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Potential of Mineral Waste from Mines in Pakistan for Carbon Dioxide Capture: Considering the Case of Baluchistan

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ABSTRACT

In the 21st century, environmental pollution has become a serious threat to biodiversity and human health in addition to ecosystem. In particular, anthropogenic activities contribute significantly for the release of CO_2 in earth's atmosphere. Thus, atmospheric pollution due to CO_2 is one of the grave concerns faced by humanity around the globe. There various triggering sources which include combustion of fossil fuels for electricity generation, transportation, industry and other activities thereby releasing ca. 50 billion metric tons of greenhouse gases (GHG) annually. In addition, mines (mineral exploration) are among the major contributors through both direct and indirect ways. For instance; BHP (an Australian multinational mining company) alone have emitted over 3.4 Mt of GHG from iron and nickel mining sites in 2020. Moreover, it should be noted that mineral waste is believed to have less economic importance, approximately 2 to 6 Giga tons of such mineral or mine tailings exist worldwide. Interestingly it has significant potential for capturing of CO_2 and its sequestration. In particular calcium, magnesium and silicate rocks are candidate materials for the same. Indeed, it would be monumental for the environment and economy of the country. With particular reference to Pakistan; Baluchistan province having plenty of mineral treasures which stimulated development of mining industry at large, produces 1 Mt of mineral waste annually. Therefore, in this study, detailed X-ray fluorescence spectroscopy (XRF) was carried out on numerous mineral waste samples collected from the Muslim Bagh District of Baluchistan, Pakistan. In addition, the estimation of the waste generation from various mines and beneficiation plants of Muslim Bagh District was also discussed.

KEYWORDS: Mining waste, Baluchistan, XRF, beneficiation plants, carbon dioxide.

INTRODUCTION

Carbon dioxide is a known greenhouse gas globally. The CO_2 concentration has been sharply increased from 280 ppm in the 1750s to 420 ppm in 2022 (NOAA's Mauna Loa Atmospheric Baseline Observatory record (2022) and Verma Loretta et al., 2022). It traps outgoing heat from the planet's surface causing the global warming accompanied with extreme weather changes, such as heat waves, hurricanes, floods, etc. The rise in CO_2 level has increased the Earth's temperature to 1.1° C thereby raising the global mean sea level by 0.2 m, which is a life threatening trend for many coastal communities (Nobuo Mimura et al., 2013).

To reduce the amount of CO_2 entering the atmosphere, various options for the capturing and storage through natural sequestration or similar processes have been explored. Carbon mineralization (CM) entraps CO_2 in a solid matter as a carbonate (Thonemann N. et al., 2022). It occurs naturally when certain rocks are exposed to the ambient air containing CO_2. Geological CM can be done either by; (i) injection of CO_2 into deep underground rock formations or by (ii) exposure to surface of rocks. The latter is true for the mine waste too. Igneous, ultrabasic and porous sedimentary rocks have a great potential for CM. The mineral waste rocks rich in earth alkali metals have an inherent ability to bind CO_2 and chemically “fix” it permanently (Abass A. O. et al., 2013).

Direct CM method has been reported for the capture of CO_2 from the atmosphere using magnesium rich silicate mining wastes such as olivine and serpentine. Approximately 2-6 Gt of mine tailings exist worldwide, and 20-60 Mt of tailings are being produced every year. The mineral waste has capacity to sequester 100-200 Mt of CO_2 per year globally (Gregory M. Dipple et al., 2017). Ms. Samantha Langley, an environmental specialist from the BHP Australian mining firm reported in 2014 that nickel mine waste has around 80% of the CO_2 sequestration capacity and can offset about 11% of the mine’s carbon emissions. The tailing ponds at the nickel mine were estimated to capture around 40 kt of CO_2 yearly. The total capacity of these mine tailings to sequester carbon is about ten times greater than GHG emissions released from mining and mineral processing industries.

Facing the global climate change challenge, we must advance environmental sustainability of industrial processes to find efficient mitigation methods to minimize the negative effects of anthropogenic sources. It has been studied vastly and available in open literature that mineral rocks are capable to absorb CO_2 at large scale. This include, basalt, pyroxene ($CaMgSi_2O_6$), brucite ($Mg(OH)_2$) , serpentine ($Mg_3Si_2O_5(OH)_4$), olivine ($(Mg, Fe)_2SiO_4$), feldspar ($CaAl_2Si_2O_8$) that contains high amounts of Mg, Fe and Ca (Ron Zevenhoven et al., 2010 and McGrail et al., 2003). This is favorable for CO_2 capture and sequestration. Indeed, Baluchistan is rich of Ca/Mg/Fe-silicate containing rock deposits. A wide variety of mine waste from numerous sites across this southwestern province can stand as abundant feedstock for CM. In particular, the chromite and asbestos mines left aside the alkaline metal rich rocks and tailings, including serpentine, peridotite olivines, harzburgite, dolerite, hornblende etc. Around 1 Mt of mineral waste is generated annually filling the valley with fine rocks and tailings. Owing to toxic nature of some of minerals, the waste management authorities requires special efforts particularly for chromium-containing residues. Those wastes occupy the land with no clear perspectives of how it might be utilized otherwise in the future. Moreover, due to aggressive environmental changes that we face routinely; thus every possible effort has been made to mitigate the global warming in terms of CO_2 reduction.

Therefore, this study is focused to better understand the presence of calcium and magnesium in mine and beneficiation wastes. In addition, the estimates will be developed for the generation of the mineral waste in Muslim Bagh District of Baluchistan.

DESCIPTION OF STUDY AREA

As mentioned earlier, the Muslim Bagh is a sub district of Qila Saifullah that is formerly known as Hindu Bagh which is about 74 km north east of Quetta, Pakistan. Geographically the area is mountainous that comprises of valleys with varying elevation above sea level. The area hosts the biggest spots of chromite and Asbestos Mountains. The chromite ore belt stretches over ~ 2000 sq. km area and is well-known hub in the country. This hub comprises of about 325 chromite and 5 asbestos open-cast mines as well as underground ones. Also, there are 100 dumping sites and 11 chrome beneficiation plants (Chandio et al., 2021). The location of the mines is presented in Figure 1. The chromite deposits were first discovered by Vredenburg 1901 during the course of regional reconnaissance mapping of Baluchistan and parts of eastern Persia. The chromite mining started in 1903 on small scale and is continuing till today at very large scale.

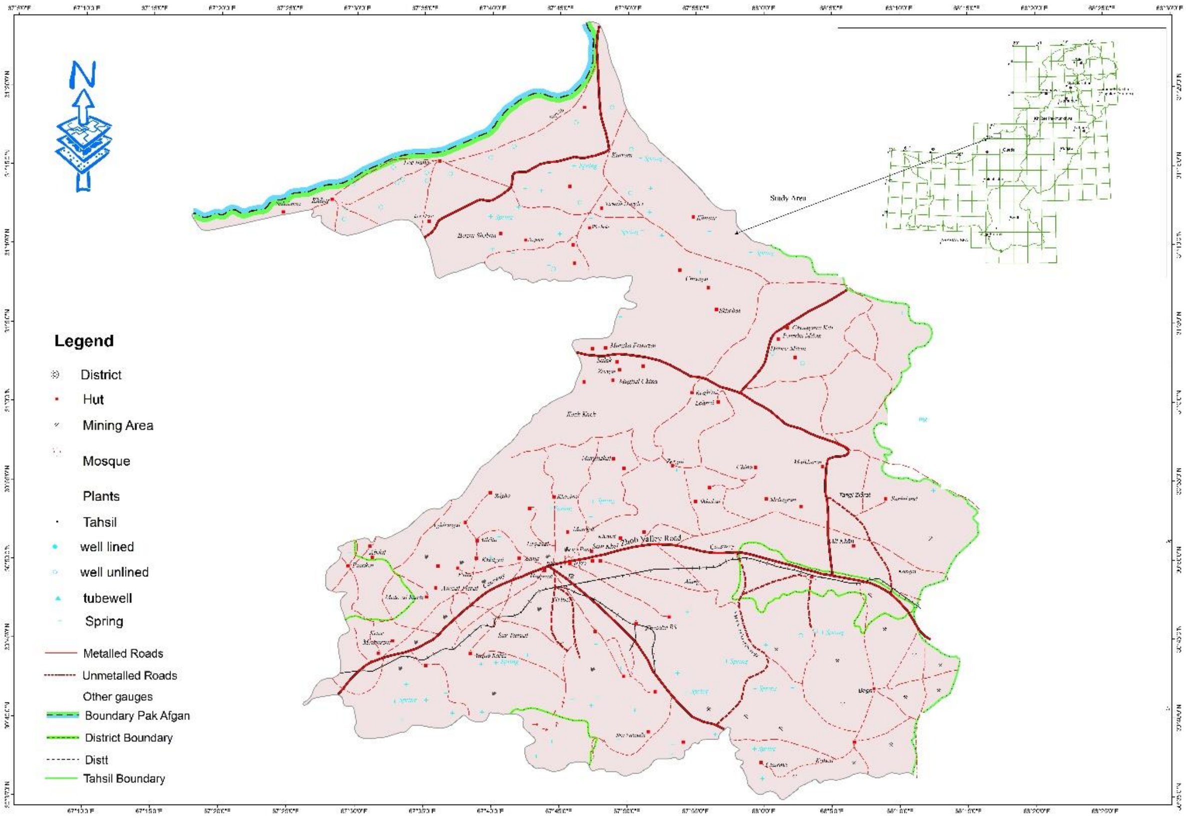

Figure 1. The map showing the mines and mineral waste sites in Muslim Bagh.

GEOLOGICAL SETTING OF STUDY AREA

The Muslim Bagh ophiolitic/ ultramafic complex is a part of discontinuous ophiolitic chain comprising Bela, Muslim Bagh, Zhob, Waziristan Khost at the western edge of the Indian plate and mark the boundary with Eurasian plate. Tectonically the sediments belonging to the Indian plate passive margin are composed of limestone, sandstone, and mudstone.

In the study area sedimentary, ophiolitic, plutonic dyke, metamorphic, ultrabasic (extrusive and intrusive) rocks are found. These rocks are developed in the igneous basins along the northern arc of the central geanticline. The outer part of the basin is formed of Jurassic and elder sedimentary rocks, mostly limestone and shale and the inner part is of cretaceous and possibly early Paleocene rocks consisting largely of volcanic and intrusive igneous types with subordinate shale, marl, lime stone, conglomerate, Jasper, basic and ultrabasic intrusive bodies both of concordant and discordant types are intermingled with the volcanic rocks. The chromite occurrences are in the ultrabasic complex which comprises of dunite, serpentine, harzburgnite and chromitite. Sedimentary rocks (Triassic to Pleistocene) of the study area mainly consists of lime stone interceded with shale and sandstone. Dykes are traversed by zeolite and secondary mineral veins up to two inches thick.

METHODOLOGY

The rock samples used in this study were collected from the Muslim Bagh district of Baluchistan, Pakistan. The collected rock samples were carefully dried to remove any moisture content that could potentially affect the analysis. Subsequently, the dried samples were crushed to a fine powder using a mechanical crusher, ensuring homogeneity and consistency in the particle size. The prepared rock powder samples were then transported to the Department of Metallurgy, NED University Karachi, Sindh, Pakistan, where further analysis was conducted. At the Department of Metallurgy, the rock powder samples were processed to form homogeneous beads. The analysis of the beads was performed using an energy dispersive X-ray fluorescence spectrometer (EDX-7000, Na-U, Shimadzu, Japan).

RESULTS AND DISCUSSION

Estimates of Chromite

Chromite production and overburden generation from chromite mines and beneficiation plants of Muslim Bagh is shown in Table 1 and 2. The waste management requires special efforts because of the toxicity of chromium-containing residues. Those wastes occupy the land with no clear perspectives of how it might be utilized otherwise in the future.

Table 1. Chromite production and overburden generation from chromite mines of Muslim Bagh area wise.

Table 2. Production and overburden generation is in metric tons from chromite beneficiation plants of Muslim Bagh, Baluchistan, Pakistan.

S#	Location		Owner/no. of plants owned	Production (Tons/year)	Overburden Generation (Tons/Year)	Overburden area (Hectares)
	N	E				
1	30^{o}48.420'	67^{o}45.720'	A/1	3705.2378	8247.1422	50
2	30^{o}48.042'	67^{o}45.698'	B/1	3031.5582	6747.6618	26
3	30^{o}49.147'	67^{o}45.518'	C/1	2526.2985	5623.0515	30
4	30^{o}49.757'	67^{o}46.406	D/1	4378.9174	9746.6226	40
5	30^{o}49.486'	67^{o}46.872'	E/1	9431.5144	20992.7256	124
6	30^{o}49.305'	67^{o}47.023'	F/1	1684.199	3748.701	36
7	30^{o}49.429'	67^{o}47.019'	G/1	2391.56258	5323.15542	80
8	30^{o}38.591'	67^{o}55.327'	H/1	3065.24218	6822.63582	90
9	30^{o}38.792'	67^{o}55.336'	I/1	774.73154	1724.40246	20
10	30^{o}38.960'	67^{o}55.332'	J/1	1684.199	3748.701	25
11	30^{o}47.957'	67^{o}45.698'	K/1	1010.5194	2249.2206	20

S#	Year	Bostan area			Gawal area		
		No. of Mines	Annual Production	Overburden Production	No. of Mines	Annual Productio n	Overburde n Production
1	2003-2004	22	1923.2	1155.8	12	1049.0	743.8
2	2004-2005	22	3608.7	2168.8	12	1968.4	1395.6
3	2005-2006	22	2345.7	1409.7	12	1279.5	907.1
4	2006-2007	22	2752.7	1654.4	12	1501.5	1064.5
5	2007-2008	22	2289.0	1375.7	12	1248.6	885.2
6	2008-2009	22	4315.2	2593.5	12	2353.8	1668.8
7	2009-2010	22	12275.0	7377.3	12	6695.4	4747.1
8	2010-2011	22	7204.5	4329.9	12	3929.7	2786.2
9	2011-2012	22	7355.3	4420.5	12	4012.0	2844.5

X-ray Fluorescence Analysis

Geological Survey of Pakistan (GSP) has been conducting numerous studies in composition of rocks across the country. Within the scope of present topic, the results of XRF analysis of selected mineral wastes from mines of Baluchistan confirmed the presence of alkaline and transition metals such as calcium, magnesium and iron. This can be utilized as a CO_2 capturing agent. In addition, their weight fractions in the most abundant mineral wastes are reported as shown in Figure 2. It is clearly seen that the CO_2 binding metals (Ca, Mg, Fe) in form of metal oxides constitute roughly a half of the sample weight i.e., 57.6 wt% in olivine, 48.37 wt% in dunite, 39.03 wt% in serpentine and 57.7 wt% in peridotite. Additionally, it was also established, that these wastes contain a wide variety of elements, namely, Mn, Ni, V, P, S, Cu, Pb, and Zn, As, Sn, Cr (as toxic $Cr^{6+/3+}$), which might be extracted for other purposes too. Hence, these mineral wastes can be considered as a readily available feedstock to be utilized by a carbon capturing facility.

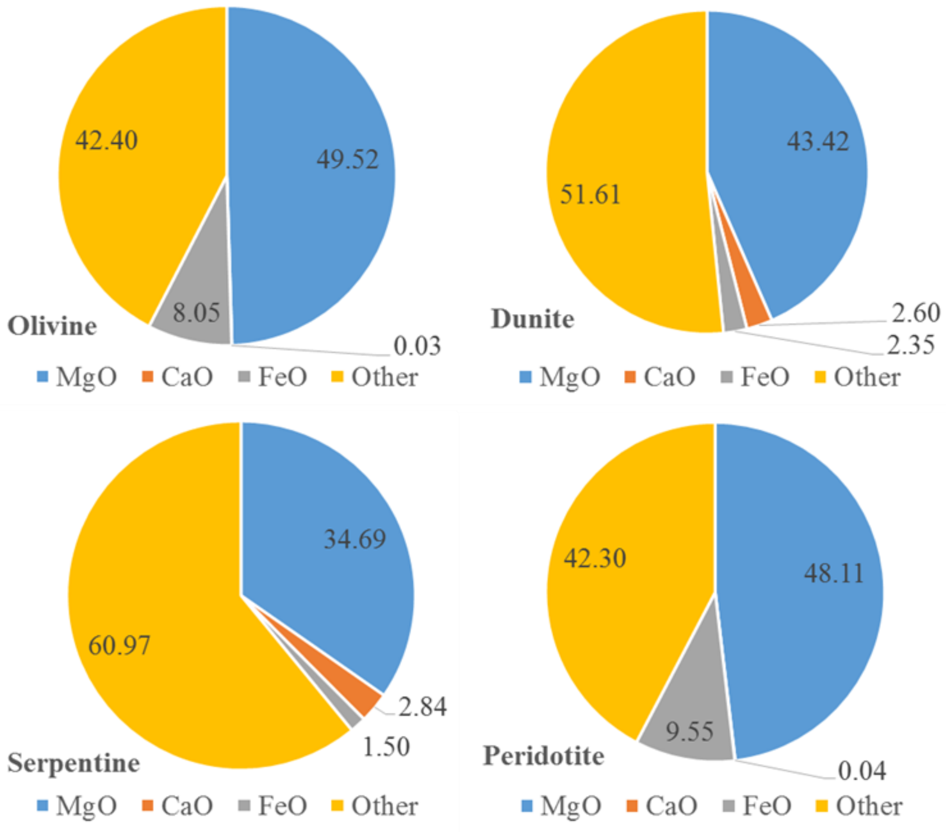

Figure 2. Diagrams of weight percentages of three main metal oxides (MgO, CaO, FeO) in four common mineral wastes (olivine, dunite, serpentine and peridotite).

Specifically, this research was focused on the potentials of rocks and mineral wastes in Baluchistan for direct CO_2 capture and sequestration. Furthermore, the present situation with mining industry in regard to carbon emission can be described by the following workflow diagram as shown in Figure 3 (left side). The multiple mining sites across the province also generate CO_2 gas due to the consumption of fossil fuels for energy generation, and dumping of waste rocks / tailings. The extracted mineral-rich ores are transferred to the respective ore beneficiation plants. Again, the existing technological cycles are based on utilization of combustibles for energy generation and then depleted ores leave behind the mineral wastes as discussed earlier.

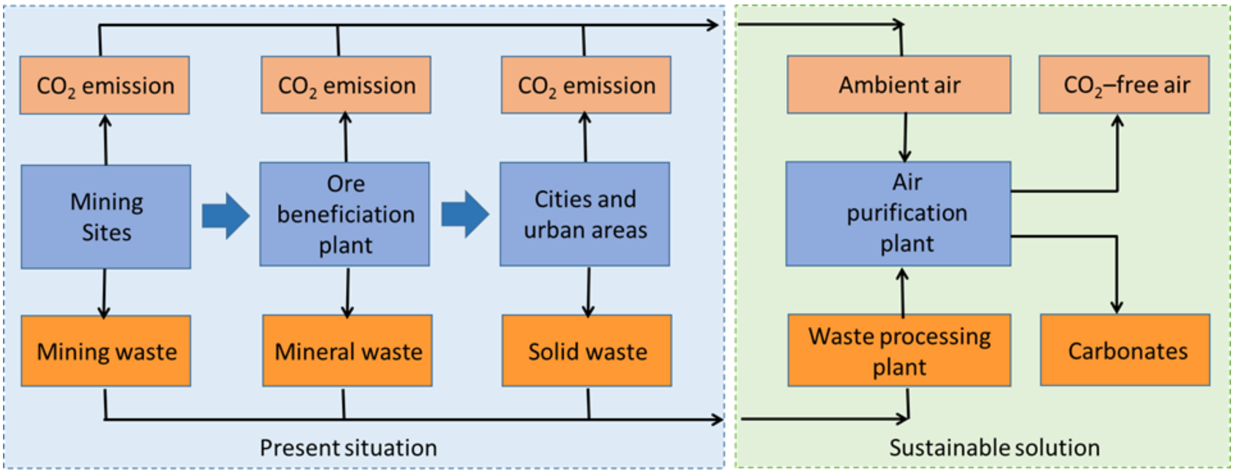

Figure 3. Schematic diagram depicting potential ways to utilize mineral wastes in terms of carbon-capture.

The sustainable solution for existing situation could be the one presented in Figure 3 (right side). The air purification plant should use abundantly available mineral wastes and to form the carbonates of industrial relevance. There is a number of technologies available that capture and reuse CO_2 from the air and point sources utilizing chemical reactions in much the same way trees do however at a larger scale. One of the most relevant of them is the direct air capture (DAC), which uses chemical reactions between alkaline metals and CO_2 molecules in the air as discussed in earlier Figure 1. Here the extracted metal ions will serve as CO_2 capturing agents. For example, Vesta Company uses olivine to capture CO_2. According to the Global CCS Institute, there are 19 large-scale commercial carbon capture and sequestration facilities operating around the world, 10 of which are in the United States alone.

Moreover, the Year 2020's report of Mineral Deposit Research Unit of The University of British Columbia suggests that the 50 wt. % content of MgO in brucite could sequester about 120 kt of CO_2 from the atmosphere by using 40 Mt of tailings per year. Noah McQueen et. al; 2020 demonstrated that rocks wastes containing olivine, serpentine, peridotite as well as harzburgite can be converted into a reactive material for CO_2 capture and storage by a heat treatment. Antoine Gras et. al; 2020 and a team also revealed that 1.4 $kgCO_2$/ton/year conversion efficiency of CM by utilizing serpentine, gabbro, dunite and peridotite of mining residues. According to their assumptions, the 15 Mt of mineral wastes produced every year could potentially sequester 21 kt of CO_2 per year by passive CM.

These examples suggest, that abundant alkaline metal rich mineral wastes in Baluchistan is a valuable resource and there is only need for respective technology to be developed and implemented. Establishment of such model plant will realize sustainable waste management approach thereby creating new jobs and improving air quality at large.

CONCLUSION

In conclusion, the study highlights the CO_2 storage potential of mineral waste generated from mines and beneficiation plants located in Muslim Bagh District of Baluchistan province. In addition, the identification and assessment of rocks and mineral wastes with high CO_2 capturing potential offers a promising solution to mitigate the catastrophic effects of greenhouse gas emissions thereby facilitating the country's circular economy and solid waste management strategies. The X-ray fluorescence spectroscopy of numerous samples exhibits the presence of calcium and magnesium oxides. This further suggests that mineral waste could be effectively utilized in terms of CO_2 mitigation strategy. Thus, this study is a way forward to achieve the goals of Paris Agreement which is an International Treaty to limit and cut greenhouse gases. In future, deployment of proactive exploration and implementation technologies of CO_2 storage and sequestration within mineral waste stand poised to make substantial contributions towards a sustainable future of Pakistan

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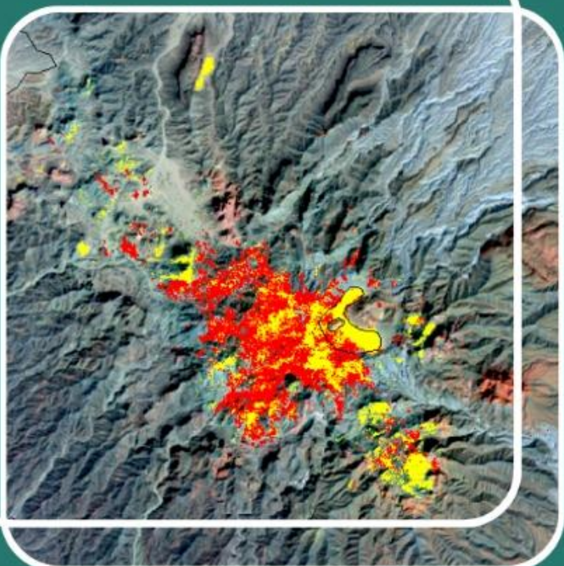

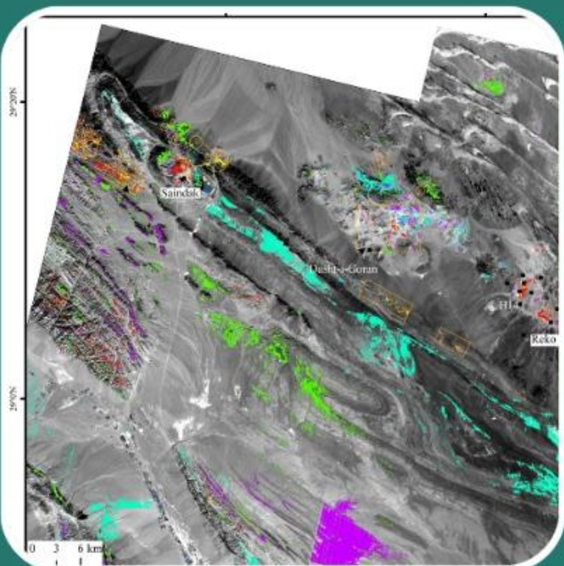

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