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Degana tungsten project—present plant practice and future scenario

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Abstract. Experiments/testworks were carried out on Degana tungsten ore by various R & D organizations to recover the strategic mineral wolframite. Process flowsheet developed after tests on the dump ore assaying 0·151% WO_3 is being tried on a very small scale till the 150 tpd pilot beneficiation plant is commissioned. Tungsten bearing granite samples were also found amenable to physical beneficiation. Hence 168 Mt granitic resources analysing 0·08% WO_3 has ushered a hope for large scale exploitation subject to detailed exploration. By-product recovery of lithium, caesium, rubidium and some other trace elements, if feasible, will be of added advantage.

Keywords. Degana tungsten; present practice; future scenario.

1. Introduction

Degana Tungsten Project in Nagaur District (Rajasthan) is located midway between Jaipur and Jodhpur, and about 82 km from Ajmer by road. Since discovery in 1912, it was sporadically exploited by various agencies with peak operation during the world wars. The Directorate of Mines and Geology (DMG), Rajasthan, started its operation after the Indo-China war in 1962. The operation continued subsequently by Rajasthan State Industrial and Mining Development Corporation (RSIMDC), Rajasthan State Mineral Development Corporation Ltd. (RSMDC) and Rajasthan State Tungsten Development Corporation Ltd. (RSTDC) by selective underground vein mining with concentration by manual sorting and panning. Due to low tenor and limited reserve, production from underground operation was limited and the beneficiation process was made exclusively manual. The activities were handed over to Hindustan Zinc Limited (HZL) w.e.f. 4.6.1991 with a view to large scale operation for strategic importance.

This paper deals with the activities of HZL towards tungsten development in Degana.

2. Geology/mineralogy/characteristics

Tungsten mineralization has been reported in: (1) granite vein lode, (2) eluvial deposit and (3) dissemination in phyllites.

Four decades of mining of wolframite was confined to underground mining on narrow 2 to 22 cm wide quartz wolframite veins in granite ground mass. Though beneficiation of eluvial and quartz vein type ore may be economically viable, known resources cannot sustain any large scale operation and underground exploitation will be cost prohibitive.

Though numerous thin quartz veins contain tungsten mineral (Bhatnagar 1991), their exploitation by underground method of mining is cost prohibitive. Exploration by RSTDC has indicated that the poorly mineralised granitic ground mass with their mineralised veins may make up the grade for open pit large scale exploitation. Four deep boreholes by the Mineral Development Board (MDB) and detailed surface

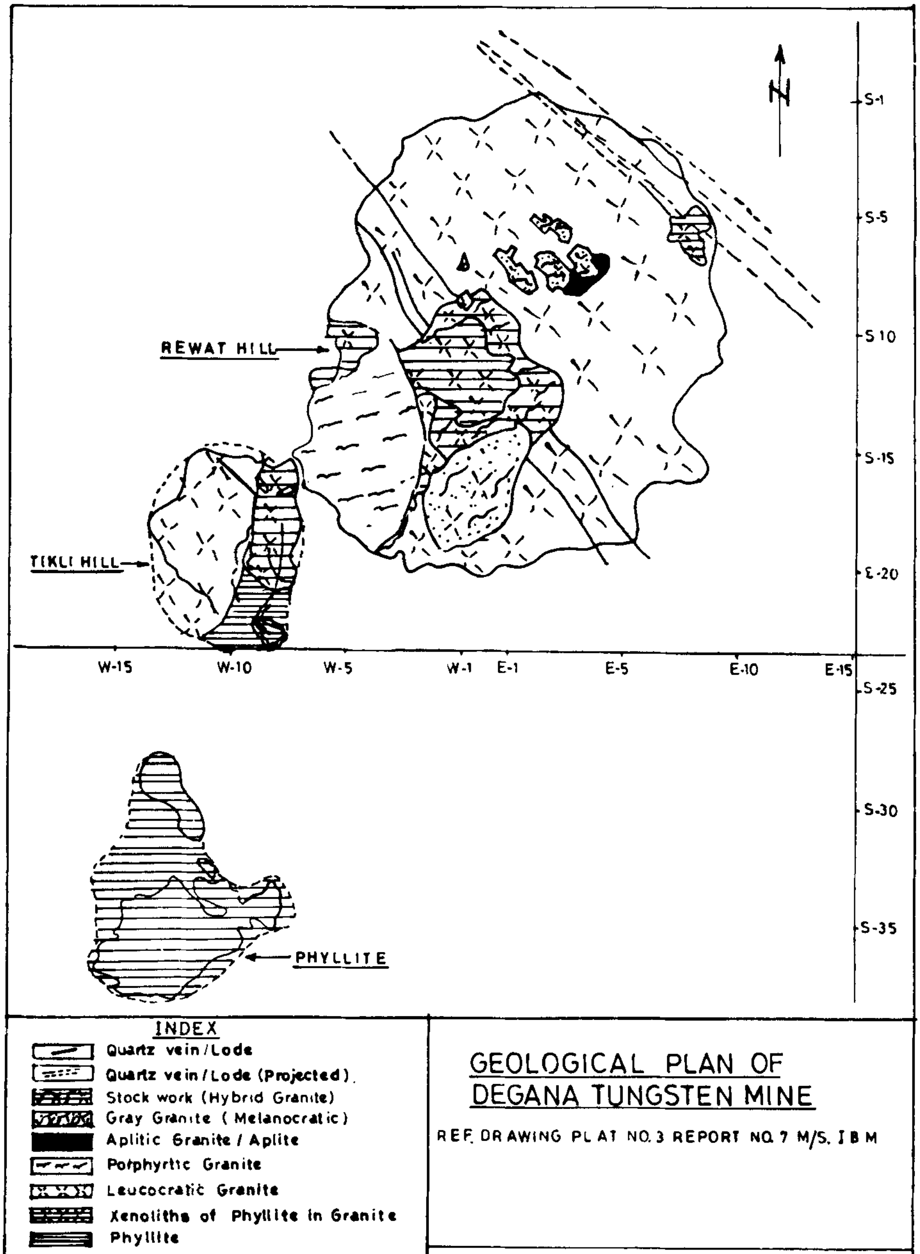

Figure 1.

mapping by the Indian Bureau of Mines (IBM), Nagpur have given further indication of potential ore deposits mineable by open cast. Orebody modelling conceptualized by HZL (Bhatnagar 1991) on stockwork (an admixture of all types of granites and a hybrid rock at the central part of the hill) (figure 1) suggest possibilities of 12–15 Mt of ore with about 0·13% WO_3. Accordingly exploration—(i) underground by HZL and (ii) surface by Mineral Exploration Corpn. Ltd. (MECL)—has been initiated. HZL has also initiated a pilot scale mining at 150 tpd on the same zone from hill top. Waste rocks rejected from vein mining operations and manual sorting in the past have been found to assay 0·151% WO_3 (IBM 1990) and amenable to beneficiation. Presently beneficiation is confined to these waste dumps only.

2.1 *Ore resources/reserves of various loads*

Ore resources/reserves of various loads are summarized in table 1 (Report of 1988) and mineralogical analysis of the ore is given in table 2. Wolframite is identified as the tungsten bearing mineral in the ore. A typical hand-picked pure wolframite sample analysed to have (BARC Report 1984):

SiO_2	. .	0·24%	MnO	. .	10·74%
WO_3	. .	72·63%	$(Nb/Ta)_2O_5$	. .	0·75%
FeO	. .	12·29%	TiO_2	. .	0·05%
Fe_2O_3	. .	1·89%	CaO	. .	0·42%

This corresponds to wolframite with Ferberite ($FeWO_4$) and Huebnerite ($MnWO_4$) ratio of 1:1.

Micro-indentation hardness of different grains vary between VHN_{100} 459–566 with average of VHN_{100} 515. Modes of occurrence with distinct grain sizes as observed are:

(a) Very coarse tabular crystals measuring up to 8 mm in size occurring in quartz veins.
(b) Coarse prismatic grains disseminated in granite, measuring in size between 150 and 500 μm.
(c) Smaller elongated prismatic crystals disseminated in aplite and granite. Rarely some of the crystals may be as long as 1 mm with a width of about 50 μm. Often aggregates of such crystals crowd quartz veins cutting across granite and aplite, the wolframite crystals in such cases generally project inwards from the border of veins.
(d) Aggregates of needle-shaped crystals, sometimes in the form of radiating rosette, disseminated in aplite veins.

Table 1. Reserve/resources (in million tonnes).

	Ore reserves (M.t.)	WO_3 %	Concentrate 65% WO_3 (t)	Source
A: Vein type:				
D, C, E & F Lodes	0·25	0·28	1088	IBM
Trench Lode	0·64	0·12	1158	RSTDC
Sub-total	0·90	0·17	2274	
B: Trench lode wide zone (granite)	6·17	0·13	12340	RSTDC
C: Gravel bed	3·35	0·04	2062	IBM/RSTDC
D: Stockwork (Phyllite)	2·70	0·025	1038	IBM/RSTDC
E: Granite resources	168·80	0·086	223335	RSTDC

Table 2. Mineralogical analysis of ore.

	Dump ore		Granite mass			Granite trench
	(1)*	(2)	(1)	(2)	(3)	
Quartz %	50	50	50–55	62·5	65·12	
Feldspar %	25	1–2	20–25			98·76
Mica %	5	35	10–15	23·4	25·14	
Topaz %	10	8–10	10	13·5	8·52	
Iron oxide %	5	3–5	Tr.	0·2	0·99	
Sulphides %						
– Pyrrhotite	1	3–5	1	0·2	0·09	1·09
– pyrite		1	< 1			
Others (Calcite/garnet/tourmaline/fluorite/amphibole/zircon/rutile/ilmenite)		Traces				
Other opaque minerals including wolframite	4	Traces		0·2	0·14	0·15
Other transparent minerals				0·2		
Sources #	IBM report (1992)	IBM report (1990)	IBM report (1987)	BARC report (1988)	NML report (1991)	

(Mica in granite is lithiferous (zinnwaldite)).
*Composite sample from dump ore are collected by HZL to pilot plant test by IBM (IBM/AJM/R1-173)
#Refer respective references.

(e) Short stubby crystals of variable size from about 50 μm to about 250 μm in quartz–topaz–muscovite veins cutting across granite. These are commonly associated with bismuthinite native bismuth composite grains.
(f) Very small nearly irregular crystals of size 10 to 50 μm in fine-grained aplite veins. The wolframite grains are interstitial to quartz and felspar grains.
(g) As very narrow skeletal crystals occurring as inclusions in coarse quartz and mica (probably zinnwaldite). These crystals have a width of 5–10 μm and length of upto 100 μm.

2.1a *Sulphide assemblage* (*BARC Report 1984*): This assemblage contains major pyrite and pyrrhotite, minor chalcopyrite, covellite, marcasite, sphalerite, bismuthinite, native bismuth and arsenopyrite and traces of molybdenite and stibnite. Native bismuth is commonly surrounded by bismuthinite and these two are often common associates of wolframite in quartz–topaz veins. Marcasite is finely intergrown with pyrite while chalcopyrite is often altered to covellite. Alteration of pyrite into a mixture of geothite and lepidocrocite (orthorhombic hydrous oxide of iron – $Fe_2O_3 \cdot H_2O$/a dimorphous form of geothite) is very common, and this iron oxide reports with wolframite during magnetic separation affecting the grade of the wolframite concentrate. Emulsoid intergrowth of chalcopyrite in sphalerite is common. Interestingly no paragentic association of pyrite-pyrrhotite sulphide minerals with wolframite is noticed, hence composite particles between wolframite and sulphide minerals are never

Table 3. Trace elements in Degana ore (in ppm) (from bore hole cores (Report of 1988)).

No.	Cu	Zn	Mo	Sn	W	Ge	Bi	Nb	La	Y	Yb	Sc	Zr	Mn	Ce	Li	Rb	Cs
1.	100	200	10	20	150	20	20	100	100	250	30	10	30	1000	500	700	700	250
2.	70	—	15	40	100	20	20	100	100	70	15	—	20	5000	500	3000	1000	350
3.	150	—	15	4	25	20	100	70	100	100	20	—	20	3000	500	1500	1000	400
4.	30	—	100	70	2000	20	30	70	100	200	30	—	20	4000	500	1700	1000	500
5.	300	—	700	50	200	30	300	100	150	100	20	15	20	3000	500	1700	1000	600
6.	500	3000	15	700	2000	20	70	50	150	50	10	—	20	2000	500	1200	700	400
7.	70	200	10	5	2500	20	30	40	—	20	15	15	20	5000	500	100	150	50
8.	20	200	10	10	1000	20	20	20	—	20	5	—	20	500	500	40	100	50
9.	5	1000	20	100	70	20	20	30	—	50	7	15	15	7500	500	1700	1200	600
10.	1000	200	50	100	—	30	300	200	100	300	—	20	20	1000	500	1500	1000	700
11.	1500	200	200	100	—	20	200	150	—	150	—	20	—	1500	—	2000	2000	700
12.	1000	300	100	70	—	20	150	150	—	200	—	20	20	1000	—	1500	1500	500
WO_3 %																		
13.	70	300	150	70	0·08	20	100	100	—	200	—	20	20	1500	—	2000	1500	500
14.	150	200	20	70	0·08	20	100	100	—	200	—	20	—	1000	—	1500	1500	500

Table 4. Trace elements in Degana ore (in ppm) (from surface exploration) (Sood 1985–88).

Sl. no.	Sample description	Li	Rb	Cs	W	P%	B(ppm)
		(ppm)					
1.	Por. granite	100	600	50	50	0·64	15
2.	Por. granite	125	500	50	50	0·85	15
3.	Por. granite	500	600	50	75	1·65	15
4.	Por. granite	275	400	50	75	0·97	15
5.	Grey granite & mica	800	600	50	350	2·20	10
6.	Por. granite & mica	700	700	50	150	2·10	10
7.	Grey granite & mica	900	800	50	900	1·28	15
8.	Granite	25	300	50	150	0·54	15
9.	Granite	200	500	50	200	0·92	15
10.	Granite & mica	225	600	50	75	0·73	15
11.	Grey granite with mica	0·14%	900	50	300	1·74	10
12.	Quartz-mica veins	0·24%	0·18%	50	75	1·50	10
13.	Granite with lot of mica & fluorite (?)	0·16%	0·19%	50	0·18%	1·67	10
14.	Mica of quartz-mica veins	0·20%	0·27%	50	800	1·20	10
15.	Granite with aplite pebble & mica	900	700	50	900	0·34	10
16.	Mica & quartz veins	0·53%	0·67%	90	0·14%	0·98	10
17.	Granite and mica	600	700	50	100	0·36	15
18.	-do-	300	600	50	175	0·64	15
19.	Granite	150	160	50	250	0·91	15
20.	Grey granite with quartz veins	0·22%	800	50	500	0·91	15
21.	Quartz mica veins	0·26%	0·50%	70	350	0·40	15
22.	Grey granite	0·26%	900	50	450	1·15	10
23.	Granite	400	400	50	300	1·24	10
24.	Por. granite with veins with mica	0·15%	800	50	150	0·95	10
25.	Quartz veins with mica	0·43%	0·91%	100	150	1·63	10
26.	Breccia zone	600	500	50	150	0·66	15
27.	Granite porphyry	150	400	50	50	0·36	15
28.	-do-	75	300	50	50	0·07	15
29.	Grey granite with plenty of mica	0·10%	700	50	50	0·97	40
30.	Granite	500	500	50	200	0·50	10
31.	Granite with thin mica veins	0·11%	800	50	150	1·85	10
32.	Granite	800	600	50	200	0·61	10
33.	Granite with quartz mica	0·10%	700	50	0·90%	0·76	10
34.	Breciated zone	600	600	50	300	0·67	10
35.	Grey granite & micaceous veins	0·12%	700	50	50	0·86	10
36.	Grey granite	800	600	50	350	0·95	10
37.	Quartz + mica veins	0·13%	0·22%	50	1·60	1·00	10
38.	Mica content only	0·12%	600	50	0·55	1·10	10
39.	Breccia zone (granite pebbles & micaceous matrix)	0·62%	0·89%	75	50	0·76	10
40.	Granite pebbles of breccia zone	0·12%	500	50	600	0·36	10
41.	Breccia zone	250	500	50	200	0·60	10
42.	Granite porphyry	0·10%	500	50	150	0·72	10
43.	Granite with dark material	125	250	50	50	0·13	10
44.	Granite with mica	600	700	50	50	0·43	10

(*Continued*)

Table 4. (*Continued*)

Sl. no.	Sample description	Li	Rb	Cs	W	P%	B(ppm)
		(ppm)					
45.	Granite porphyry	450	600	50	0·20%	0·58	10
46.	Granite porphyry	150	350	50	100	0·34	10
47.	Granite porphyry	250	500	50	75	0·56	10
48.	Grey granite	250	400	50	150	0·46	10
49.	Grey granite & mica	300	500	50	75	0·34	10
50.	Por. granite with mica	0·10%	700	50	50	1·02	10
51.	Mica quartz veins	700	600	50	75	1·07	10
52.	Grey granite + mica	0·16%	0·25%	80	75	1·80	10
53.	Grey granite + mica	0·14%	800	60	50	0·35	10

observed. The only sulphide association of wolframite is bismuthinite-native bismuth composites.

2.1b *Oxide minerals* (*BARC Report 1984*): Magnetite, ilmenite, hematite, geothite and lepidocrocite are the main oxide minerals. Traces of cassiterite are also noticed. Magnetite being strongly paramagnetic is readily separated from wolframite during magnetic separation. After pyrite, geothite and lepidocrocite are paramagnetic and report with wolframite during magnetic separation. At some places, the mineral has been altered insignificantly to scheelite ($CaWO_4$). Samples from (MDB) bore holes taken during exploration by RSTDC and analysed by the Bhabha Atomic Research Centre (BARC) showed presence of various trace elements in the Rewat granite hill (Degana) (Report of 1988) (table 3). Field investigation (Sood 1985–88) by the Geological Survey of India (GSI) for lithium in Gujarat and Rajasthan reported presence of trace elements in Degana ore (table 4).

2.2 *Liberation*

The trimodal distribution of wolframite grains occur as observed (IBM Report 1987; Rao *et al* 1987): (a) Coarse crystals of 2 to 8 mm size, (b) medium size crystals and aggregate crystals in 50 μm – 250 μm sizes and (c) very fine sized skeletal crystals of 10–25 μm which occurs as inclusions in quartz, mica and topaz.

In general, first two categories account for about 90% of WO_3 distribution. Occurrence of wolframite is found to be more disseminated in the trench lode granite. In general test work suggests 80% liberation of wolframite at $-400\,\mu$m (35 mesh) grinding for pre-concentrate.

3. Beneficiation at Degana

HZL has initiated installation of a 150 tpd pilot plant based on IBM flowsheets on dump ore. The beneficiation by manual panning ceased in preference to mechanised system just prior to takeover by HZL. Meanwhile in the interim period, some equipments have been mobilised from other units for continued testwork on grinding, tabling as well as familiarisation of the equipments/process to the staff to be deployed.

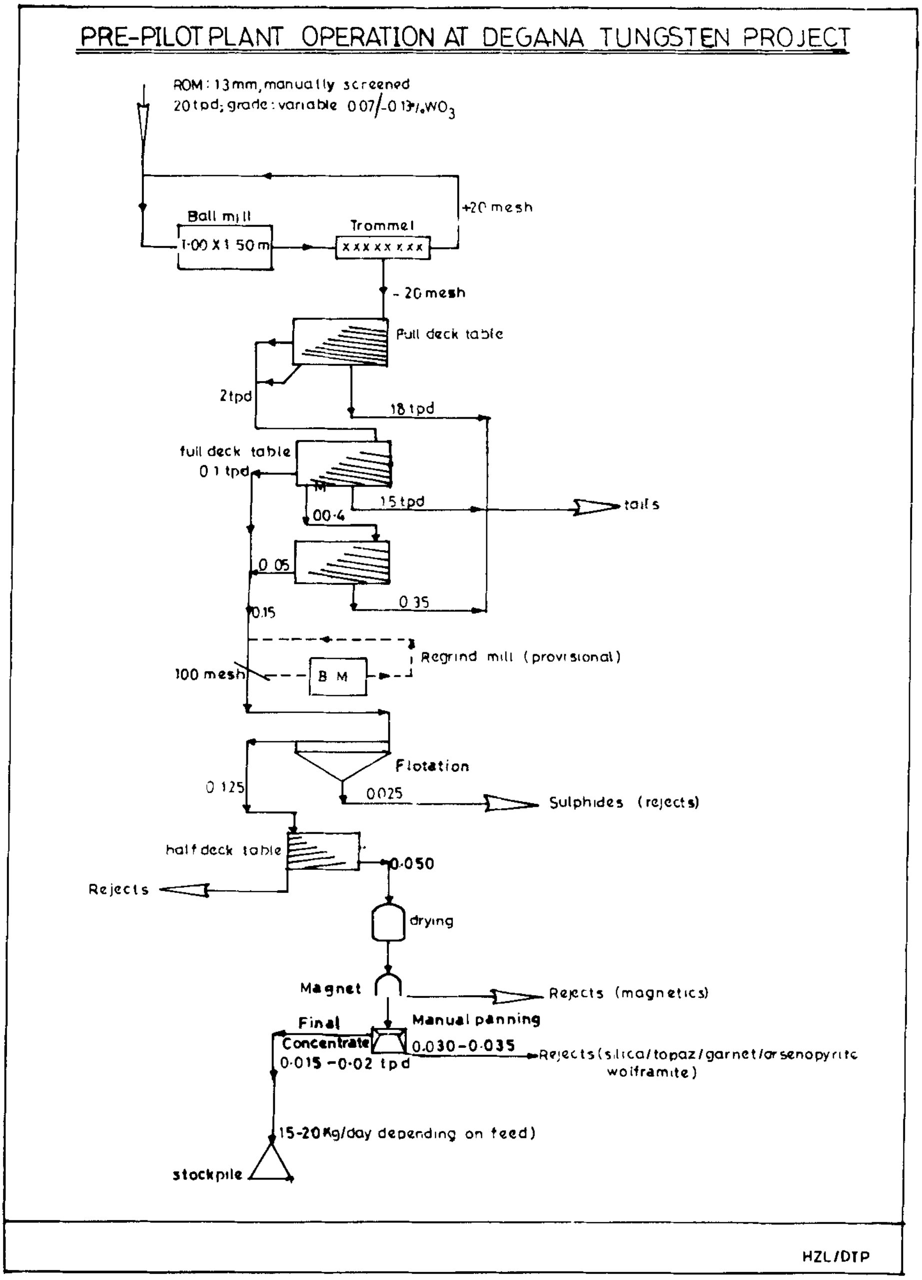

Figure 2.

3.1 *Present beneficiation practice*

Against sp. gr. of 2·7–3·3 for gangue minerals, the sp. gr. of 7·3 for wolframite suggests wet gravity separation as the most appropriate one. Brittleness of wolframite against hard quartz/granite dictates coarse narrow range grinding such as rod milling for optimal mineral liberation without significant losses by overgrinding. Eighty per cent liberation of wolframite can be achieved at $-400\,\mu$ (35 mesh) grinding. These basic principles are adopted on the processes adapted for obtaining preconcentrate/rough concentrate.

Manually screened -13 mm dump ore is fed to one 1·0 m dia × 1·5 m Sala Rubber Roller (SRR) ball mill in close circuit with a trommel of 0·8 mm (20#) opening (figure 2). The pre-concentrate from standard concentrating table (1·8 m × 4·5 m) goes for regrinding at $150\,\mu$ (100#). The material after conditioning with xanthate and frother (MIBK) is fed to one self-aerated flotation cell. The sulphides (froth) are continuously removed till their generation seizes to appear. The tails from the flotation go to table (half size) concentration. The clean concentrate now obtained is dried and further upgraded from highly magnetics with the help of permanent bar-magnet. Non-magnetics (silica, topaz, garnet etc.) are moved by manual panning.

The mineralogical and petrological studies (Roy 1991) on typical samples shows that: (a) in sulphide floats (rejects), liberated mineral accounts for around 97% (pyrite over 88%) and rest being pyrrhotite, chalcopyrite, wolframite and other gangue minerals and (b) in magnetic rejects, liberated mineral accounts for 95%, ilmenite being the principal constituent accounts for about 80%. Others are wolframite, pyrite, pyrrhotite, chalcopyrite, molybdenite, cassiterite, etc.

The product is stockpiled only after analytical confirmation (DMRL Report 1987) to meet the grade, e.g. $WO_3 - > 65\%$; Mo $- < 0{\cdot}1\%$; SiO_2/Bi/S/F/(Ca + SiO_2) each $- < 1{\cdot}0\%$; As/Sn/P each $- < 0{\cdot}05\%$; Cu $- < 0{\cdot}5\%$; Ca $- < 0{\cdot}2\%$.

3.2 *Observation*

(i) Brackish water as available at site does not affect physical beneficiation.
(ii) Significant losses are reported due to overgrinding in the ball mill. Under consultation with the manufacturer Trelleborg/SALA, these SRR ball mills got converted into SRR rod mills to get the desired grinding. These SRR rod mills are to be used in regrinding circuit of the 150 tpd plant.
(iii) Due to absence of analytical facilities at site at present, mass balance, grade etc. cannot be ascertained. Hence tails/slimes are stored for reprocessing in future. Analytical laboratory facilities are now incorporated in the 150 tpd plant.
(iv) Regrinding was very limited and was carried out by roll crusher only. This is due to fairly liberated grains in finer fraction of the dump. Detailed sampling (IBM Report 1990) showed about 56% of WO_3 distributed in -13 mm fraction of the dump which constituted about 34% of the dump.
(v) Present drying process (sun drier/hot plate) will not be adequate for 150 tpd plant where dry high intensity magnetic separator will be adopted.

3.3 *Operations in the plant*

One 150 tpd plant under construction will treat primarily the dump ore to produce concentrates of the desired grade and generate design data for commercial plant while optimizing recovery. Based on the flowsheet (figure 3) suggested by IBM on bench scale test (IBM/AJM/RI-127), the process flowsheet as developed by HZL is shown in figure 4. The operations suggested in the plant will be:

(A) Crushing–screening module of existing SALA CARAVAN Mill in HZL will operate 2 shift/day basis. The settings of jaw crusher and hydrocone crusher are to be adjusted for − 15 mm screened product against original − 6 mm product for ball mill feed.

(B) In the milling circuit, operating 3 shift/day basis, one rod mill (1·8 m dia × 3·3 m) will grind the ore to − 417 μm (− 35 mesh) in close circuit. The rod mill discharge

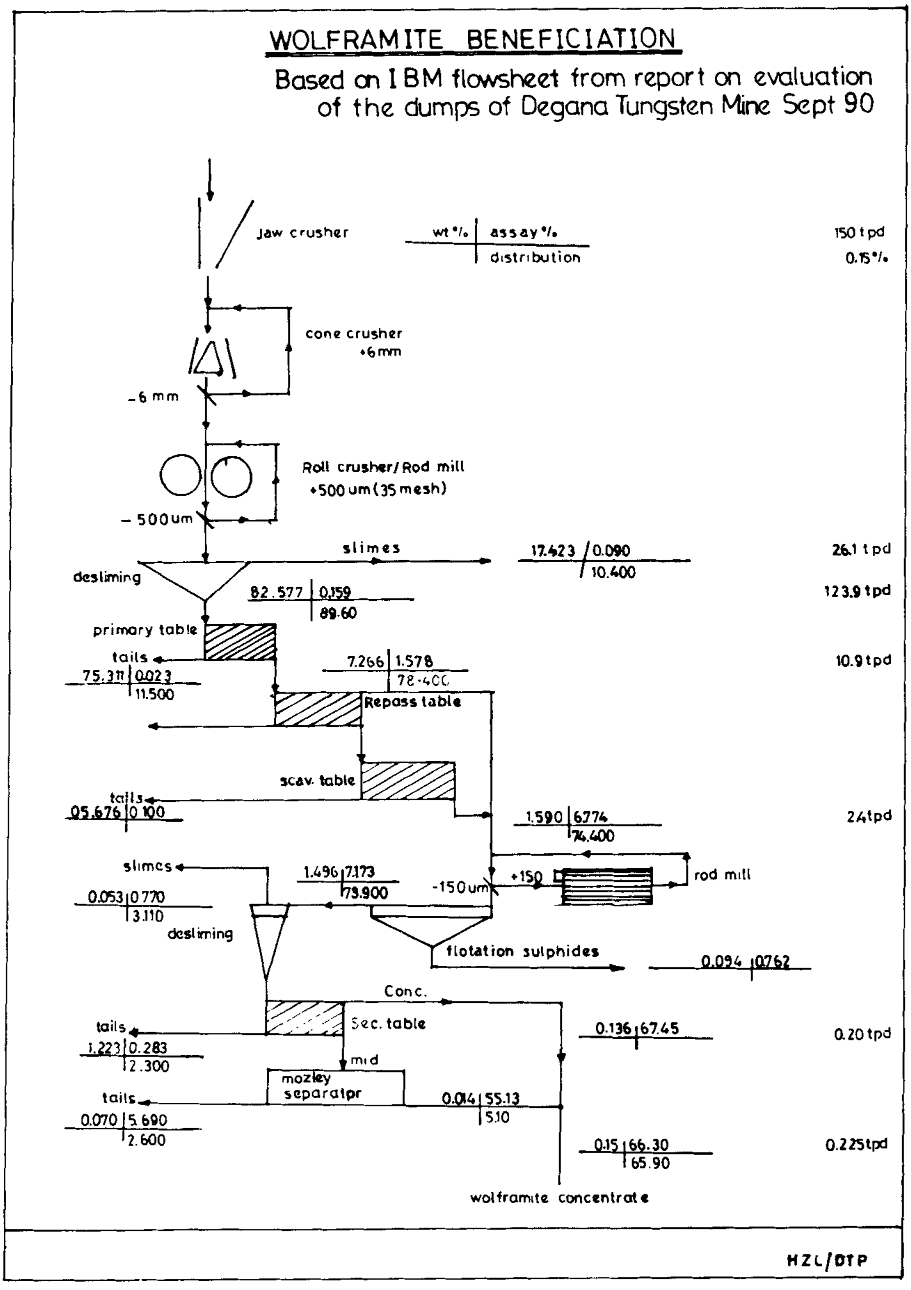

Figure 3.

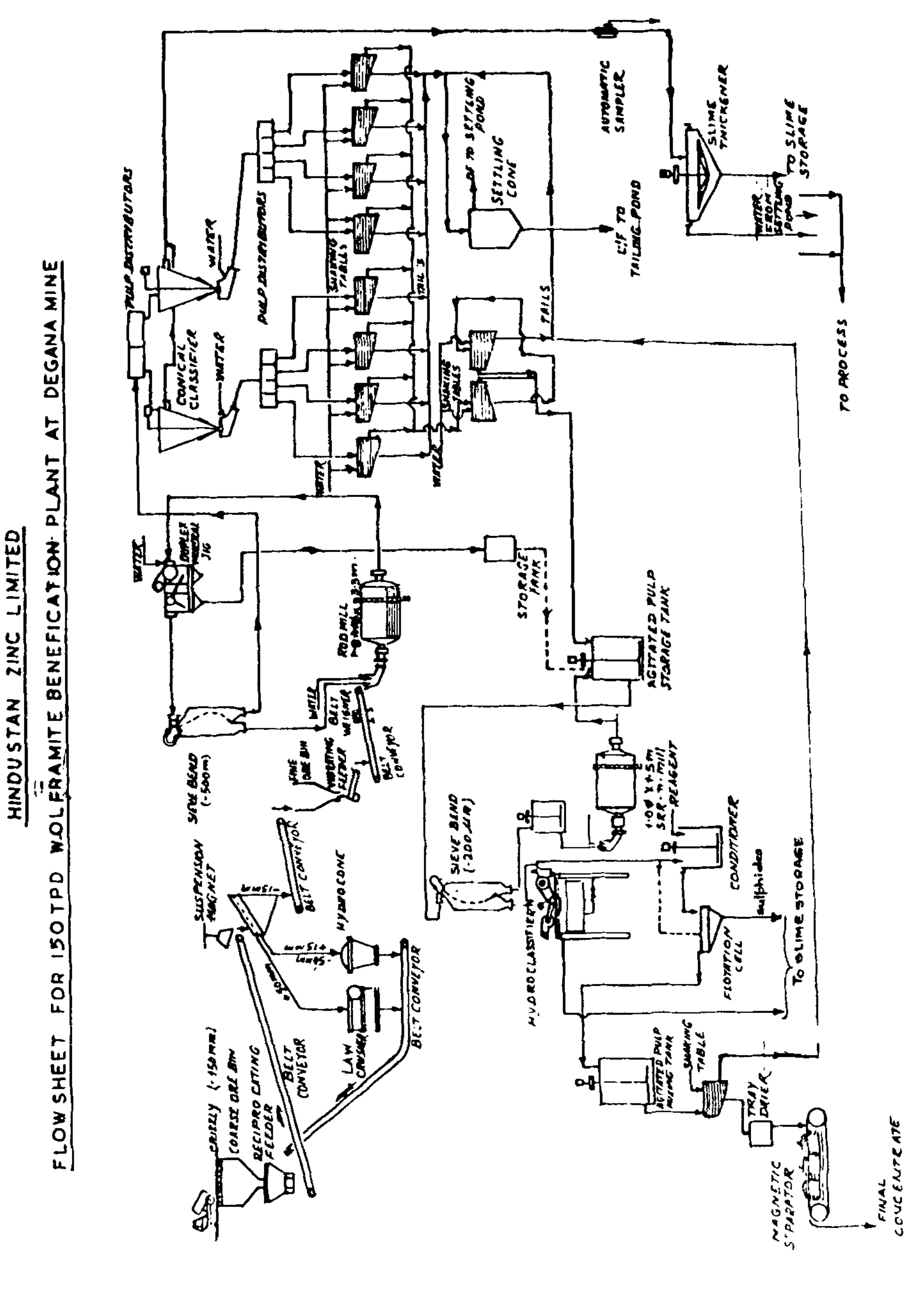
HINDUSTAN ZINC LIMITED
FLOW SHEET FOR 150TPD WOLFRAMITE BENEFICATION PLANT AT DEGANA MINE
GRIZZLY (-150 mm)
COARSE ORE BIN
RECIPROCATING FEEDER
BELT CONVEYOR
JAW CRUSHER
BELT CONVEYOR
SUSPENSION MAGNET
HYDROCONE
BELT CONVEYOR
SIEVE BEND (-500m)
FINE ORE BIN
VIBRATING FEEDER
BELT WEIGHER
BELT CONVEYOR
WATER
ROD MILL
DUPLEX MINERAL JIG
PULP DISTRIBUTORS
CONICAL CLASSIFIER
WATER
PULP DISTRIBUTORS
SHAKING TABLES
WATER
SHAKING TABLES
TAILS
STORAGE TANK
AGITATED PULP STORAGE TANK
SETTLING CONE
U/F TO TAILING POND
O/F TO SETTLING POND
AUTOMATIC SAMPLER
SLIME THICKENER
TO SLIME STORAGE
WATER FROM SETTLING POND
TO PROCESS
SIEVE BEND (-200 μm)
REAGENT
CONDITIONER
HYDROCLASSIFIER
FLOTATION CELL
Sulphides
TO SLIME STORAGE
AGITATED PULP MIXING TANK
SHAKING TABLE
TRAY DRIER
MAGNETIC SEPARATOR
FINAL CONCENTRATE

Figure 4.

Table 5. Comparison of IBM test results.

	Low grade composite dump sample		
	Present work IBM/AJM/RI-173		Earlier work IBM/AJM/RI-127
Items			
1. Sample drawn by	HZL Degana		Tech. Cons. of IBM. Nagpur
2. Feed assay	0·134% WO_3		0·151% WO_3
3. Mineralogy (approx.)	Quartz	50%	50%
	Mica	5%	35%
	Topaz	10%	8–10%
	Iron oxide	5%	3–5%
	Feldspar	25%	1–2%
4. Wolframite grains size	0·02 to 0·2 mm		0·18 to 0·54 mm
5. Beneficiation process attempted	Identical		Identical
6. Final concentrate produced	Wt.%	0·120	0·150
	Assay (%WO_3)	66·51	66·30
	Dist (%WO_3)	59·8	65·9
7. Low grade conc. (Mozley tails)	WO_3%	0·273	1·223
	Assay % WO_3	3·520	0·283
	Dis. (%WO_3)	7·200	2·30

will pass through a mineral jig for recovery of coarse liberated wolframite, before screening in a sieve bend. Sieve bend has been selected in preference to hydrocyclone, to screen heavy undersize wolframite particles to avoid recirculation and losses in regrinding. Underflow goes to cone classifier for removal of slime (about 15% by weight) which will be stockpiled to treat by a different route under development. Classifier underflow goes for pre-concentration by 8 nos. standard concentrating table and gets cleaned by 2 nos. concentrating table. The clean table-concentrate and jig underflow go to agitated storage tank while tails go to dam.

(C) In the final upgrading circuit, operating on one shift basis, the pre-concentrate will be reground to 208 μm (65 mesh)/150 μm (100 mesh) in close circuit with a sieve bend. While the fines/slime from hydroclassifier is removed/stored, the underflow goes to sulphide separation by froth flotation; the flotation cell underflow/tails goes to table concentration. The concentrate, after drying in tray drier system, will be subjected to high intensity magnetic separator (HIMS) for separation of wolframite.

Water is scarce in Rajasthan, therefore, in the above process, water reclamation has been made from tailing, slime thickner etc. Once the system stabilizes, recovery of wolframite and byproducts (lithia–mica and trace elements) will be attempted. In continuation of earlier testwork (IBM/AJM/RI-173) on bench scale test, IBM has recently re-confirmed (IBM/AJM/RI-173) about recovery and product grade on the pilot plant operation of the dump ore conducted at Ajmer and the pre-pilot plant operation at Degana. A comparison is shown in table 5.

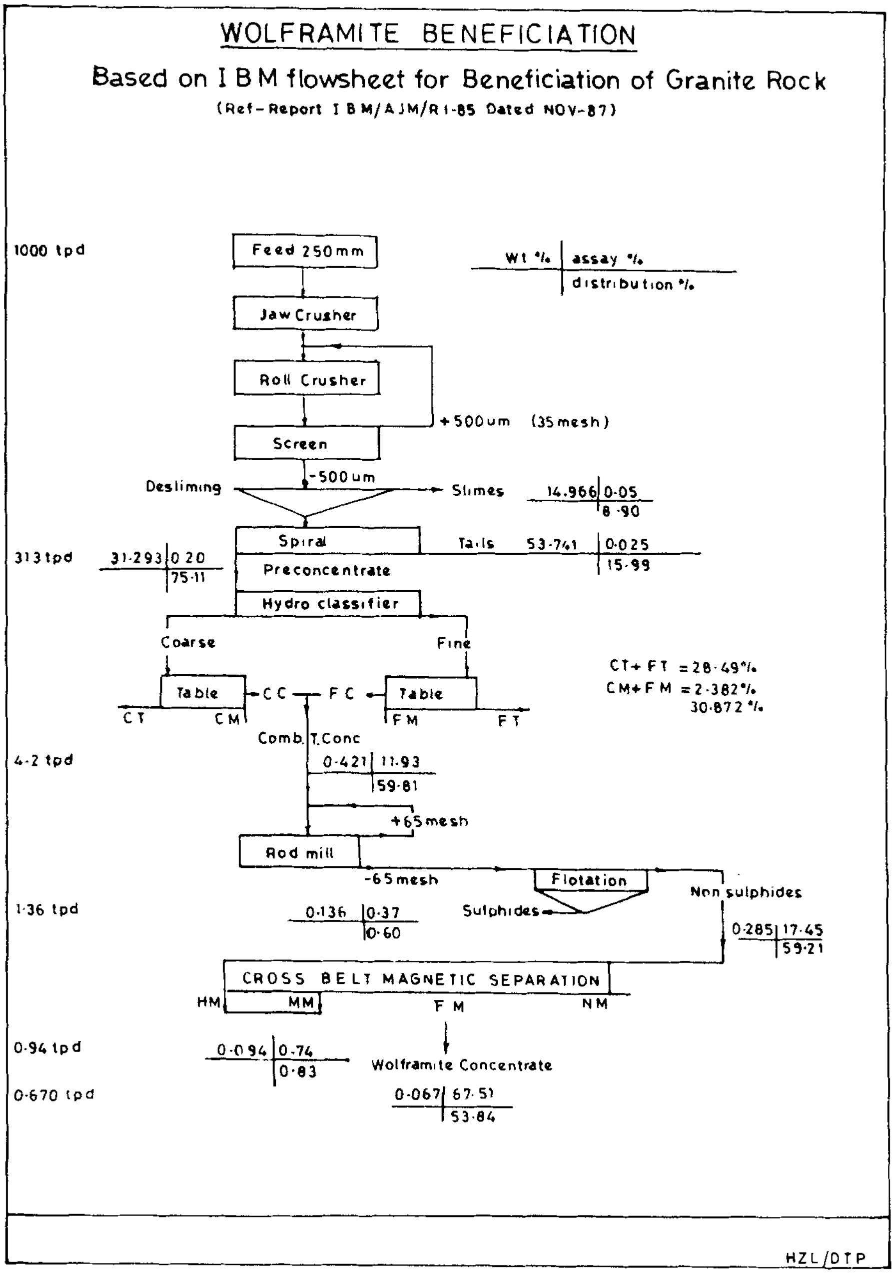

Figure 5.

4. Future scenario

4.1 *IBM*

IBM has also conducted beneficiation test (IBM/AJM/RI-85) on granitic ore from Degana and a flowsheet (figure 5), only for recovery of wolframite, has been suggested.

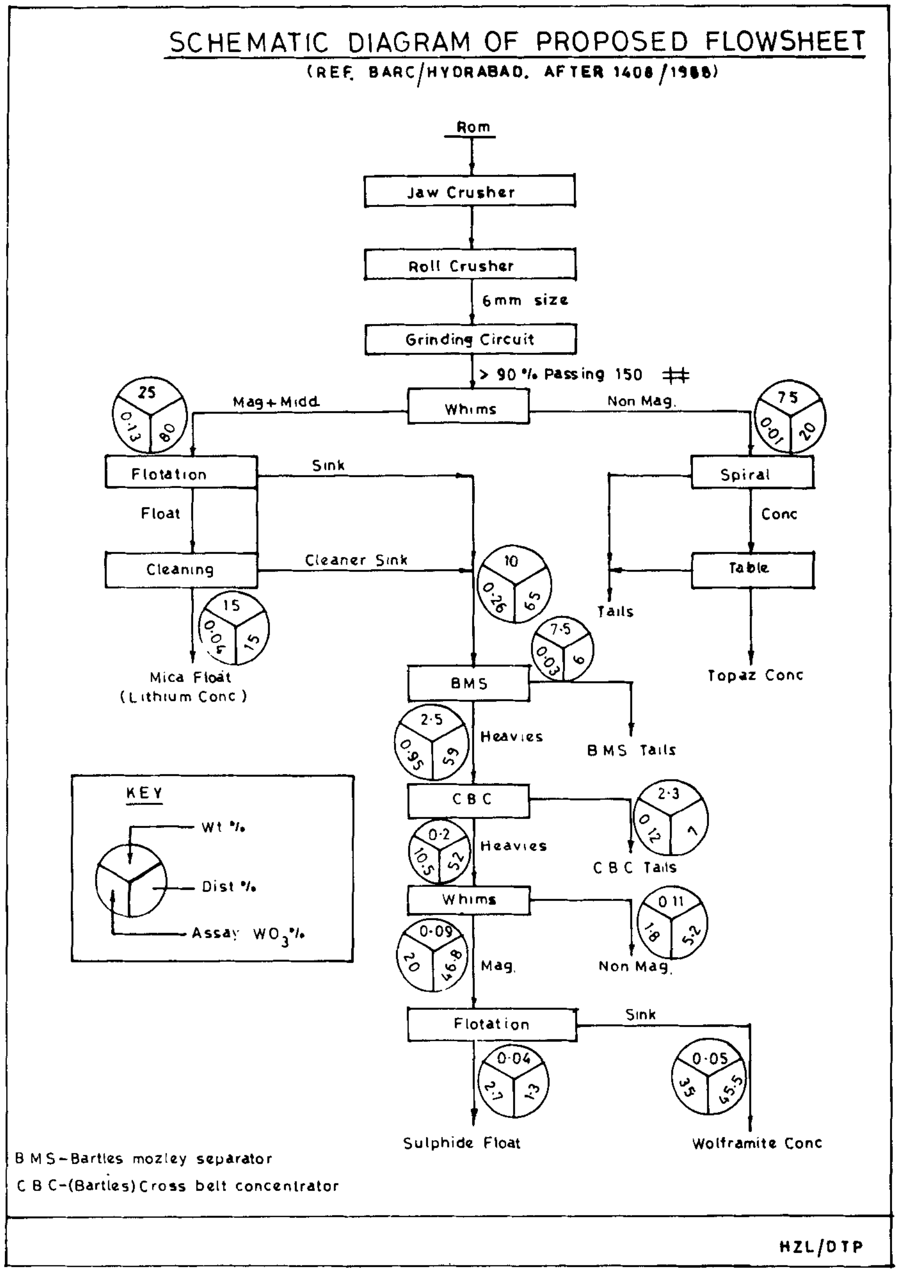

Figure 6.

The flowsheet, which slightly differs from that for dump ore, incorporates hydrocyclone for desliming and spiral for ore-concentration prior to tabling.

They have also been engaged in technical consultancy for: (a) stabilizing the process in 150 tpd plant, (b) related test work towards identification of lithium and other associated trace elements and possible recovery as byproducts and (c) augmentation of the plant to 300 tpd for treating dump/granitic ore with minimum investment on major equipments in the existing plant.

4.2 *BARC*

BARC has also carried out laboratory investigations on recovery of wolframite from low grade granite type ore from Degana (Rao *et al* 1987; BARC Report 1988). This test work as well as the flowsheet developed (figure 6) is unique and differs from earlier investigations on tungsten beneficiation by BARC and other agencies. The process flowsheet considers tungsten recovery with byproduct recovery of lithium and topaz. Better viability has been suggested at 0·1% WO_3 of the granite ore. The granite sample analysed 0·23% Li_2O and an average of 0·15% Li_2O has been suggested for entire granite mass. Granite samples from various parts analysed to contain Li_2O varying from 0·111% to 0·284% with highest incidence at 1·4% in mica vein. The ore is ground to $-100\,\mu m$ (-150 mesh) and then is subjected to wet high intensity magnetic separation (WHIMS) at 15 k·Gauss when wolframite and mica rich magnetics separate out, topaz is recovered from nonmagnetic tails by spiral followed by tabling. Mica (Zinnwaldite, lithium rich) is separated by froth flotation followed by cleaning with magnetic separator to give 1·0 – 1·1% Li_2O with recovery at 50–60%. For example a 1000 tpd plant may yield a recoverable lithia in concentrate at about 450 tonnes annually. Magnetic susceptibility of mica concentrate was also reported to vary with Li_2O content. The tails go for wolframite concentration by Bartles-Mozley-Separator (BMS), Bartles Cross Belt Concentrator (CBC), (WHIMS) and lastly by reverse flotation. Since BMS and CBC are effective in recovering heavy particles down to $10\,\mu m$, the loss of fines are less. During this test work on granite with very low tungsten values (0·04% WO_3), it was observed that about 21% wolframite remains unliberated even at the grind size of -100 microns. It is estimated that 8% is interlocked with quartz/granite, 4% is interlocked with mica and 9% is interlocked with topaz. BARC has expressed confidence in developing processing scheme for extraction of lithium from lithia mica and also for conversion of topaz into mullite. HZL is considering to take up these as R&D activity. In a recent communication BARC have indicated the mica sample from Degana to contain 0·53% Rb and 0·27% Cs. This information has given more importance to detailed exploration and by-product recovery from Degana ore.

4.3 *National Metallurgical Laboratory, Jamshedpur*

NML, a premier national scientific organization in metallurgical field, has been entrusted as the nodal agency by Defence Research and Development Organization (DRDO) for evaluation of process flowsheets along with the development of beneficiation technology for all indigenous tungsten resources (PMCTD). It is envisaged that the flowsheet evolved by NML would be transferred to HZL for large scale production (PMCTD 1990).

Testwork have been carried out on various types of ore, preconcentrate, jig concentrate etc. NML in general suggests physical beneficiation (NML Report 1991; PMCTD) to 10–30% WO_3 followed by chemical beneficiation to APT (ammonium paratungstate: $5(NH_4)_2O{\cdot}12\,WO_3$) to be most promising economic route for the low tenor tungsten bearing granite.

The trench load granite in the northern sector is of difficult metallurgical grade. The test work on this granite by NML yielded best value at -100μ grinding, vanning followed by magnetic separation, a concentrate assaying 5·86% WO_3 with weight recovery of 0·3% and distribution at 37·7%.

HZL has sent 10 tonnes of granite sample from Rewat hill top (proposed zone for mining) to NML and 1·0 tonne to IBM. IBM has recently indicated following results (IBM/AJM/R1-157) by gravity concentration:

Feed grade: Granite ore with 0·08% WO_3

Percentage	Final concentrate	Low grade concentrate
Grade, WO_3	65·65	40·0
Weight recovery	0·07	0·018
WO_3 distribution	56·10	8·80

Another lot of freshly blasted granitic ore from underground, about 50 m below surface, crushed to -13 mm was sent to NML. It assayed at 0·2% WO_3. Complete report on these test works along with physical and chemical beneficiation is awaited.

4.4 *Tata Research Development and Design Centre, Pune*

This organization had carried out studies on recovery of tungsten values from slimes generated at Degana and those produced during the test work conducted by BARC on the granite ore assaying 0·04–0·05% WO_3. About 50–60% of WO_3 is lost in tailing (Tata Research Development and Design Centre Report 1991) and any method to recover some from tailing will be value added operation. The test work involving flotation of slimes has given encouraging results. These findings need to be further confirmed by conducting testwork on the slimes generated during the proposed 150 tpd plant.

5. Conclusion

If the exploration initiated is successful, the quality and quantity of the ore will significantly improve rendering large scale operation economically viable. The selected process in some combination of processes described may achieve high recovery to be split into a high grade wolframite concentrate as per the Defence Metallurgical Research Laboratory (DMRL) specification (DMRL Report 1987) and a significant quantity of middling (low grade) for APT process.

The thrust has been given by HZL on R&D activities for identifying and recovery of trace elements. The viability is expected to improve significantly with recovery of trace elements like lithium, yttrium, caesium, rubidium, etc.

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