



The Contribution of PCSIR towards Exploration of Minerals Reserves of Pakistan

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Abstract: Pakistan has been blessed with extensive deposits of metallic, non-metallic and industrial minerals. Deposits of iron, copper, lead-zinc, chromite and coal are the top most among 15 major mineral reserves of the country. This study highlights the contribution of Pakistan Council of Scientific and Industrial Research (PCSIR) in the field of ore beneficiation.

In Pakistan, iron ores of Kalabagh, Noukundi, Chitral and Chiniot areas have been upgraded from 30-45% to 55-66% iron content by froth flotation and magnetic separation techniques. Saindak copper ore has been upgraded from 0.46% Cu content to Chalcopyrite (CuFeS_2) concentrate containing 30% Cu. Concentrates of sphalerite (ZnS) and galena (PbS) have been developed containing 55% metal content respectively by froth flotation from Besham lead-zinc ore. Indigenous chromite ore has been concentrated from 32% Cr_2O_3 to 52% Cr_2O_3 . Other important metallic ores, like Tungsten ore of Chitral, containing 0.55% WO_3 has been beneficiated to make Scheelite concentrate containing 64% WO_3 .

Graphite concentrate containing more than 98% graphitic carbon has been developed from local material of grade 17% C. Non-metallic minerals, like Sulphur, Barite and Nepheline Syenite, have also been upgraded by different mineral processing techniques. Beneficiation studies on Lakhra and Makerwal Coal deposits have also been carried out at PCSIR, Lahore.

Key words: Ore, Beneficiation, Metallic and non-metallic minerals, Flotation, Up-gradation.

INTRODUCTION

Pakistan is enriched with significant mineral resources. It is reported that more than 600,000 square kilometre outcrop area of Pakistan possesses huge resources of metallic, non-metallic and industrial minerals as stated in National Mineral Policy (MPNR, 2013). Various geological surveys conducted by multi-national mining companies and exploration done by government agencies have confirmed a great potential of metallic minerals, like copper, iron, chromium, aluminum, lead, antimony, zinc and manganese as well as precious metals, such as, gold, silver, platinum and palladium. There are also significant reserves of non-metallic industrial minerals, like gypsum, limestone, calcite, dolomite, magnesite, barite, graphite, halite, rock salt, rock phosphate, feldspar, soapstone and clay minerals (Table 2). Pakistan has a vast potential of building stones, such as, multi-coloured granite, marble, onyx and gemstones of high quality for export purpose. However, despite having significant mineral resources, the current contribution of mineral sector to the Gross Domestic Product (GDP) is less than 1%. It can be increased considerably by commercial exploitation of these deposits and development of

local mineral-based industries (Sethi, 2011). Keeping in view of vast potential of mineral reserves in the country, it is realized that there are great opportunities for the multinational mining companies and local investors to invest in this important sector, which will be ultimately beneficial for the country as stated in National Mineral Policy (MPNR, 2013).

Significant mineral resources of Pakistan

Metallic minerals of Iron, copper, chromium, aluminum, lead, zinc and non-metallic industrial minerals, such as gypsum, limestone, barite, rock salt, rock phosphate, coal, china clay, building stones and gemstones, are reported as the top fifteen minerals of the country (MPNR, 2013; EAC, 2004).

Major iron deposits are found in Kalabagh and Chiniot areas of Punjab, Noukundi and Dilband areas of Balochistan and Chitral area of Khyber Pakhtunkhwa (Sethi, 2011; EAC, 2004; PCSIR, 1988).

Pakistan is endowed with huge reserves of copper including deposits of Gilgit and Waziristan. Saindak, Ziarat, Pir Sultan and Reko Diq areas of Balochistan are capable of becoming significant source of copper production in the world. Considerable amount of gold and silver is also present in Balochistan copper ores (Planning Commission, 2014; Sethi, 2011).

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Low to medium grade lead-zinc deposits are found in Azad Kashmir, Besham (Khyber Pakhtunkhwa) Khuzdar and Duddar (Balochistan). Chromite is available in Azad Kashmir and Muslim Bagh (Balochistan) with Cr₂O₃ content 30-40% (MPNR, 2013); Sethi, 2011; EAC, 2004).

The non-metallic minerals, like, nepheline syenite is found in Koga Swat (KPK), Barite, Sulphur, in Balochistan, while graphite with 10-20% graphitic carbon in Malakand and Azad Kashmir (MPNR, 2013). The total proven reserves of coal in Pakistan are 188 billion tons, the 6th largest in the world. The biggest good quantity of low-rank coal lies in Thar

(Sindh), where the coal reserves are estimated to be over 175 billion tons (Planning Commission, 2014; Hameed *et al.*, 2015; MPNR, 2013; Sethi, 2011).

Pakistan holds an important position among the leading gem-hosting countries (MPNR, 2013; EAC, 2004). KPK, Azad Jammu and Kashmir and northern areas of Pakistan are the main gem hosting areas. The significant gemstones include emerald, topaz, peridot, garnet, aquamarine, tourmaline and ruby are presented in Table 1. Most of the other gemstone deposits have not been yet investigated scientifically and still remains undocumented.

Table 1: Gemstones of Pakistan.

Gemstones potential of Pakistan	Estimated reserves (Million Carats)
Khyber Pakhtunkhwa (KPK)	
Emerald (Swat)	70.0
Pink Topaz (Mardan)	09.0
Peridot (Hazara, Kohistan)	10.0
Aquamarine, Tourmaline (Chitral)	(Not assessed)*
Garnet (Bajor)	(Not assessed)*
Northern Areas	
Ruby (Hunza, Neelam valley)	1.5
Aquamarine (Gilgit, Chitral)	0.2
Tourmaline (Chitral, Neelam valley)	0.1
Topaz, Garnet and other (Skardu, Malakand)	(Not assessed)*
Azad Kashmir	
Kashmir Ruby	125.0
Tourmaline pink beryl, etc.	(Not assessed)*
Spessartine garnets and aquamarine	(Not assessed)*

* MPNR, 2013.

Table 2: Major mineral resources of Pakistan.

Minerals/Ores	Location	Estimated reserves (Million tons)	Grade/Quality
Metallic			
Antimony	Kirinj (Chitral), Qila Abdullah, Khuzdar	0.09	Low to medium
Aluminum (Laterite/Bauxite)	Ziarat, Kalat, Khushab, Muzafarabad	74.0	Low to medium
Chromite	Malakand, Muslim bagh, Jijal	2.527	Low to medium
Copper	Saindak, Reko Diq, Chitral, Dir, Waziristan	1882.5	Low to high
Gold, Silver	Saindak, Reko Diq	11.24 million Ounces	Low grade
Iron	Noukundi, Chitral, Kalabagh, Chiniot, Dilband	903.4	Low to high
Lead-zinc	Besham, Gunga, Dhuddar	23.72	Low to medium
Manganese	Lasbela, Khuzdar	0.60	Low to medium
Non-metallic minerals			
Barite	Gunga, Moner Talar, Hariapur	13.71	Medium
Bentonite	Punjab	40	Medium to high
China clay	Hazara, Nagarparkar, Gilgit	More than 2.5	Medium to high
Coal	Lakhra, Thar, Thatta, Jherruck	185 billion	Low grade
Dolomite	Mianwali, Jhimpur	Large	High grade
Feldspar	Mingora (Swat)	Very large	High grade
Fire clay	Dadu, Gilgit	Fairly large	Medium to high
Fluorite	Maran, Kalat, Khuzdar	0.1	Low to medium
Fuller's earth	D.G. Khan, Khairpur, Swat	Large	Medium to high
Gravel	Punjab, Sindh, Balochistan, Khyber Pakhtunkhwa	Very large	Medium to high
Graphite	Malakand, Azad Kashmir		
Gypsum	Sibi, Kohat, D.G. Khan	4850	Medium to high
Limestone	Punjab, Sindh, Baluchistan, Khyber Pakhtunkhwa	Large	High grade
Magnesite	Hazara, Muslim Bagh	12	Medium to high
Marble	Baluchistan, Khyber Pakhtunkhwa	Very large	High grade
Nepheline syenite	Koga	Large	Low to medium
Rock salt	Punjab	Very large	High grade
Silica sand	Punjab	Very large	Medium to high
Soapstone	Hazara	3.0	Medium to high
Sulphur	Koh-e-Sultan	0.80	Low to medium
Granite	Baluchistan, Khyber Pakhtunkhwa	Very large	Medium to high

PCSIR is the premier R&D organization of country. It was established in 1953 to promote the cause of scientific and industrial research in the country. Its R&D efforts are directed towards the optimum utilization of indigenous resources for industrial development leading to self-reliance of country. It conducts R&D to develop processes and technologies for establishment of new industries, using indigenous raw materials, to enhance local production to substitute import and promote export, to solve the problems faced by the industries. It also extends testing and calibration services to clients.

PCSIR centres, at Lahore, Peshawar and Quetta, are engaged in R&D work for mineral beneficiation and utilization. This study highlights the contribution of PCSIR in the field of ore beneficiation. Most of the beneficiation work, presented in this study, is conducted at Multipurpose Ore Beneficiation (MOB) Pilot Plant of Mineral Processing Research Centre (MPRC), PCSIR Laboratories Complex, Lahore.

Mineral processing at PCSIR

Most of the ores when mined are low-grade in nature. These ores are not suitable for final applications until and unless the unwanted impurities are removed from them and valuable minerals are concentrated. It is necessary to develop an appropriate beneficiation process for every ore on laboratory scale. The process developed on lab scale is verified on pilot plant scale to establish its economic and industrial viability. On the bases of pilot plant beneficiation studies, process flow-sheets are designed and pre-investment feasibility reports are prepared, which help to take investment decisions for the set up of mineral utilization industries.

Multipurpose Ore Beneficiation (MOB) Pilot Plant of MPRC, Lahore, is the first integrated mineral processing unit within the country that was

established in 1986 with the help of UNDP. The processing capacity of the plant is 5-6 metric tons per day depending upon the nature and characteristic of the ore. It is a centralized facility capable of handling beneficiation studies on almost all types of metallic and non-metallic minerals. It is mainly designed for up-gradation of low grade ores to produce concentrates which provide feed stock for various metallurgical operations and value-added products. The pilot plant has the beneficiation facilities for processing of almost all types of ores, using different processing techniques, such as, froth flotation, gravity-based separation, low and high intensity magnetic separation and hydrometallurgical. Washability and beneficiation facilities of indigenous coal are also available. Material Research Centre, PCSIR, Peshawar, and Minerals Division of PCSIR, Quetta is equipped with mineral evaluation, identification and beneficiation facilities at lab scale only. PCSIR centres, at Peshawar and Lahore, have facilities for the development of mineral based products and chemicals.

Contribution of PCSIR for Ore Beneficiation

Mineral based concentrates: Pakistan is a mineral rich country but its mineral potential, particularly, metallic minerals have not been fully utilized due to certain reasons. However, PCSIR is contributing continuously to the best of its efforts in mineral evaluation, beneficiation and ultimately its utilization. Various laboratory and pilot plant scale studies have been completed at MPRC, PCSIR, Lahore, on different metallic and non-metallic ores/minerals of the country (Bhatti *et al.*, 2016; MPRC-PCSIR, 2015; Mahmood *et al.*, 2014; Kazmi *et al.*, 2011; Kazmi *et al.*, 2008; Bhatti *et al.*, 2008a; Bhatti *et al.*, 2008b). A brief summary of minerals upgraded at PCSIR, Lahore, is presented in Table 3.

Table 3: Minerals upgraded at PCSIR, Lahore.

Name (Ore/Mineral)	Grade		Technique applied
	Head sample	Concentrate	
Metallic minerals			
Kalabagh iron ore	30-34% Fe	55% Fe	Froth flotation
Chiniot iron ore	34% Fe	66% Fe	Froth flotation/Magnetic separation
Noukundi iron ore	45% Fe	66% Fe	Low intensity magnetic separation
Chitral iron ore	59.4% Fe	65.5% Fe	Magnetic separation
Saindak copper ore	0.46% Cu	30% Cu	Froth flotation/Magnetic separation
Besham lead-zinc ore	0.6% Pb	56% Pb	Froth flotation
	6-7% Zn	54% Zn	
Duddar lead-zinc ore	3.12% Pb	65% Pb	Froth flotation
	7.04% Zn	55% Zn	
Azad Kashmir lead-zinc ore	13% Pb	65% Pb	Froth flotation
	12% Zn	60% Zn	
Muslim Bagh chromite ore	32% Cr ₂ O ₃	52% Cr ₂ O ₃	Gravity concentration
Chitral tungsten ore	0.55% WO ₃	64% WO ₃	Gravity concentration, froth flotation, magnetic separation
Chitral antimony ore	19% Sb	62% Sb	Froth flotation
Non-metallic minerals			
Malakand graphite ore	16-18% C	98.2% C	Froth flotation
Azad Kashmir graphite ore	10-12% C	98.6% C	Froth flotation
Sulphur Koh-e-Sultan ore	32% S	99% S	Froth flotation
Nepheline syenite ore (Koga, Swat)	3-6% Fe	0.06% Fe	High intensity magnetic separation

Mineral based processes: Various technologies have also been developed for the production of mineral based chemicals from indigenous ores/minerals directly or from concentrates produced at PCSIR, e.g., lead-zinc based chemical (zinc carbonate, zinc oxide, zinc chloride, litharge, red lead and lead acetate), chromite-based chemicals (chromosol, potassium chromate, potassium dichromate) and gypsum-based chemicals (sodium sulphate, sodium sulphide, calcium carbonate, calcium sulphide, sodium bicarbonate, sodium carbonate). Similarly, different graphite concentrates, having purity from 95% to more than 98%, have been produced from indigenous graphite ores to utilize in pencil making and to make bushes and electrodes of graphite. High quality flake graphite concentrate has also been produced from a graphite-based waste of steel making which is known as Kish. Some other industrial chemicals, based on indigenous ores/minerals, like magnesium stearate, magnesium sulfate, zinc stearate, barium nitrate,

barium chlorate and indelible ink/pad ink, have also been produced and supplied to potential customers from public and private sectors as per their specification, requirement and demand.

Mineral-based projects: Mineral processing is the intermediate stage between mining and extractive metallurgy. It plays an important role of removing minor impurities from industrial mineral, e.g., iron from nepheline syenite or recovering valuable metallic minerals from host rock (e.g., copper, gold, silver recovery from copper ore). Obviously, mineral raw materials cannot be utilized without the provision of solid mineral processing base. To provide base for mineral sector, PCSIR has undertaken various projects of vital importance on minerals and mineral based products. Table 4 presents a list of such projects, undertaken for various agencies of public and private sectors.

Table 4: Projects of national importance undertaken by various agencies.

Mineral/Ore	Project	Agency
Iron	Processing of Chichali iron ore	Annual Development Project (ADP)
	Processing of Noukundi iron ore	Pakistan Industrial Development Corporation (PIDC)
	Processing of Chitral iron ore	PECO/FLEC
	Reduction of Kalabagh iron ore	Pakistan Science Foundation
	Reduction of mix iron and iron oxide waste	Magna Steel (Pvt.) Limited, Karachi
Copper	Processing of Saindak copper ore	Resource Development Corporation (RDC)
	Evaluation of Dir and Chitral copper ore	Sarhad Development Authority (SDA)
	Evaluation of Waziristan copper ore	FATA Development Corporation
Chromite	Pilot plant beneficiation study on low-grade Chromite ore of Muslim bagh, Balochistan, Pakistan	M/s BESROCK (Pvt.) Ltd., Islamabad
	Processing of Muslim bagh Chromites	Baluchistan Development Authority (BDA)
	Processing of Chromite ore of Balochistan	Pakland Cement, Karachi
	Processing Malakand Chromites	Pakistan Mineral Development Corporation (PMDC)
Lead-zinc	Processing of Besham lead-zinc ore	Ministry of Science and Natural Resources
	Processing of Azad Kashmir lead-zinc ore	Azad Kashmir Mineral and Industrial Development Corporation (AKMIDC)
Scheelite	Process development on Scheelite ore	NESCOM, Islamabad
	Processing of Tungsten ore	NESCOM, Islamabad
	Beneficiation of Tungsten ore of Chitral	University of The Punjab, Lahore
Antimony	Recovery of Antimony Sulphide and Metal from Chitral stibnite ore	Sarhad Development Authority (SDA)
Laterite	Recovery of Iron, Alumina and Titania from Ziarat Laterite	Annual Development Project (ADP)
Gold and silver	Processing of Chilghazi ore for the recovery of gold and silver	Pakistan Mineral Development Corporation (PMDC) and Sarhad Development Authority (SDA)
Graphite	Processing of Azad Kashmir graphite ores	Azad Kashmir Mineral and Industrial Development Corporation (AKMIDC)
	Processing of Malakand graphite ore	M/s Malakand Mines (a plant set up in private sector)
	Beneficiation of graphite	Pak Graphite Industries, Islamabad
Sulphur	Processing of Koh-e-Sultan ore	Baluchistan Development Authority (BDA/UNDP)
Nepheline syenite	Processing of Koga ore for glass industry	Sarhad Development Authority (SDA)
	Processing for mould powder	Pakistan Steels, Karachi
Magnesite	Evaluation of Kumhar magnesite	Pakistan Mineral Development Corporation (PMDC)
Barite	Production of Barium chemicals	Ministry of Science and Natural Resources
Manganese	Production of Manganese carbonate	Imperial Chemical Industries (ICI)
Gravels	Studies on Rock/Gravel	High Tech Engg. Co. Ltd., Islamabad
	Stone/Cobbles reduction studies	Dongfan Electric Corporation (DEC)
	Size reduction studies on aggregates	CMTL, WAPDA, Lahore
	Bhasha Dam Gravels Project (Norite material)	CMTL, WAPDA, Lahore
	Bhasha Dam Gravels Project (Thore material)	CMTL, WAPDA, Lahore
	Bhasha Dam Gravels Project (Rock material)	CMTL, WAPDA, Lahore
	Studies on Stone Aggregates for Diamer Dam	CMTL, WAPDA, Lahore
	Bhasha Dam Gravels Project (Pozzolanic Material)	CMTL, WAPDA, Lahore
	Grinding of natural pozzolan	CMTL, WAPDA, Lahore
	Potential alkali reactivity of aggregates	CMTL, WAPDA, Lahore

MATERIALS AND METHODS

Metallic and non-metallic minerals were procured through sponsoring agencies from different areas of Pakistan. Minerals processing techniques, like, froth flotation, gravity concentration and magnetic separation, were applied for beneficiation. Laboratory scale tests were performed, using Denver Flotation Machine (Model: D-12, USA), Diagonal Deck Shaking Table (Deister, USA) and Permroll Magnetic Separator (Ore Sarter, USA).

The pilot plant flotation tests were carried out with Denver flotation cells, No. 8, 12 and 15, in three banks, six cells in each row for continuous operation. Three larger cells for batch testing and ball and rod mills for re-grinding are also provided in the circuit. The concentrates of sulphide minerals, like those of copper, lead, zinc, antimony, and non-sulphide minerals, like those of iron, tungsten, graphite and sulphur, etc., were prepared for further metallurgical processing or marketing. The capacity of the flotation continuous circuit is 0.5-2.5 tons per day (tpd).

Gravity concentration tests were conducted on Wilfley Tables (Local), Bartless Cross Belt Separator (Cornwall, UK) and Humphrey Spirals (Denver, USA). These equipments were used to separate high specific gravity minerals, like chromite, scheelite, magnetite, precious metals and heavy mineral sands from the associated low specific gravity gangue materials. The processing capacity of the gravity concentration tests was 0.5 tpd.

Magnetic separation experiments were performed with low (Master Magnets Ltd, UK) and high intensity (Eriez Magnetics, USA), dry and wet magnetic separators. These separators were used to separate the iron minerals, like magnetite, hematite, goethite, etc., at the processing capacity of 0.5- 2.5 tpd.

RESULTS AND DISCUSSION

Pakistan has significant potential of metallic minerals of copper, chromium, aluminum, iron, silver, gold, lead, antimony and zinc and non-metallic minerals, like graphite, sulphur, rock phosphate, rock salt, gypsum and limestone (Table 2). As for as industrial minerals are concerned there is a vast potential of dimensional stones, such as, marble, onyx, granite and other gemstones of export quality (Table 1).

Mineral processing technique applied to the specific ore and the final grade of the concentrate Kalabagh iron ore and Chiniot iron ore have been upgraded from 30-34% and 37% Fe content to 55% Fe and 63-65% Fe content, respectively, by froth flotation. As major mineral in Noukundi iron ore is magnetite which was upgraded even by low intensity magnetic separator to get a concentrate containing 66% Fe content. Saindak copper ore has also been

beneficiated by differential flotation process. The final chalcopyrite concentrate made is of 30% copper.

Besham lead-zinc ore containing sphalerite and galena as a major metallic mineral has been upgraded from 0.6% lead and 6-7% zinc to get lead and zinc concentrates containing more than 50% metal content in each one. Duddar lead-zinc ore has also been upgraded to get lead concentrate containing 65% Pb and zinc concentrate containing 55% Zn.

Antimony ore of Chitral areas containing stibnite as a valuable mineral has been upgraded by flotation technology. The various parameters of flotation, such as, feed size, pulp pH, pulp density, impeller speed, conditioning time, collecting and frothing agents, were optimized to obtain maximum grade and recovery of antimony. Chitral antimony ore could be beneficiated up to 62% Sb content with 95% recovery. Chromite ore from Muslim Bagh area of Baluchistan has been upgraded from 32% Cr₂O₃ to a concentrate containing 52% Cr₂O₃ by gravity concentration.

Tungsten ore of Chitral has been upgraded from 0.55% WO₃ to a concentrate containing 64% WO₃ by a combination of three techniques, i.e., gravity concentration, froth flotation and magnetic separation.

Non-metallic minerals, like, graphite and sulphur, have also been upgraded by froth flotation. Graphite has been upgraded from 10-18% C to a concentrate containing more than 98% graphitic carbon. Sulphur ore has been upgraded up to 99% purity. By high intensity magnetic separation, iron content in nepheline syenite, Koga, Swat, has been reduced to 0.06% iron.

Projects of national interest

A few commendable contributions of PCSIR for projects of national interest are shown in Table 4.

- Project on Beneficiation of Saindak Copper Ore, Balochistan
- Graphite Ore Processing Plant at Hattar, KPK
- Establishment of Nepheline Syenite Processing Plant at Peshawar, KPK.
- Evaluation of aggregate material for construction in Kalabagh Dam, Processing of Pyrex, sand admixture and gravels for Mangla Dam Raising Project, Ghazi-Barotha Power Project, and Bhasha Dam Project.
- Numerous successful feasibility studies have been prepared for clients of public and private sectors (WAPDA, SDA, BDA, PMDC, AKMIDC, NESPAK, FATA, PECO, ICI, PAK Steel, etc).

CONCLUSION

Pakistan is bestowed with numerous important mineral resources and, as a result, it is becoming a very promising area for mineral exploitation.

Mining, Exploration and Mineral Processing play a vital role in the development and uplifting of economy of any country. PCSIR has contributed a lot in mineral evaluation, beneficiation and ultimately its utilization.

The contribution of mineral sector to the GDP may be increased significantly by the commercial exploitation of Saindak and Reko Diq copper-gold deposits, Duddar lead-zinc ore deposits, Thar coal and gemstones.

There are vast opportunities for investment in mineral sector, which will be beneficial for the economy of the country as well as for the investors in the long run.

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