakhshan, Helmand and Hindukush), while in another classification Mosazai et al. (2017) separated 16 fields within three blocks of Shahristan, Kabul and Nuristan. More than 55 different minerals classified as primary minerals, secondary minerals, rare-metals and accessory minerals were reported by Mosazai et al. (2017) that can reflect the geologic and economic importance of this belt (Table 2). These pegmatites exhibit varying compositions, ranging from simple compositions consisting of quartz, feldspars, and micas to more complex, zoned structures with additional accessory minerals (Bowersox, 1985).

Rare-metal pegmatites in Afghanistan exhibit distinctive characteristics, including the presence of dikes, lenses, and sheet-like formations of variable sizes. The formation of rare-metal pegmatites in Afghanistan appears to be closely related to the third phase of Oligocene granitoid masses (Figure 2). Phase one of these granitoids consists granosyenite, granites, plageogranites, tonalites, granodiorite and quartz – granodiorites and diorites with gray to green-gray medium to large grains. Phase one rocks consists different amounts of feldspars with 70 – 50% oligoclase – andesine, 10 – 15% microcline, 20 – 5 % quartz, 5 – 20 % biotite and 10 -30 hornblende. Second phase comprises porphyritic granites and biotite – granites with small amounts of granodiorite and plageogranites. The main composition of these rocks is 20 – 60% oligoclase, 30 – 40% microcline, 25 – 40% quartz, 5 – 15 % biotite and around 5% hornblende. Phase 3 consists pegmatitic granites with large grains, two-mica granites (small to medium size, light gray and rarely gray). The mineralogical composition of phase 3 shows 30 – 50% K-feldspar, 25 – 30% quartz, 20% plagioclase, 5 – 10% muscovite and biotite (Rossovsky and Chmyrev, 1977; Tarin, 2022). Pegmatite fields of APB have a genetic relationship with the third phase of Arghandab and Helmand complexes in central Afghanistan, Baraki complex in Kabul block, Mustak, Wakhan and Baharak complexes in Badakhshan and Laghman complex in Nuristan (Mosazai et al., 2017). Factors influencing the metallogenic characteristics of these pegmatite belts include regional geochemistry, granite composition, tectonic conditions during emplacement, and physical structure of the veins (Rossovskiy, 1990). Ore minerals found in beryllium pegmatites include beryl, cordierite, eosphorite, aquamarine, and emerald. Tantalum and niobium-bearing minerals such as tantalite and columbite are also present, with regions like Dara-e-Pich, Paron, Wardish, Kulam, and Alingar considered promising for these minerals. Lithium-bearing minerals such as spodumene, petalite, amblygonite, montebrasite, and lepidolite are common in the APB. However, they are notably absent in oligoclase-microcline pegmatites due to the high-temperature nature of oligoclase, which inhibits lithium concentration during fractional crystallization (Tarin, 2022). Overall, rare-metal pegmatites in Afghanistan are believed to have formed at depths ranging from 3 to 7 kilometers, rarely extending to 11 kilometers (Tarin, 2022). According to Abdullah et al. (2008) a limited number of pegmatites in various regions of the APB have been dated using the K-Ar method on different samples such as muscovite, biotite, spodumene, lepidolite, albite, microcline, and bulk samples. According to Abdullah et al. (2008), the absolute ages of pegmatites in the Laghman complex received from 27 samples range from as recent as 16.5 ma to 375 ma.

Table 1. Location and important commodities of 24 pegmatite fields in APB (Rossovskiy, 1974; Abdullah et al., 2008; Cocker, 2011; Peters, 2011; Panahi et al., 2015; Tarin, 2022)

	Pegmatite Field	**Province**	**Coordinate (XXº YY’ ZZ’’)**	**Host Rocks**	**Length and Thickness (m)**	**Important Commodities**
Nuristan Pegmatite Belt	Surkhrud	Nangarhar	34 26 05 70 15 23	Silurian and Devonian quartz – biotite carbonate schists	10 -200 1.5 - 10	Cs
	Dara-e-Nur	Nangarhar	34 37 00 70 45 00	Upper Triassic quartz – biotite schist and garnet staurolite schist Permian – Carboniferous carbonate rocks Cretaceous diorites and quartz diorite	10 – 100s 0.3 – 3.0	Beryl, Topaz
	Chawki	Kunar	34 40 20 70 46 56	Proterozoic crystalline schists Carboniferous and Lower Permian marbles and quartzite	10 – 200 1 – 10	Emerald, Ta, Beryl
	Wardish	Kunar	35 00 00 70 49 00	Lower Proterozoic metamorphic rocks Gabbro, Granite, Gneiss	300 – 500 1.5 – 7	Tourmaline, Kunzite, Rubellite, Indicolite, Verdelite, Beryl, Morganite, Li, Cleavelandite, Nb, Ta
	Paron	Nuristan	34 54 34 70 52 15	Lower Proterozoic crystalline schists and gneiss Upper Triassic weakly – metamorphosed schists	60 – 5000 2 – 30	Li, Ta, Nb, Sn, Cs, Rb Beryl, Hiddenite, Triphane
	Kantiwa	Kunar	35 26 11 70 45 35	Proterozoic crystalline schists and gneiss Diorite	10 – 400 1 – 3	Quartz, Kunzite, Tourmaline, Ta
	Pachigram	Nuristan	35 31 40 71 00 00	Upper Triassic phyllite like schists Proterozoic Gneiss and crystalline schists	10 – 150 1 – 3	Li, Cs, Ta, Sn, Nb
	Eshkashem	Badakhshan	36 27 19 70 36 23	Upper Triassic black schists and quartzite	15 – 1000 1 – 15	Ta, Li, Sn, Beryl
	Marid	Kunar	35 08 00 71 17 58	Proterozoic Gneiss Biotite – garnet – staurolite schist	-	Li
Hindukush Pegmatite belt	Shamakat	Laghman	34 40 10 70 00 20	Gneiss, granite gneiss	200 – 750 Up to 18	Li, Ta, Nb, Kunzite, Cs,
	Kulam Nilaw	Laghman	35 15 36 70 15 18	Lower Cretaceous Gabbro-Norite, Diorite Lower Proterozoic Migmatites, Gneiss, crystalline schists	Up to 4000 Up t0 40	Ta, Nb, Li, Kunzite, Quartz
	Alingar	Laghman	34 52 41 70 16 48	Upper Triassic schists	15 - 500 0.7 – 12	Cs, Li, Ta, Nb
	Korgul	Nuristan	35 04 06 70 18 20	Lower Proterozoic biotite crystalline schists and gneiss	10 – 100s 1 – 50	Cs
	Mundol	Laghman	35 17 28 70 09 57	Garnet – sillimanite – biotite gneiss	70 – 400 0.5 – 5	Beryl
	Shahidan	Laghman	34 29 34 69 56 04	Lower Proterozoic quartz – biotite schists	10 – 200 1 – 5	Beryl, Aquamarine, Morganite
Badakhshan Pegmatite belt	Sheva	Badakhshan	37 22 07 70 24 43	Archean metamorphic rocks	-	Ta
	Kokcha	Badakhshan	36 36 35 70 24 43	Archean metamorphic rocks	10s 1.5 – 3	Needs more exploration
	Talbuzanak	Badakhshan	37 12 06 70 33 36	Proterozoic amphibolite and crystalline schists	200 20 - 30	Needs more exploration
Helmand Pegmatite belt	Tagablor	Daikundi	33 42 30 66 19 00	Proterozoic schists	58 – 2000 20 – 25	Li, Ta, Sn
	Behsud	Maidan Wardak	34 24 30 67 48 30	Archean – Proterozoic Gneiss Proterozoic marble, phyllite	-	Sn, Li, Ta, Nb
	Kanakas	Oruzgan	34 00 00 66 41 30	Proterozoic formations	10 – 100s 1.5 – 20	Muscovite
Independent Pegmatite fields	Salang -Panjshir	Parwan, Panjshir	35 28 00 69 00 00	Paleozoic – Lower Triassic sedimentary – volcanogenic rocks Gneiss, Schist, Limestone, Gabbro, Diorite	7 -700 2 -17	Li, Ta. Nb, Emerald, Amethyst
	Pachaghan, Daram – Daram	Kapisa, Kabul, Laghman	35 02 03 69 43 10	Proterozoic metamorphic rocks Gabbro, Gabbro-Diorite	10 – 100 2 – 4	Muscovite, Ruby, Sapphire, Corundum, Spinal
	Jalriz – Takana	Maidan Wardak	34 26 00 68 35 00	Proterozoic Gneiss	200 – 400 2 – 30	Muscovite

Table 2. Gem-quality minerals and museum specimens reported from the APB (Bariand et al., 1978; Bowersox, 1985; Sahak, 2014; Lyckberg, 2017; Tarin, 2022)

Mineral	Chemical Formula	Crystal system	Mineral	Chemical Formula	Crystal system
Albite	$NaAlSi_3O_8$	Triclinic	Kunzite (Spodumene)	$LiAlSi_2O_6$	Monoclinic
Almandine (Garnet)	$Fe_3Al_2(SiO_4)_3$	Cubic	Lepidolite	$KLi_{1.5}Al_{1.5}AlSi_3O_{10}F_2$	Monoclinic
Amazonite (microcline)	$KAlSi_3O_8$	Triclinic	Morganite (Beryl)	$Be_3Al_2Si_6O_{18}$	Hexagonal
Aquamarine (Beryl)	$Be_3Al_2Si_{16}O_{18}$	Hexagonal	Nanpingite	$CsAl_2AlSi_3O_{10}(OH)_2$	Monoclinic
Bavenite	$Ca_4Be_2Al_2Si_9O_{26}$	Orthorhombic	Natrolite	$Na_2(Al_2Si_3O_{10})\ 2H_2O$	Monoclinic
Beryllonite	$NabePO_4$	Monoclinic	Opal (hyalite)	$SiO_2 \cdot nH_2O$	Amorphous
Biotite series	$KMg_3AlSi_3O_{10}(OH)_2$	Monoclinic	Petalite	$LiAlSi_4O_{10}$	Monoclinic
Cassiterite	SnO_2	Tetragonal	Pezzottaite	$Cs\ (Be_2Li)\ Al_2Si_6O_{18}$	Trigonal
Childrenite	$Fe^{2+}Al\ (PO_4)\ (OH)_2 \cdot H_2O$	Orthorhombic	Pollucite	$Cs(Si_2Al)O_6\ .\ nH_2O$	Hexoctahedral
Chloritoid	$Fe^{2+}Al_2O(SiO_4)(OH)_2$	Monoclinic	Quartz	SiO_2	Trigonal
Columbite-(Fe)	$Fe^{2+}Nb_2O_6$	Orthorhombic	Rubellite (Tourmaline)	$Na\ (Li_{1.5}Al_{1.5})\ Al_6Si_6O_{18}(BO_3)_3(OH)_4$	Trigonal
Columbite-(Mn)	$Mn^{2+}Nb_2O_6$	Orthorhombic	Ruby (Corundum)	Al_2O_3	Hexagonal
Chrysoberyl	$BeAl_2O_4$	Orthorhombic	Scapolite	$Na_4Al_3Si_9O_{24}Cl$	Tetragonal
Elbaite (Tourmaline)	$Na\ (Li_{1.5}Al_{1.5})\ Al_6Si_6O_{18}(BO_3)_3(OH)_4$	Trigonal	Schorl	$NaFe_3Al_6(Si_6O_{18})\ (BO_3)_3(OH_3)\ OH$	Trigonal
Emerald (Beryl)	$Be_3Al_2(SiO_3)_6$	Hexagonal	Spessartine (Garnet)	$Mn_3Al_2Si_3O_{12}$	Cubic
Eosphorite	$Mn\ Al\ (PO_4)\ (OH)_2 \cdot H_2O$	Monoclinic	Stannite	Cu_2FeSnS_4	Tetragonal
Fluorapatite	$Ca_5(PO_4)_3F$	Hexagonal	Stibiotantalite	$SbTaO_4$	Orthorhombic
Fluorite	CaF_2	Cubic	Stilbite-(Ce)	$NaCa_4(Al_9Si_{27}O_{72}) \cdot 28H_2O$	Monoclinic
Fluornatromicrolite	$(Na, Ca, Bi)_2Ta_2O_6F$	Cubic	Tantalite-(Mn)	$Mn^{2+}Ta_2O_6$	Orthorhombic
Fiotite	$(Fe_2, Al)\ Al_6(Si_6O_{18})\ (BO_3)_3(OH)_3OH$	Monoclinic	Triphane (Spodumene)	$LiAlSi_2O_6$	Monoclinic
Grossular (Garnet)	$Ca_3Al_2Si_3O_{12}$	Cubic	Topaz	$Al_2SiO_4(F, OH)_2$	Orthorhombic
Goshenite (Beryl)	$Be_3Al_2Si_6O_{18}$	Hexagonal	Tungstibite	Sb_2WO_6	Orthorhombic
Hambergite	$Be_2BO_3(OH)$	Orthorhombic	Väyrynenite	$MnBe\ (PO_4)\ (OH)$	Monoclinic
Heliodor (Beryl)	$Be_3Al_2Si_6O_{18}$	Hexagonal	Verdelite (Tourmaline)	$Na\ (Li_{1.5}Al_{1.5})\ Al_6Si_6O_{18}(BO_3)_3(OH)_4$	Trigonal
Hessonite (Garnet)	$Ca_3Al_2Si_3O_{12}$	Cubic	Viitaniemiite	$Na\ (Ca, Mn^{2+})\ Al\ (PO_4)\ (F, OH)_2(OH)$	Monoclinic
Hiddenite (Spodumene)	$LiAlSi_2O_6$	Monoclinic	Wodginite	$Mn^{2+}Sn^{4+}Ta_2O_8$	Monoclinic
Hydroxyl herderite	$CaBePO_4(OH)$	Monoclinic	Zircon	$ZrSiO_4$	Tetragonal
Indicolite (Tourmaline)	$Na\ (Li_{1.5}Al_{1.5})\ Al_6Si_6O_{18}(BO_3)_3(OH)_4$	Trigonal			

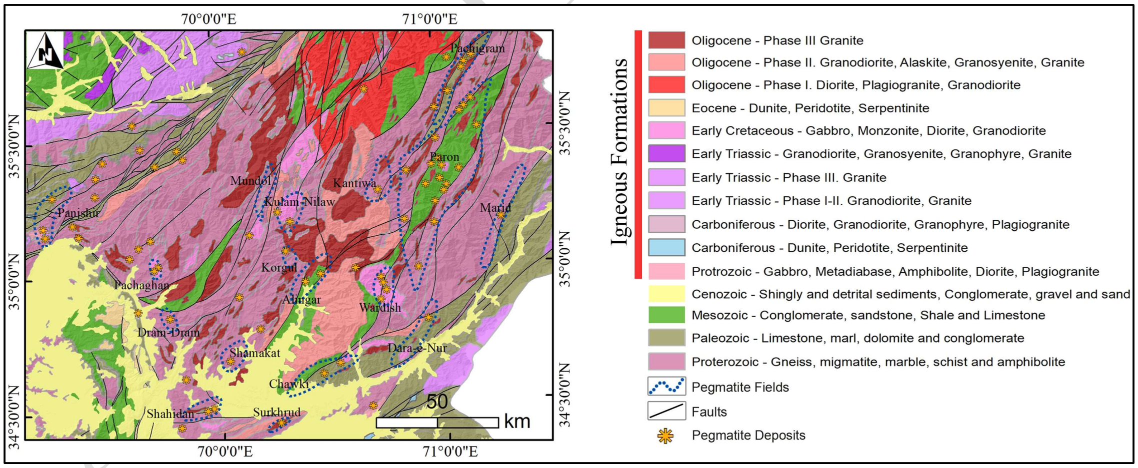

Figure 2. Geologic map of NE Afghanistan pegmatite fields and deposits (Doebrich and Wahl, 2006)

In the Tamazan complex in Helmand block, two samples yielded ages between 330 ma and 230 ma, while in the western Hindukush and Waras the age are 175 ma and 265 ma, respectively. This small number of dated samples does not provide sufficient information about the pegmatites ages in the APB.

Classification and Zonation of Pegmatites in APB

According to Černý and Ercit (2005) and Ginzburg et al. (1979), two approaches are used for the classification of pegmatites. The first approach, based on geological location, identifies five classes: abyssal, muscovite, muscovite–rare-element, rare-element, and miarolitic. These classes are subdivided into subclasses with basic differences in geochemical and geological characteristics and further divided into, types and subtypes based on differences in P–T conditions of solidification and accessory mineral assemblages. The second approach classifies pegmatites into three families based on petrogenetic differences derived from igneous differentiation from plutonic parents:

1. *NYF Family:* The NYF (Niobium, Yttrium and Fluorine) family is characterized by an array of elements including niobium (Nb) more abundant than tantalum (Ta), titanium (Ti), yttrium (Y), scandium (Sc), rare earth elements (REE), zirconium (Zr), uranium (U), thorium (Th), and fluorine (F). The parent granites are generally consistent in texture and composition, though they can vary somewhat in these aspects and may also include pegmatitic features. These granites are mainly subaluminous to metaluminous and are classified as A-type to I-type, but some also show peraluminous compositions and peralkaline characteristics.
2. *LCT Family:* The LCT (Lithium, Cesium and Tantalum) pegmatite group generally contains and becomes increasingly enriched in elements like lithium (Li), rubidium (Rb), cesium (Cs), beryllium (Be), tin (Sn), tantalum (Ta), and niobium (Nb) (with tantalum being more abundant than niobium). It also often includes boron (B), phosphorus (P), and fluorine (F) as the melt undergoes further fractionation. The granites from which these pegmatites originate are typically mildly to significantly peraluminous and belong to the S-type, I-type, or a combination of both.
3. *NYF + LCT Family:* The mixed NYF + LCT family includes granites and pegmatites that exhibit a combination of geochemical and mineralogical traits from both NYF and LCT groups.

Considering this classification and based on previous literature a considerable portion of pegmatites in APB (Table 1) can be classified as LCT for having high concentration of lithium, cesium and tantalum (ESCAP, 1995; Rossovsky 1976; Abdullah et al., 2008; Cooker, 2011; Mosazai et al., 2017; Tarin 2022; Arian et al., 2024). LCT pegmatite intrusions are generally emplaced late during orogeny, controlled by pre-existing structures. They usually crop out near evolved, peraluminous granites and leucogranites, from which they are derived by fractional crystallization. This process involves H_2O, F, P, and B as fluxing components, which depress the solidus temperature, lower density, and increase rates of ionic diffusion, enabling pegmatites to form thin dykes with massive crystals despite their felsic composition and lower crystallization temperatures (350°C to 550°C) (Bradley et al., 2017; London, 2018).

A prominent characteristic of pegmatites is their zonation (Figure 3). The nomenclature and examples of zoned pegmatites are summarized by Cameron et al. (1949), focusing on the internal distribution of principal minerals. The term "zone" describes complete or incomplete, successive shells of contrasting mineralogy that reflect the overall structural features. Heinrich's (1958) classification of internal zonation includes:

1. *Simple Pegmatites:* Show no segregation of minerals, with relatively uniform grain size throughout. They consist mainly of feldspar and quartz, with subordinate mica.
2. *Zoned Pegmatites:* Non-uniform, differentiated into discrete mappable zones differing in mineral content and texture. Regional zonation changes mineralogy relative to the parent granite, with rare-metal mineralization occurring further from the parent granite.
3. *Complex Pegmatites:* Exhibit more intricate zonation patterns.

The vertical zonation of pegmatites within the APB has been documented at various deposits, such as Drumgal, Tagablor and Kulam-Nilaw, with enrichment in minerals like spodumene and lepidolite observed at greater distances from parent granites (Figure 4). Additionally, internal zonation (Figure 5) has been reported from deposits like Dara-e-Pich (Rossovskiy & Chmyriov, 1977; Mosazai et al., 2018; Safi, 2021). In APB, zoned, simple and complex pegmatites were reported.

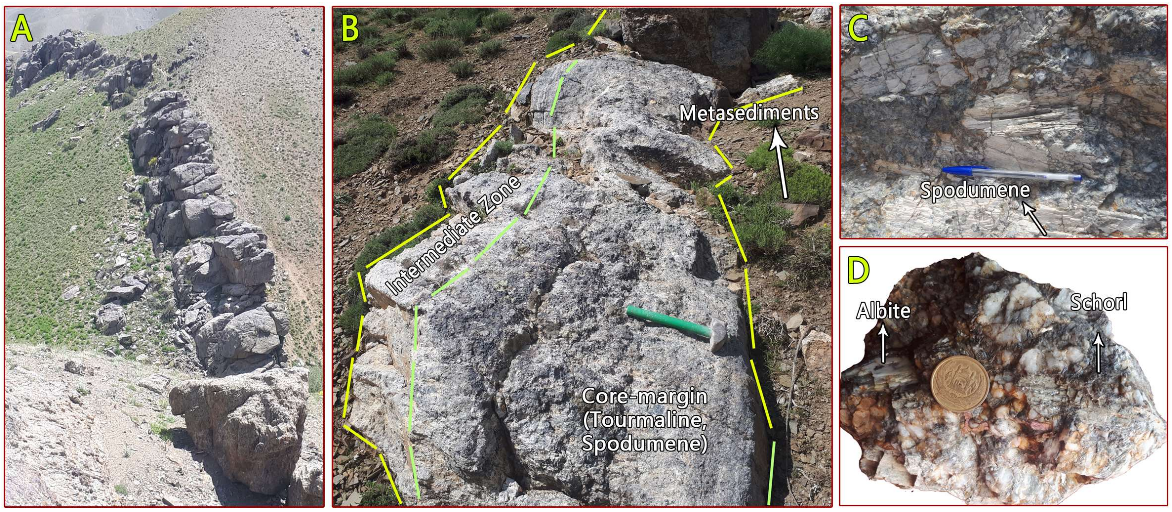

Figure 3. A) pegmatite dikes in Ghujgerd zone in Tagablor pegmatite field in Daikundi province, Central Afghanistan, the width of the dike is around 2 meters; B) zonation in pegmatite hosted by metasediments in Ghujgerd zone of Tagablor pegmatite field; C) presence of spodumene; and D) presence of schorl, albite, muscovite, spodumene and quartz in Ghujgerd zone of Tagablor pegmatite field

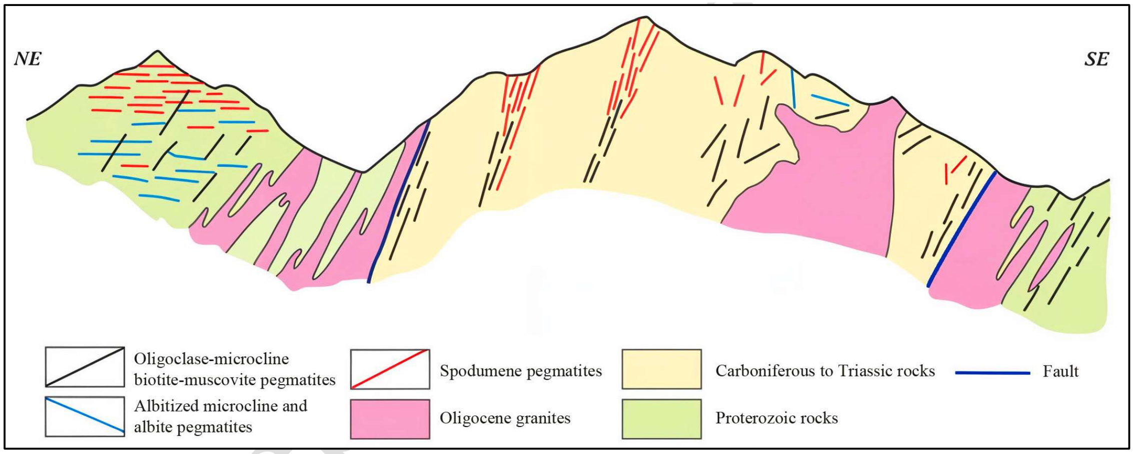

Figure 4. Diagrammatic geologic cross section of the Paron graben-syncline (modified by Cooker, 2011 from Rossovskiy and Konovalenko, 1979). (Many maps and diagrams in the Russian literature lack vertical and horizontal scales.)

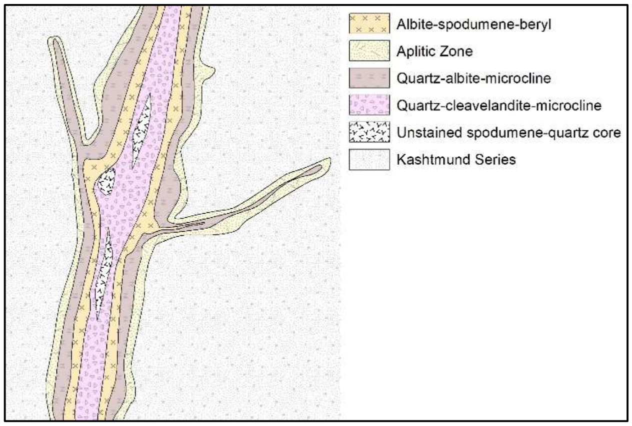

Figure 5. Schema of a dike with symmetric zoning structure at Drumgal deposit

For instance, in Nuristan, pegmatites show gradual changes in composition with elevation: microcline–albite at lower heights, spodumene–microcline–albite in the middle, and spodumene–albite at higher elevations. Regional zonation is also observed in the Tagablor pegmatite field, where pegmatites in granite bodies are microcline, but spodumene content are in the distance from their related parent granites. Three distinct zones are classified in regional zonation: the interior (least fractionated), marginal (intermediate complexity), and exterior (complex mineralogy and structure). Most LCT pegmatites occur in exterior zones, highlighting the importance of APB as a lithium resource. Mosazai et al. (2017) divided Afghan rare-metal pegmatites into two groups based on dike orientation and zoning structure:

1. *Vertical or Steeply Sloped Veins:* Have symmetric zoning structures, often found in schists of the Alingar formation and sometimes within gneisses of the Nuristan series.
2. *Horizontal or Less Steeply Sloped Veins:* Exhibit asymmetrical zoning, with finer grains at the bottom (footwall) and coarser grains at the top (hanging wall), typically lacking a central core. These veins are found in rigid rocks of the Gabbro–Diorite Nilaw complex and sometimes within gneisses of the Nuristan series.

Pegmatites in Afghanistan were classified mostly based on their mineralogical classification. Fon instance, Rossovskiy (1976) separated 6 types of pegmatites in APB with respect to their mineralogical composition with albite zone considered as rare-metal pegmatites path finder; 1) oligoclase-microcline biotite-muscovite with rare beryl; 2) albitized microcline with schorl, muscovite and beryl; ores of crystalline beryl; 3) albitized microcline ores with nests of blue cleavelandite, lepidolite, spodumene, polychromium tourmaline-deposits of precious stones like kunzite, vorobyevite, tourmaline; 4) albite ores with nests of lepidolite, tantalite, spodumene, pollucite, tantalum ores; 5) spodumene-microcline-albite and spodumene-albite (spodumene pegmatites): lithium ores; 6) lepidolite-spodumene-albite with polychromium tourmaline, tantalite, pollucite: cesium and tantalum-cesium ores. Mosazai et al. (2017) separated 5 classes in APB; 1) oligoclase-albite-microcline with biotite, muscovite, schorl and columbite; 2) muscovite-albite-microcline with large crystals of beryl, schorl and columbite; 3) microcline-albite type with columbite-tantalite, beryl, schorl and gemstones; 4) spodumene, microcline, albite with tantalite-columbite, microlite, cassiterite, lepidolite, beryl, tourmaline and gemstones; 5) lepidolite-spodumene-albite with tantalite, microcline, tantalite-(Mn), cassiterite and gems. Tarin (2022) suggested 7 different groups of rare-metal pegmatites in Nuristan; 1) oligoclase-microcline with biotite, muscovite and schorl; 2) schorl-muscovite-microcline with beryl; 3) albite-microcline; 4) albite; 5) spodumene-microcline-albite; 6) spodumene-albite; and 7) lepidolite-spodumene-albite.

Lithium Potential in APB

APB is one of the largest lithium-bearing pegmatite belts in the world (Rossovsky, 1976; Cooker, 2011; Tarin 2022) and the pegmatites are mostly located in median masses of Afghanistan, such as Nuristan block, with more than 55 different minerals. The commodities in this belt can be classified into four different pegmatite formations based on mineralogical composition and field observations: 1) muscovite; 2) rare-metals with muscovite; 3) rare-metals; and 4) precious and semi-precious gemstones. LCT pegmatites are widespread in north-eastern (Nuristan, Badakhshan, Laghman and Kunar) and Central Afghanistan (Daikundi). A total of 76 deposits and occurrence located within the 24 aforementioned pegmatite fields were separated. Unfortunately, data and report related to the exact resource of these deposits are lacking, sparse and scattered, and even some of the investigation in APB were kept confidential. Out of these, 12 deposits , mostly located in north-eastern of Afghanistan and one in central Afghanistan (Tagablor mine) resources were estimated at a depth of 100 m to have 3,800,000 tons of Li_2O (1.8Mt Li) with an average grade of around 1.7%, 8070 tons of Ta_2O_5 with an average grade of 0.025%

estimated from 5 deposits (Tagablor, Yarygul, Drumgul, Samgul and Kalatan) and 0.033% Nb_2O_5 with an estimated resource of 372 tons in two deposits (Yarygul and Drumgul), and 66 tons of Cs_2O with an average grade of 9% in Tatang mine, positioning Afghanistan as one of the biggest lithium resources in the globe. (Abdullah et al., 2008; Cocker, 2011; Peters, 2011; Baudino et al., 2021; Tarin, 2022; Brian, 2024). These resource estimations are only calculated on some of the pegmatites; for instance, in Tagablor pegmatite field around 300 dikes were reported and only 5 of them were speculated to have 130,000 tons lithium oxide (Sahak, 2014; Tarin, 2022). This suggests that the total rare-metal resources across all pegmatites with a depth of more than 100 m and other sources could be considerably higher if fully assessed (Figure 6).

Globally, lithium resources from mineral sources are in various stages of development or exploration across several countries. However, Afghanistan has not yet mined lithium from pegmatites or other sources like brines although residents of Konar province reported that huge crystals of spodumene (more than 1 m long) were mined illegally and were transported to neighboring countries when lithium prices peaked in 2022. The classification and characteristics of pegmatites in the APB suggest significant potential for lithium resources, especially given the occurrence of LCT pegmatites. As global demand for lithium continues to rise, the untapped potential of the APB could play a crucial role in the future supply of this critical mineral. Lithium reserves from mineral sources were at varying stages of development or exploration in Australia, Austria, Brazil, Canada, China, Congo (Kinshasa), Czechia, Ethiopia, France, Finland, Germany, Ghana, India, Iran, Kazakhstan, Mali, Namibia, Nigeria, Peru, Portugal, Russia, Rwanda, Serbia, Spain, Thailand, Turkey, the USA, and Zimbabwe (Brian, 2024). The reported quantity of lithium reserves found in literature can vary significantly and is influenced by the methodology employed, as it is determined by the extent of deposits taken into account (Baudino et al., 2021). The recent data from the USGS (2024) account for 105 Mt of lithium globally (without mentioning Afghanistan lithium resources), spread among different countries (Table 3).

Table 3. Lithium resources distribution by countries (USGS, 2024)

Country	Lithium Resources	Country	Lithium Resources
Bolivia	23 Mt	Serbia	1.2 Mt
Argentina	22 Mt	Peru	1 Mt
Chile	11 Mt	Russia	1 Mt
Australia	8.7 Mt	Mali	890
China	6.8 Mt	Brazil	800 kilotons
Germany	3.8 Mt	Zimbabwe	690 kilotons
Canada	3 Mt	Spain	320 kilotons
Congo	3 Mt	Portugal	270 kilotons
Afghanistan	>1.8 Mt	Namibia	230 kilotons
Mexico	1.7 Mt	Ghana	200 kilotons
Czechia	1.3 Mt	Finland	68 kilotons

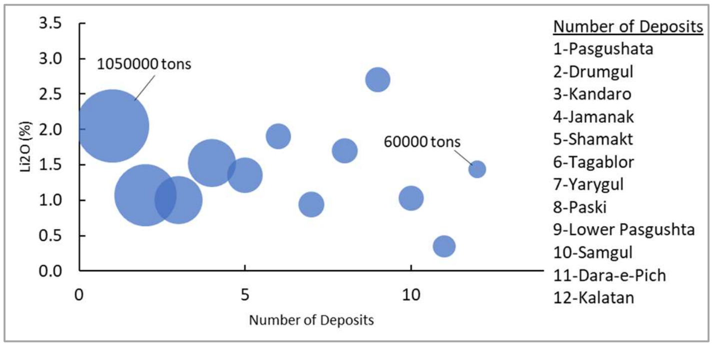

Figure 6. The estimated resource and average grade of Li_2O in twelve different deposits in Afghanistan mostly located in NE of the country. Bubble sizes equated to Li_2O resources

Prospects and Challenges

Afghanistan holds a wealth of mineral resources across various regions in the country. Among these, lithium stands out as a critical element, essential for applications like lithium-ion batteries for vehicle electrification, and has garnered international attention. APB contains substantial amounts of rare metals, positioning it as a potential key player in meeting future global demand. However, extracting lithium from the APB presents several challenges: difficult topography, a lack of necessary machinery and experts, limited transportation networks (including roads and railways), geopolitical issues, security concerns, instability, corruption, weak institutions, and poor governance. Overcoming these obstacles and effectively utilizing these resources could greatly impact Afghanistan's economic future, especially in the context of global green energy transitions.

To use lithium from the APB, three strategic approaches was considered by Shroder et al. (1992): national, regional, and international strategies. A national or inward-oriented strategy aims to rehabilitate and extend the current mineral exploitation system to primarily serve Afghanistan's domestic needs. A regional strategy, in addition to meeting Afghanistan's internal requirements for minerals and mineral products, aims to serve markets in neighboring countries. This strategy would necessitate significant investment, active collaboration with one or more neighboring countries, and considerable assistance from worldwide, regional, and national development institutions. An international strategy seeks to serve global markets, including many purchasers around the globe. This approach would require collaboration with multinational corporations and substantial assistance from worldwide, regional, and national development institutions. Regardless of the strategy chosen, the APB requires comprehensive studies to understand the genesis, geochronology, geochemistry, and evolution of the pegmatite belt, leading to more accurate resource estimates and investment strategies. The lithium estimates in this paper are based only on 12 of the 76 recognized deposits and occurrences in the APB, each explored to a depth of just 100 meters. For instance, in the Tagablor pegmatite field, only a few of more than 300 separate pegmatite bodies have been studied for their lithium content. There are likely many undiscovered areas in the APB with high potential for lithium that remain unexplored and is suggested to overpass lithium resources in Bolivia (Scarlat, 2015). Beyond lithium, the APB holds high potential for other rare elements, estimated to be worth 7.5 billion dollars (Yousaf, 2009). These include tantalum, niobium, tin, tungsten, rubidium, beryllium, and various precious and semi-precious gemstones, further enhancing the economic significance of this belt (Figure 7).

Discussion

The significance of strategic elements in Afghanistan, particularly within the APB, has garnered attention in previous literatures. The potential for significant lithium deposits within this region highlights Afghanistan's opportunity to become a key player in the global lithium market in future. While the 24 pegmatite fields within the APB have not been systematically studied, this study suggests that just 12 deposits could hold approximately 1.8 Mt of lithium, underscoring the country's potential as a valuable source of this critical element. Oligocene granites have been proposed as the parent rocks for the rare-metal pegmatites in the APB. However, dating data from Abdullah et al. (2008) shows that the ages of these pegmatites range widely, from as recent as 16.5 million years to as old as 375 million years, indicating their formation over various geological periods. Despite this, the number of dated samples is limited, and more accurate techniques are needed. Furthermore, while Oligocene granites with S-type characteristics have been suggested as their parent rocks (Cooker, 2011), the granites in the Tagablor pegmatite field are considered to be Cretaceous and I-type (Siehl, 2015).

Figure 7. Showing gem-quality minerals from APB from Nuristan, selected from Jawad Amiri's Collections. A) Achroite on albite, B) Lepidolite and watermelon tourmaline, C) Muscovite and quartz, D) Muscovite, topaz and quartz on albite, E) Aquamarine and muscovite, F) Watermelon tourmaline, G) Schorl on albite, H) Schorl and quartz on albite, I) Schorl on feldspar, J) Tourmaline and quartz on albite, K) Watermelon tourmaline on smoky quartz, L). Cleavelandite, muscovite, aquamarine

This discrepancy suggests that further geochemical and geochronological studies are necessary to better understand the age, origin, and composition of these pegmatites and their parent granites. Instability in Afghanistan in the last decades has unfortunately hindered efforts to thoroughly study and exploit the mineral resources of the country, including those within the APB. The lack of comprehensive research on the APB emphasizes the need for further exploration to better understand the genesis, evolution, and reserves available within the belt. As lithium continues to play a vital role in emerging technologies, the development of these deposits could offer substantial economic benefits to Afghanistan.

Lithium as the most critical element, primarily used in electric vehicles (EVs), is facing a growing demand amidst concerns about insecure supplies. The criticality of lithium may lead to efforts to find substitutions with alternative elements such as sodium. Gardiner (2024) presents different scenarios for the future of lithium, ranging from it remaining critical to potential changes in battery technology and new sources of lithium as well as global geopolitics. If lithium remains critical in the future, the exploitation of these deposits could have a positive impact on Afghanistan's economy. However, considerations must be made for environmental impacts, rugged topography, geographical location and the political situation in Afghanistan. While some studies have focused on the APB in recent years, more exploration is necessary to fully evaluate its economic potential. Despite limited literature on exploration techniques for rare-metal pegmatites (*e.g.* Selway et al., 2005; Trueman, 1982; Maneta and Baker, 2019), remote sensing has proven to be a valuable tool in identifying potential mineral deposits (*e.g.*

Cardoso-Fernandes, 2019; Mashkoor et al., 2022; Gao et al., 2020). By conducting more systematic studies and utilizing advanced exploration methods, Afghanistan can better harness the economic potential of its natural resources such as lithium and other rare-metal while addressing environmental and geopolitical challenges.

Conclusion

Most known deposits and occurrences in APB are partly explored and have no history of operation and many of them remain to be discovered and studied. As one of the largest lithium resources in the world, APB have an encouraging and challenging outlook as primary source of both industrial commodities and rare-metals as well as gem-quality minerals. In addition, determination of zonation on basis of gradual changing of mineralogical composition within pegmatite veins and relative to their parent granite according to their dipping can decrease exploration expense significantly. Economic grade, high quality and vast resources of spodumene, pollucite and columbite-tantalite in Afghanistan attracts many countries to look access by offering considerable investments that is considered to have the ability to fuel the hopes for revival of Afghanistan's reeling economy. Despite the APB containing vast amounts of lithium, potentially positioning it as one of the world's largest lithium resources, preliminary estimates from just 12 out of 76 deposits and occurrences already place Afghanistan ahead of Mexico, Czechia, and Serbia.

Acknowledgement

We would like to extend our appreciation to Prof. Dr. David R. Lentz for his review and valuable feedbacks on this paper. We would also like to express our gratitude to the anonymous reviewer for their thoughtful comments and suggestions.

Conflict of Interest Statement

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

Abdullah, K., 1940. Mica mines of Panjshir river. Kabul. AGS.

Abdullah, S., Chmyriov, V. M., 1977. Map of mineral resources of Afghanistan: Kabul, Afghanistan, Democratic Republic of Afghanistan, Ministry of Mines and Industries, Department of Geological and Mineral Survey. V/O Technoexport USSR, scale, 1(500,000).

Abdullah, S.H., Chmyriov, V.M., Dronov., V.I., 2008. Geology and Mineral Resources of Afghanistan, 2 Volumes., British Geological Survey-Occasional Publication No. 15. (Reprint of the 1980 English translation of the 1977 Russian publication). British Geological Survey.

Arian, H., Alaminia, Z., Nero, A., Haydari, A., Shirzad, A., 2024. Mineralization Potential of Afghanistan Pegmatite Belt. Regionals Symposium on Science and Technology, Ferdowsi University of Mashhad.

Azevedo, M., Campagnol, N., Hagenbruch, T., Hoffman, K., Lala, A., Ramsbottom, O., 2018. Lithium and cobalt: A Tale of Two Commodities.

Baudino, L., Santos, C., Pirri, C. F., La Mantia, F., Lamberti, A., 2021. Recent advances in the lithium recovery from water resources: From passive to electrochemical methods. Advanced Science, 9: 1-27.

Bogatskiy, V.V., Rossovskiy, L.N., Konovalenko, S.I., 1978. System of structural and morphologic types of zones of rare-metal pegmatite veins and the potential for predicting deposits: Transactions (Doklady) of the U.S.S.R. Academy of Sciences: Earth Science Sections, 240(1-6): 78–80

Bowersox, G. W., 1985. A status report on gemstones from Afghanistan. Gems Gemology, 21(4): 192-

204.

Bowersox, G. W., Chamberlin, B. E., Dietrich, R. V., 1996. Gemstones of Afghanistan. Economic Geology and the Bulletin of the Society of Economic Geologists, 91(2): 482-482.

Brian W. Jaskula., 2024. US Geological Survey, Mineral Commodity Summaries, January 2022.

Cameron, E. N., Jahns, R. H., Mcnair, A. H., Page, L. R., 1950. Internal structure of granitic pegmatites. Geologiska Föreningen i Stockholm Förhandlingar, 72(3): 361-362.

Cardoso-Fernandes, J., Teodoro, A. C., Lima, A., 2019. Remote sensing data in lithium (Li) exploration: A new approach for the detection of Li-bearing pegmatites. International Journal of Applied Earth Observation and Geoinformation, 76: 10-25.

Černý, P., Ercit, T. S., 2005. The classification of granitic pegmatites revisited. The Canadian Mineralogist, 43(6).

Chmyriov, V.M., Mirzad, S.H., 1972. Map of mineral resources of Afghanistan: Ministry of Mines and industries of Royal Afghanistan, Department of Geology and Mines, scale 1:1,000,000.

Cocker M., 2011. Summaries of important areas for mineral investment and production opportunities of nonfuel minerals in Afghanistan. USGS, 2.

Cocker, D., 2011. Summary of the Mineral Information Package for the Nuristan Rare-Metal Pegmatite Area of Interests. USGS.

Ehsan, M., 1934. Afghanistan mines. Kabul, AGS.

ESCAP, U., 1955. Geology and mineral resources of Afghanistan. United Nations.

Gardiner, N. J., Jowitt, S. M., Sykes, J. P., 2024. Lithium: critical, or not so critical?. Geoenergy, 2(1), Geoenergy 2023-045.

Ginzburg, A. I., Rodionov, G. G., 1960. On the depth of formation of granite pegmatites. Econ. Geol. US SR, (1-2): 44-53.

Goldfarb, R. J., 2006. Giant Metallic Deposits—Future Sources of Industrial Metals. Peter Laznicka. 2006. Pp. 732. Berlin, Springer. ISBN-10 3-540-33091-7. Price US $199. Economic Geology, 101(7): 1445-1446.

Gourcerol, B., Gloaguen, E., Melleton, J., Tuduri, J., Galiegue, X., 2019. Re-assessing the European lithium resource potential–A review of hard-rock resources and metallogeny. Ore Geology Reviews, 109: 494-519.

Gruber, P. W., Medina, P. A., Keoleian, G. A., Kesler, S. E., Everson, M. P., Wallington, T. J., 2011. Global lithium availability: A constraint for electric vehicles?. Journal of Industrial Ecology, 15(5): 760-775.

London, D., 2018. Ore-forming processes within granitic pegmatites. Ore Geology Reviews, 101: 349-383.

Maneta, V., Baker, D. R., 2019. The potential of lithium in alkali feldspars, quartz, and muscovite as a geochemical indicator in the exploration for lithium-rich granitic pegmatites: A case study from the spodumene-rich Moblan pegmatite, Quebec, Canada. Journal of Geochemical Exploration, 205:106336.

Mashkoor, R., Ahmadi, H., Rahmani, A. B., Pekkan, E., 2022. Detecting Li-bearing pegmatites using geospatial technology: the case of SW Konar Province, Eastern Afghanistan. Geocarto International, 37(26): 14105-14126.

Mosazai, A. M., Yousufi, A., Ahmadi, H., 2017. The geological characteristics and economical importance of pegmatite belt of Afghanistan. Геология и охрана недр, (4): 26-33.

Mosazai, A. M., Yousufi, A., Ahmadi, H., 2018. The zoning structure of rare-metal pegmatites of Afghanistan. Department of geology engineering and exploration of mines.

Orris, G. J., Bliss, D. J., 2002. Mines and Mineral Occurrences of Afghanistan. USGS, Open file report 02-110.

Panahi, F., Modaberi, S., Mirnezhad, H., 2015. Geochemistry and Economic Potential of Rare – metal Pegmatites of Taghma, Salang, Afghanistan. Second International Conference of Science and Earth, Iran.

Peters, S. G., 2011. Summary of Daikundi tin, tungsten and lithium area of interest. USGS.

Peters, S.G., Ludington, S.D., Orris, G.J., Sutphin, D.M., Bliss, J.D., Rytuba, J.J., eds., and the U.S. Geological Survey-Afghanistan Ministry of Mines Joint Mineral Resource Assessment Team, 2007. Preliminary non-fuel mineral resource assessment of Afghanistan, U.S. Geological Survey Open-File Report 2007–1214, 810 P, 1 CD–ROM.

Rossovskiy, L. N., 1976. Rare metallic pegmatite belt of the Hindukush, Eastern Afghanistan. USSR.

Rossovskiy, L. N., Chmyrev, V. M., 1977. Distribution patterns of rare-metal pegmatites in the Hindu Kush (Afghanistan). International Geology Review, 19(5): 511-520.

Rossovskiy, L. N., Konovalenko, S. I., 1976. South Asian Pegmatite belt. Akademiia Nauk SSSR Doklady. Earth Science Section, 299: 89-91.

Rossovskiy, L.N., 1974. Rare metals (lithium, beryllium, tantalum, cesium) in Afghanistan, Kabul, Department of Geological and Mineral Survey.

Rossovskiy, L.N., 1980. Mestorozhdeniya dragotsennykh kamney Afganistana [Gemstone deposits of Afghanistan]. Geologiya Rudnykh Mestorozhdeniy, 22(3): 74–88

Rossovskiy, L.N., 1990. Evolyutsiya granitnykh pegmatitov v istorii geologicheskogo razvitiya skladchatykh oblastey (na primere Pamira i Gindukusha) [Evolution of granite pegmatites in the history of the geological genesis of folded areas, exemplified by the Pamirs and Hindu Kush]: Doklady Akademii Nauk SSSR, 313(5): 1195-1199.

Safi, Z., 2021. Pegmatites of Darra-e-Pich. Master's thesis, Politectnico Di Torino.

Scarlat, D., 2015. Afghanistan Resources and the Persepective of a New Future. Land Forces Academy Review, 20(4): 411.

Selway, J. B., Breaks, F. W., Tindle, A. G., 2005. A review of rare-element (Li-Cs-Ta) pegmatite exploration techniques for the Superior Province, Canada, and large worldwide tantalum deposits. Exploration and Mining Geology, 14(1-4): 1-30.

Shroder, J. F., Eqrar, N., Waizy, H., Ahmadi, H., Weihs, B. J., 2022. Review of the Geology of Afghanistan and its water resources. International Geology Review, 64 (7): 1009-1031.

Siehl, A., (2017). Structural setting and evolution of the Afghan orogenic segment–a review. Geological Society, London, Special Publications, 427(1): 57-88.

Tarin, G. N., 2022. Pegmatite mines of rare and precious stones of Afghanistan: Granite pegmatites of rare metals, Afghanistan Science academy publications, 659 pp.

Treloar, P. J., Izatt, C. N., 1993. Tectonics of the Himalayan collision between the Indian plate and the Afghan block: A synthesis. Geological Society, London, Special Publications, 74(1): 69-87.

Trueman, D. L., 1982. Exploration for rare-element granitic pegmatites. Short course in granitic pegmatites in science and industry, 463-493.

Yousaf, S., 2016. Afghanistan's Mineral Resource Potential: A Boon or Bane. Journal of Current Affairs, 1(1): 86-109.

U.S. Geological Survey, Mineral Commodity Summaries, January 2024