XA9745150

URANIUM MINING AND PRODUCTION OF CONCENTRATES IN INDIA

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Abstract

In order to meet the uranium requirements for the atomic power programme of the country, uranium deposits were explored, mined and concentrates were produced indigenously. The geology of the areas, mode of entries and the various extraction methods deployed in different mines with their constraints are described. The various equipments used in mining and processing activities are elaborated. The flow sheets for processing the uranium ore and that of the effluent treatment plant are given in detail. The future plans of the company for undertaking the new projects to meet the demand of uranium requirement for the increasing nuclear power programme are given.

1. INTRODUCTION

With the formulation of the Atomic Power Programme in the context of power requirements of the country with regard to the availability of various types of energy resources, the importance of uranium assumed a considerable significance. During the first phase of the nuclear power programme, natural uranium was selected as the fuel. Thus, there was an imperative need to locate the uranium deposits in the country so that the requirement of the strategic mineral could be met indigenously.

The Atomic Minerals Division under the Department of Atomic Energy undertakes the exploration programme of various radioactive minerals by various geophysical and geochemical methods. In the promising areas, they also undertake exploratory mining. Once a deposit of sufficient tonnage and grade is proved, the deposit is handed over to Uranium Corporation of India Ltd. (UCIL) for commercial mining and production of uranium concentrates.

Presently the Corporation is having three deposits under commercial exploitation, i.e. Jaduguda, Bhatin and Narwapahar. All these deposits are in the Singhbhum Trust Belt in Bihar State in Eastern India.

The occurrence of uranium-bearing minerals in Singhbhum Thrust Belt has been known since 1937. In 1950 a team of geologists was appointed with the specific task of closely examining the 160 km long Singhbhum Copper Belt to locate the presence of uranium mineralization and other radioactive minerals. The team located several anomalous radioactive areas in Singhbhum Thrust Belt of which Jaduguda, Bhatin, Narwapahar, Turamdih and Bagjata were a few. During the leastfour decades, some of these mineral occurrences have become major uranium producing mines.

UCIL was established on 16 October 1967 as a Public Sector Enterprise with its registered office in Jaduguda with the specific objective of mining and processing of uranium ore.

UCIL has a number of operating units, among them there are three mines at Jaduguda, Bhatin and Narwapahar, three uranium recovery plants to recover uranium from copper tailings, a by-product recovery plant to recover copper and molybdenum sulphide concentrates and a magnetite plant to recover magnetite present in the uranium ore.

2. JADUGUDA MINE

2.1. Geology

The original geology of Singhbhum Thrust Belt (STB) has been the subject matte of intense study for many geologists for the past 50 years. The pioneering work in this region was done by Dr. Dunn and Dr. Dey. They divided the entire area into two broad divisions, north and south of the thrust belt. On the northern side of the thrust belt, there are rocks of Chaibasa and Iton Ore series while on the southern side the rocks of Iron Ore and Dhanjori stages and Singhbhum granites have been described. The thrust zone is developed between Chaibasa and Iron Ore stage rocks.

In the Jaduguda Mine, there are two orebodies, one the Footwall Lode (FWL) and the other is called Hangingwall Lode (HWL), both are separated from each other by a distance of about 60–100 m. The FWL extends over a length of about 800 m in SE and NW direction. The HWL has only 200–300 m of length and is confined to the eastern part of the deposit only. The average width of he lodes is about 3–4 m, though at certain places in the mine the lodes are as thick as 20–25 m. The FWL is better mineralized and contains copper, nickel and molybdenum sulphide minerals in addition to uranium. Both of these lodes have an average dip of about 40–45°. The orebody in Jaduguda has been prospected up to a depth of about 800 m below ground level, and it is expected that it would continue further in depth.

2.2. Mode of entry

The main entry to the mine is through a circular concrete lined shaft of 5 m diameter. The shaft has been sunk to a depth of 640 m in two stages: one from surface to 315 m and the second from 315 to 640 m. The shaft is equipped with two tower mounted multi-rope friction winders. The Cage winder is a 280 KW D.C. winder, and the skip winder is a 360 KW AC winder. The cage and skip winders are balanced by counter-weights and tail ropes. A double deck cage is used for lowering and hoisting of men and material and for hoisting waste rock. The skip with a payload of 5 tonnes is used for hoisting ore from 605 m level. The shaft is also equipped with pipe columns for compressed air, water mains, drilling and drinking water and power and control cables.

2.3. Mine layout

The main levels are at vertical interval of 65 m, the last level being at 555 m.

During exploratory mining, 5 adits are driven to meet the lodes. The ground level (0 m.l.) and -30 m.l. were developed and connected by raises and winzes. Subsequently, levels at 50 m, 100 m and 165 m depth were developed from the principal winzes sunk from 0 m.l. and later connected to shaft and ore-pass. Development of lower levels at 230 m, 295 m, 370 m, 434 m , 495 m and 555 m depth was done from the shaft. Crushing and loading stations are located at 580 m.l. and 605 m.l. respectively.

2.4. Mine development

The mine development work involves development of winzes, raises, cross-cuts and drifts in ore and waste rock.

2.4.1. Drives

Drives in the main levels are generally 2.4 m $\times$ 2.5 m in size with a 610 mm gauge track fitted in them. Drilling is done by Jack hammer drills with Burn cut pattern. The blasted rock is cleared by pneumatic loaders (EIMCO 12 B/21) loading into side tipping tubs. These tubs are hauled by diesel locomotive for either dumping in grizzley (ore), or hoisting to surface by the cage. The ventilation in the drives and cross-cuts is provided by auxiliary fans with metal and flexible ducts.

2.4.2. Raising

Raising is a key job in the development programme of any mine. Raises are developed from bottom to top level for ventilation, ladder-ways, ore transfer etc. To bring the mine to its targeted production and efficiency, speedy raising methods are necessary. Constant efforts are made to improve the raising methods with regard to safety, speed and economy. There are three ways of raising. They are:

(i) *Open raising*

This is the simplest and most commonly used method where persons on a platform of timber planks, supported on standard rail clamps drill the face. Before each round is blasted the platform is dismantled. Access to the face is made by rope ladders etc. This method is well suited for short raises of 6–15 m and inclinations of 40°–60°.

(ii) *Compartment raising*

In this system a timber partition separates the raises in two compartments, major cross section is used by broken rock and the rest for placing of pipes and ladder for access to the face. At times the broken rock reserves as platform for performing drilling etc. The ladder-way compartment is covered with wooden planks at the time of blasting.

(iii) *Alimak raising*

Raising by Alimak Raise Climber is essentially a self powered rugged manoeuvrable platform for a limited height and angle, moving on a rail guide anchored to the roof of the raise to carry men and material. The guides are anchored to the walls by retractable expansion bolts.

Jaduguda was the first mine in India to use Alimak Raise Climbers in 1967. The ore-pass raises and ventilation raises in the I- stage and subsequently raises in II-stage shaft deepening work were all done by Alimak Raise Climber.

2.5. Stoping

The method of stoping deployed in a mine depends on the nature, shape and size of the orebody and strength of the wall rocks.

In Jaduguda the "Cut & Fill" stoping method is applied, using deslimed mill tailings as backfill. The broken ore is mechanically handled using Load Haul Dump (LHD) machines. The broken ore is transferred to the foot-wall ore-transfer passes. At the bottom of the ore-pass, the ore is loaded into 3.5 tonne capacity Granby Cars. These mine cars are hauled by diesel locomotives for automatic dumping into the main ore-pass system. The main tramming drive in each level is developed on the foot-wall side of the ore drive. By this way no ore is left in pillars. In the "Cut & Fill" method, the percentage of recovery of ore is approximately 80% and is ideally suited for the Jaduguda Mine.

Earlier the horizontal holes were drilled with the help of jack-legs standing on the muck pile and the broken ore was handled by LHD. This was changed to drilling uppers. Lately the drilling operation has been mechanized by drilling horizontal holes by hydraulic drifters and the broken ore is handled by 1 cu.yd. LHD. The filling in this case is done close to the back leaving a gap of about 1 metre. This has improved the productivity tremendously. Until the 3rd stage is ready, a decline is also being constructed to the two levels below 555 m.l.

2.6. Backfilling

The deslimed mill tailings are transported hydraulically to underground through 3" diameter (75 mm) diamond drill boreholes drilled from surface to underground. There are three boreholes located in the west, central and eastern parts of the deposit, and are connected to 100 m.l., 165 m.l. and 230 m.l. drives. The tailings are tapped from the bottom of these boreholes, and are conveyed to different stopes through 90 m High Density Polyethelene (HDPE) pipes. Boreholes are also drilled from level to level to transport the tailings for deeper working levels.

2.7. III-stage of shaft sinking

An auxiliary shaft is under construction for mining ore lying below 555 m.l. to a depth of 900 m. The location of this shaft is about 580 m north of the main shaft. The winders will be installed at 495 m.l., and between 555 m.l. and 495 m.l. the excavation is 7.5 , diameter, similar to the tower arrangement above ground level in the first stage. The ore bin and ore transfer pockets are excavated in the rock. The new levels at 620, 685, 750, 815 and 880 m.l. will be opened up. The crushing station and skip loading station would be opened at 835 and 865 metres depth respectively.

Drilling in the shaft is done in two halves, the benches differ in elevation by about a meter, thus giving two free faces for blasting, to restrict the throw and avoid damage to sollars, ladders and pipes. Spiral pattern of drilling is followed. For mucking a cactus grab of 0.6 m^3 capacity in conjunction with two 1.5 m^3 capacity buckets is used.

For ventilation two fans of 15 HP each in series are installed near the shaft top with metal ductings of 50 cm in diameter and flexible terelene ductings are used below the metal ductings and are extended to about 20 m from the shaft bottom. The shaft lining will be done by slipform method. After lining, the shaft will be equipped with buntons, rails, rope guides, pipe columns, power and control cables, etc. The cage and its counter weight will then be installed.

2.8. Ventilation

P.V. 160 Aerofoil fans with a capacity of 3000 m^3/min each at 75 mm water gauge are located at Adits No. 2 and No. 5, at the western and eastern ends of the mine.

Ventilation doors have been installed underground to prevent short circuits, and to allow fresh air to ventilate the working places from the deepest level. Air is split at alternate working levels to provide fresh air to the working stopes.

3. BHATIN MINE

Bhatin Mine is an extension of Jaduguda, located at a distance of about 4 km from it. IN between Jaduguda and Bhatin, there is a big upthrow fault whereby the Jaduguda lode has been upthrown. A separate mine is in operation at Bhatin. The orebody width varies from about 2 m to 10 m, having a gradient of about 30–40°. The deposit has an almost similar geology as at Jaduguda with the same country rock as chlorite biotite schist. Because of the low reserves the deposit is developed by adits and incline shafts and the main mining method is cut and fill. The ore is transported by dumpers to Jaduguda Mill for beneficiation.

4. NARWAPAHAR

The uranium deposit at Narwapahar is one of the many economic deposits in the Sighbhum Thrust Belt (STB). The orebodies are monomineratic — the uranium occurring as uraninite and the host rock is chlorite quartz schist containing some magnetide. The underlying schist is of similar composition but with increased magnetic content. The ore-bearing chlorite quartz-schist is overlain by a quartz chlorite schist. At their maximum extent the orebodies have a strike length of about 2100 m and extend to a vertical depth of 600 m. There are 6 uranium-bearing beds/lodes which are:

(1) Main Band I
(2) Main Band II
(3) Band No. 3
(4) HW Lode West of Fault
(5) Khundungri I
(6) Khundungri II

The average dip of the orebody is 30°-35° towards the north-east and occurs sa tabular lenticular horizons. The thickness of orebodies varies from 2.5 m to 20 m.

4.1. Mode of entry

The deposit is planned to be developed by one vertical shaft to a depth of 350 m and a 7° access decline suitable for trackless mining,

The shaft is presently being sunk and it has reached a depth of 200 m. It will have two ground mounted multi-rope friction winders — one for the cage and the other for the skip. These winders are also under installation. Once the sinking and equipping are completed, the temporary headframe will be replaced by a permanent structure and other facilities like orebin, wastebin, belt conveyor etc. will be constructed.

The 7° access decline is excavated by deploying twin boom hydraulic drill jumbos, LHDs of 1.78 m^3 and 2.8 m^3 capacities, LPDTs — 13 and 23 tonne capacities and the relevant service equipments like passenger carriers, supply trucks, service-cum-lube trucks, motor equipments which enter the mine directly from surface through the access decline. Where the orebody is narrow, it is proposed to deploy the "room and pillar" method with steps using decline as the main entry and ramps for entry to the stopes. The main haulage drives are in the foot-wall with the cross-cuts at pre-determined levels. Where the orebody is wider, the cut and fill method will be used with post pillars.

Presently when the mine is under construction, the ore is brought to surface through the decline and transported to Jaduguda Mill by road. As soon as the shaft is commissioned, the ore will be hoisted to surface by skip and then transported to Jaduguda by road.

Since most of the equipments are used for the first time in the country, great care is taken for the training for the engineers, supervisors, operators and maintenance staff, and for the adequate service backup and spare parts management. Arrangements are also made for training of the engineers aborad, posting of foreign commissioning engineers along with foreign engineers.

4.2. Use of high pressure and high capacity main and auxiliary fans

Because of the large scale use of big diesel equipments, ventilation requirements for the mine are high. The ventilation system has been designed with the help of computers. In the long run, for total mine ventilation, three fans with a capacity of 75 m^3/sec at 1.7 KPa (about 7" WG) each with 250 KW electric motors will be used for main ventilation. Provision has been kept for the installation of one additional fan in case ventilation problems are faced in the future. The total circulating quantity of air of about 200 m^3/sec is equivalent to about 0.18 m^3/sec per tonne of ore mined for rated capacity production plus an allowance of 10% additional waste. This large quantity of air required to control heat, dust and diesel emissions is also sufficient to control the radon content in mine air. Two fans Model VF-2000 supplied by M/s Voltas have already been installed in parallel at the western ventilation shaft.

5. RADIATION HAZARDS

In a uranium mine the workers are exposed to the hazards of radiation in addition to the other hazards of underground mining operations. Two main sources of health hazards are inhalation of radon gas and airborne dust. To minimize the effects of radon, the mine must have a good ventilation system, so that all radon gas generated is flushed out of the mine and the working places are well ventilated. With this in view, powerful ventilation fans are installed and are kept running. Auxiliary fans are installed wherever thy are necessary.

For suppressing dust, all operations in the mine where there are chances of raising dust are made wet operations with sprinkling of water. All drilling operations in the mine are wet and in all places where ore is handled, water is sprinkled to keep the dust down.

Monitoring of radiation, radon and dust is done by the Health Physics Group of the Bhabha Group of Bhabha Atomic Research Laboratory at Jaduguda. Members of this laboratory take samples from the mine and mill sites at periodic intervals and keep a watch on all aspects of radiation. The results of the investigation conducted at Environmental Survey Laboratory at Jaduguda show that the exposure to radiation is below the permissible limits of 5 rem per year.

6. JADUGUDA MILL

Uranium ore produced from Jaduguda, Bhatin and Narwapahar mines and uranium mineral concentrates transported from uranium recovery plants are processed in the mill located at Jaduguda. The mill has an installed capacity of 1370 tonnes of ore per day. It is now being expanded to process 200 tonnes per day.

6.1. Crushing

The uranium ore from Jaduguda is transported by conveyor belt to the crushing section while the ore from Bhatin and Narwapahar mines is fed via ground hopper for crushing and grinding. In two stage crushing — 200 mm ore is screened on — 125 mm opening scalper. Oversize is crushed in primary jaw crusher. This is screened on a triple deck screen with openings of 113 mm, 65 mm and 25 mm, -25 mm size is collected as fine ore and -113 mm +65 mm as pebbles, and the rest is recycled back for secondary crushing.

6.2. Grinding

This is followed by two stage wet grinding with a primary rod mill and secondary pebble mill to get ground material of the size of 60% passing through 200 mesh. This slurry is thickened and filtered to remove water for proper solution balance and the cake is repulped with secondary filtrate from downstream to 60% solid slurry. This was mechanical preparation of slurry.

6.3. Leaching

This slurry is pumped for leaching in leaching pachucas, which are essentially air agitated tanks. In leaching tetravalent form of uranium is oxidized to hexavalent from which is soluble in acidic medium. For this sulfuric acid and pyrolusite i.e. MnO_2 is added to maintain 1.6–1.7 pH and -480 mv emf, temp. around 36–38°C. The reaction time is 12 hrs. There are 13 Nos of pachucas, 9 in line. The slurry overflows from one pachuca to another and by the time it comes out from the last pachuca, the slurry has been retained for 12 hrs and around 95% of uranium is leached out.

6.4. Filtration

The leached slurry is filtered in two stages employing string discharge vacuum drum filters. The primary filtrate so received contains 100-500 ppm slimes. This is clarified on precoat filter to get a clear liquor of less than 8–10 ppm suspension.

At this stage the liquor contains 0.5–0.6 gm/lit of U_3O_8, ferrous and ferric sulphate, dissolved manganese, free acid and other impurities. This is concentrated and purified by the ion exchange system, strong base an ion exchange resin is used in a two column system. The complexes of uranyl sulphate, ferric sulphate and sulphate ions get absorbed which are eluted by one normal salt solution. The strong eluate contains around 5-6 gm/l U_3O_8.

This eluate is treated with lime to increase pH to 3.8, ferric sulphate and gypsum get precipitated. This is thickened and filtered. As along with iron some of the uranium complexes also get precipitated hence this is sent ahead of leaching to recover this uranium.

6.5. Precipitation

The overflow is treated with magnesia to get magnesium di-uranate or yellow cake, which is thickened, washed, filtered, dried and packed in drums. The U_3O_8 content in yellow cake is around 74% U_3O_8.

During the process of recovery of uranium, two types of wastes are generated — barren cake from filter section and barren liquor from ion exchange system. Barren liquor is neutralized to pH 10.5 to precipitate dissolved manganese etc. The barren cake slurry is sent to the magnetite plant where magnetite is recovered, then this is mixed with neutralized barren liquor. This is classified by hydrocyclone. Coarser sand is sent to mines for backfilling and finer size is sent to a tailings pond where solid and precipitates settle and clear liquor is decanted off.

6.6. Effluent treatment

The decanted liquor of the tailings pond occasionally used to have higher manganese and radium values than the prescribed limits. The final combined effluent, however, used to be within the limit due to dilution by other streams. Recently the mill has been expanded to increase its capacity needing higher water requirements, which could have been met only by water reclamation. This would have resulted in less water available for dilution and values of radium etc. would have increased in the final effluent.

Therefore a combined scheme of water reclamation and retreatment of tailings pond effluent was implemented. This has been commissioned in March 1990. This has resulted not only in a reduction of fresh water requirement, but has also resulted in the purity of the final effluent.

6.7. Scheme

The main consideration in formulating the scheme was that mine water, magnetite pit water and tailings pond water cannot be used ahead of ion exchange due to its chloride content. The scheme has been shown in a diagram and shows the different streams:

(i) The compressor water and excess vacuum seal water is collected and recycled back to the industrial water reservoir at the water treatment plant for reuse.

(ii) The mine water and magnetite pit water contains fines and hence is pumped to the thickener, the overflow is collected in a water reservoir in the mill. This water is used for secondary cake repulping and for the magnetite plant, all downstreams to ion exchange. The underflow is pumped to tailings pond.

(iii) The tailings pond overflow is brought to the water treatment plant area by gravity drain and is pumped to raw effluent thickener. The clarified effluent is stored in a tank and supplied to the mill as per requirement. Extra effluent is treated for radium and Mn removal before the same is discharged to the environment.

6.8. Treatment scheme

The re-treatment plant capacity is 100 m^3/h. The clarified effluent at controlled rate is pumped to the barium reaction tank. Barium chloride solution is dosed @ 25 mg/l of effluent to precipitate radium as barium radium sulphate, the reaction time being half an hour. This is then neutralized by lime to pH 10 to precipitate Mn, the reaction time in this case is 1 hour.

The resultant precipitate is thickened in treated effluent thickener, the settled precipitate is pumped to the tailings plant, where it is mixed with fresh tailings before pumping to the tailings pond. This is required as the barium radium sulphate precipitate is quite concentrated and is difficult to settle if pumped alone.

The overflow of this thickener, i.e. treated effluent is brought to normal pH by dosing sulfuric acid before the same is discharged to the atmosphere.

6.9. Recovery of uranium from copper tailings

The copper ores of Singhbhum Thrust Belt contain small amounts of uranium minerals which are recovered as by-products. UCIL has set up 3 uranium recovery plants at Rakha, Surda and Mosaboni, near the Copper Concentrators. Tailings after the extraction of copper are sent to UCIL plants for recovery of uranium. The uranium content of copper tailings is of the order o 0.01% U_3O_8. The copper tailings are recovered. These uranium mineral concentrates from all three plants are transported to Jaduguda Mill by road for further processing. All these plants contribute about 150 tonnes of uranium mineral concentrates per day.

6.10. By-product recovery

Uranium ores of Jaduguda, Bhatin and Narwapahar contain small quantities of sulphide minerals of copper, nickel and molybdenum. These are recovered as by-products. Sulphide minerals of Cu, Ni and Mo are recovered by floatation. The combined concentrate of copper and nickel, containing about 20% CuS, are sold to Hindustan Copper Ltd., Ghatsila for smelting and recovery of copper metal. The sulphide concentrate of molybdenum is converted into ferromoly which is used in Ordinance Factories.

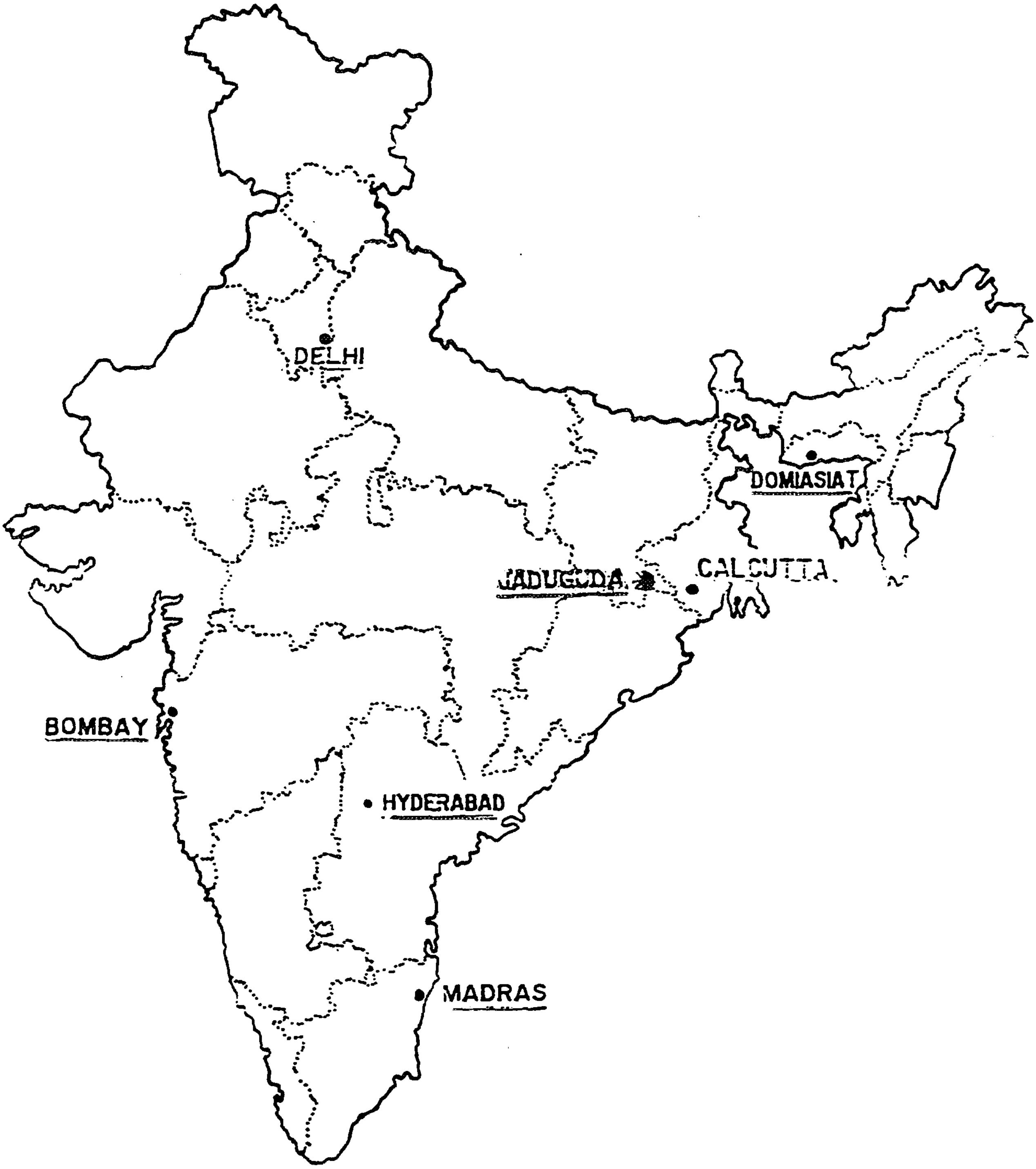

FIG. 1. Location map of Jaduguda in India.

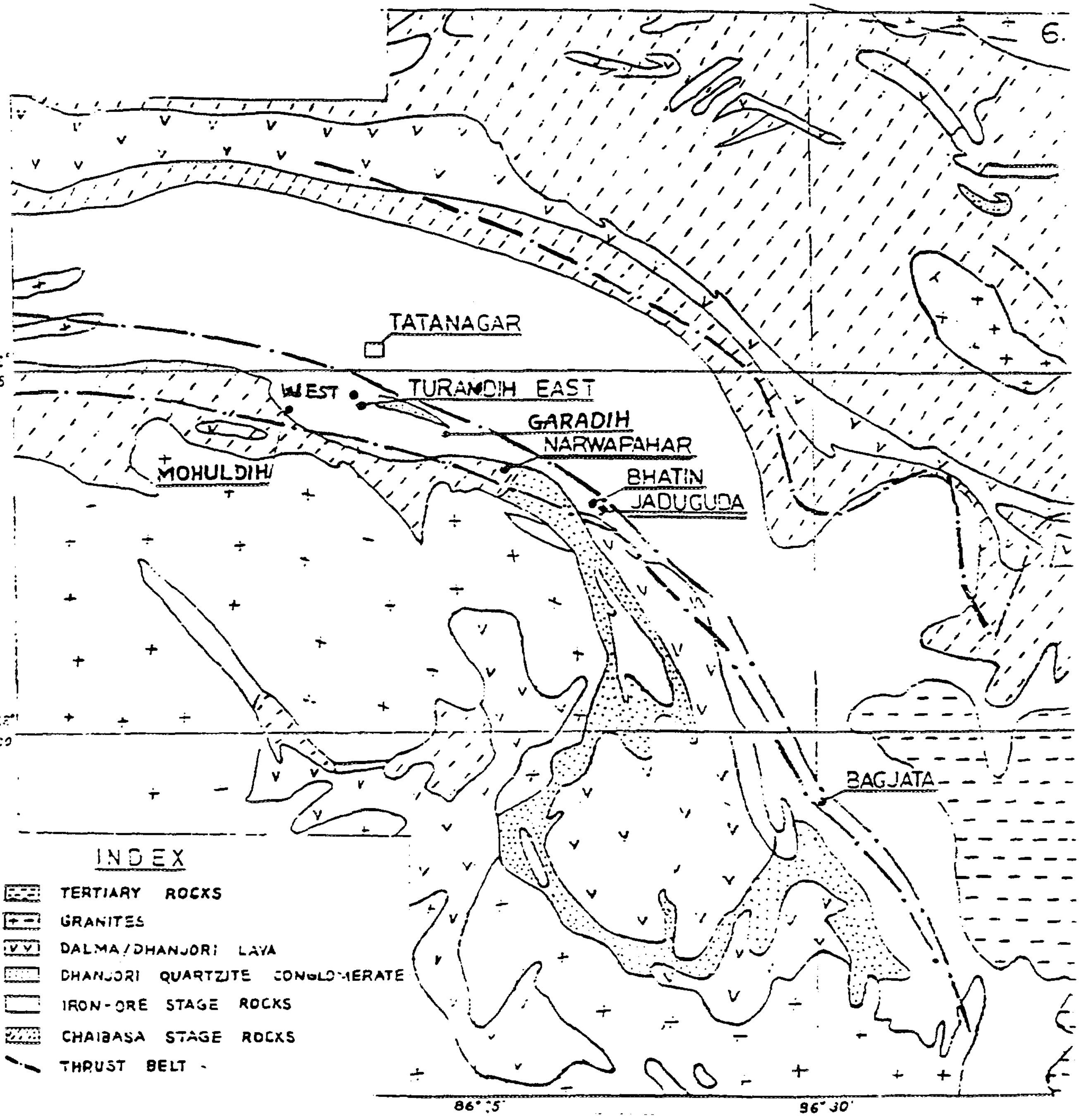

FIG. 2. Geological map of Singhbhum Thrust Belt.

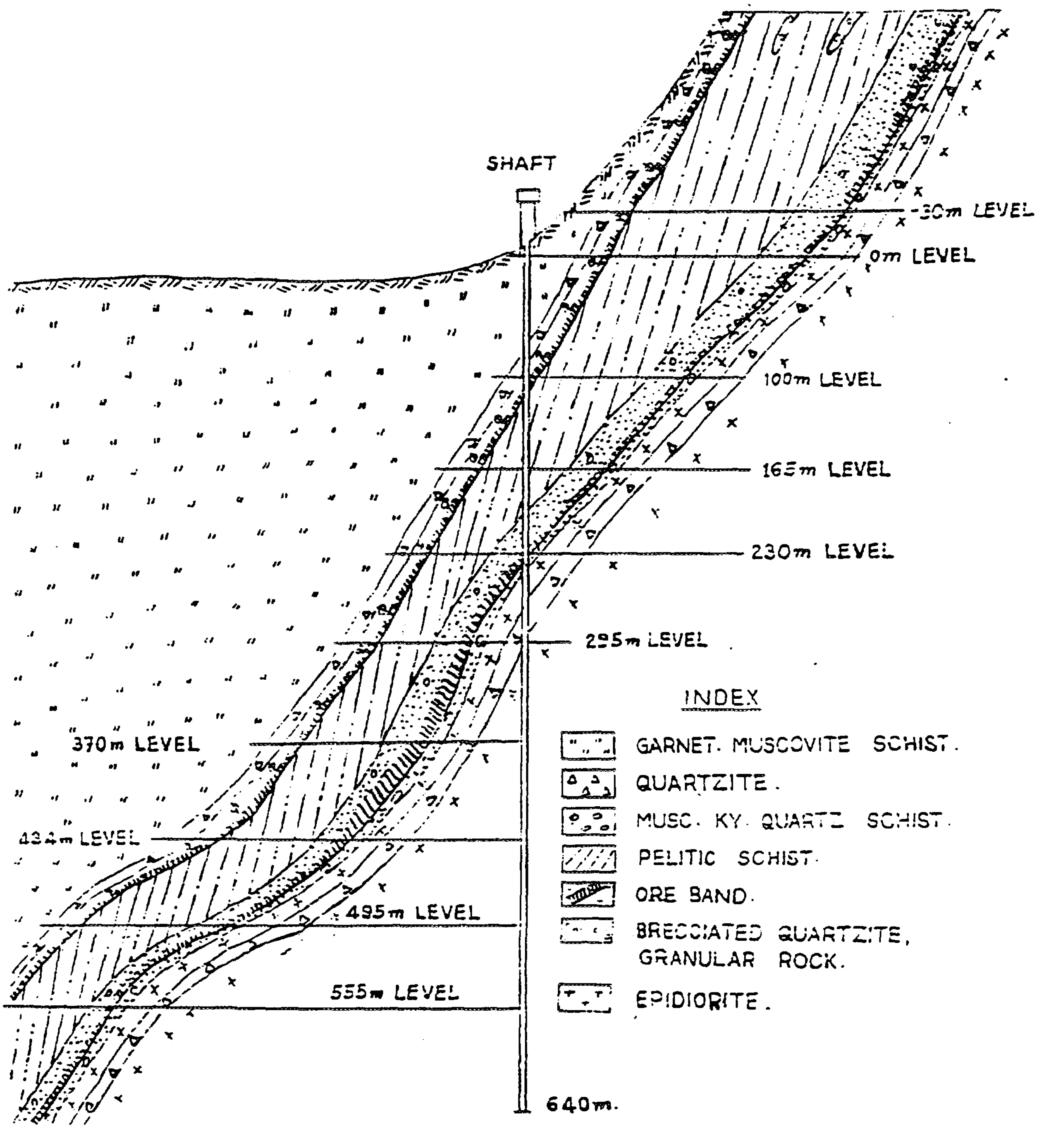

FIG. 3. Transverse section across Jaduguda Hill. Scale: 1:4000.

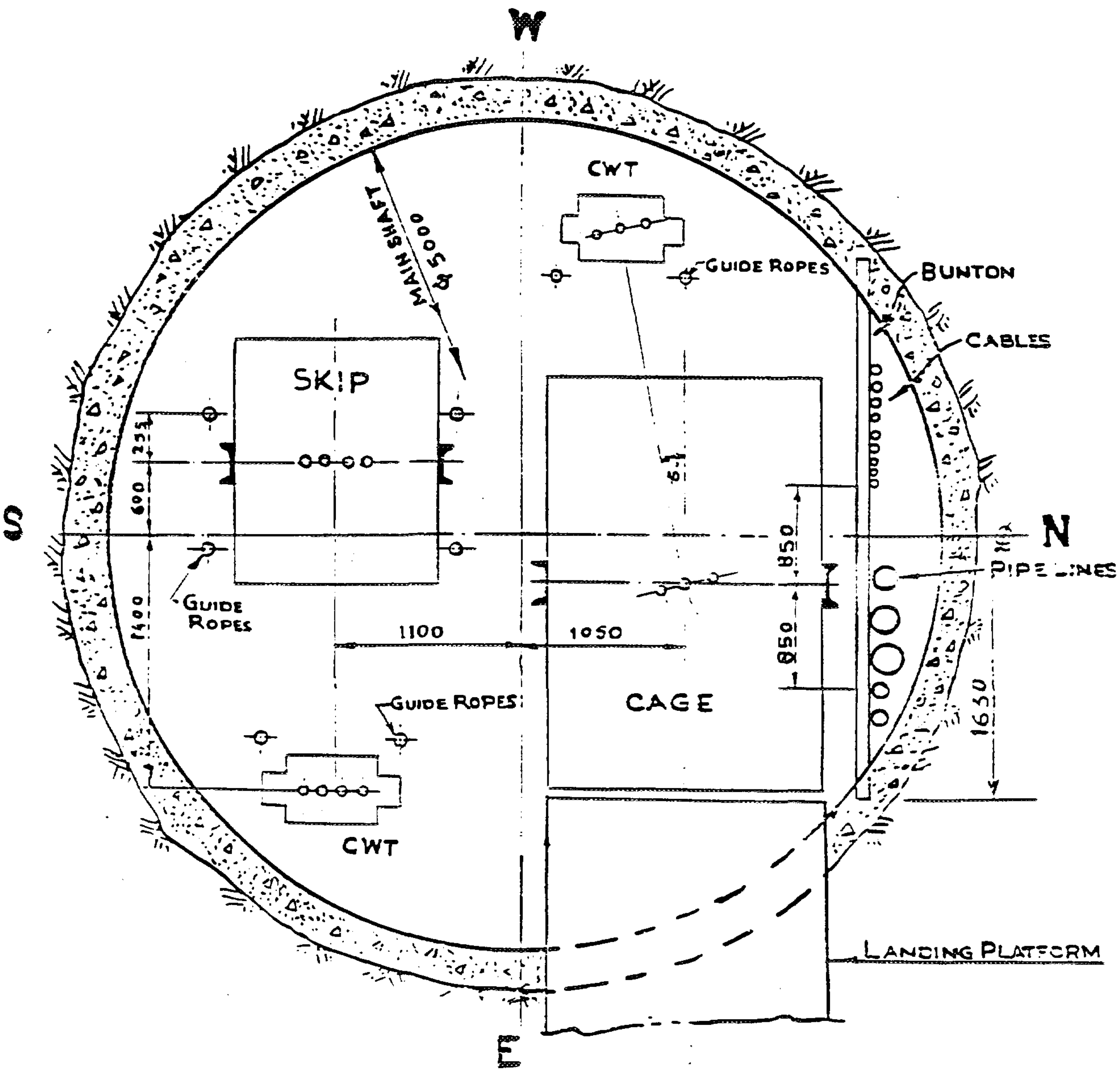

FIG. 4. Shaft plan.

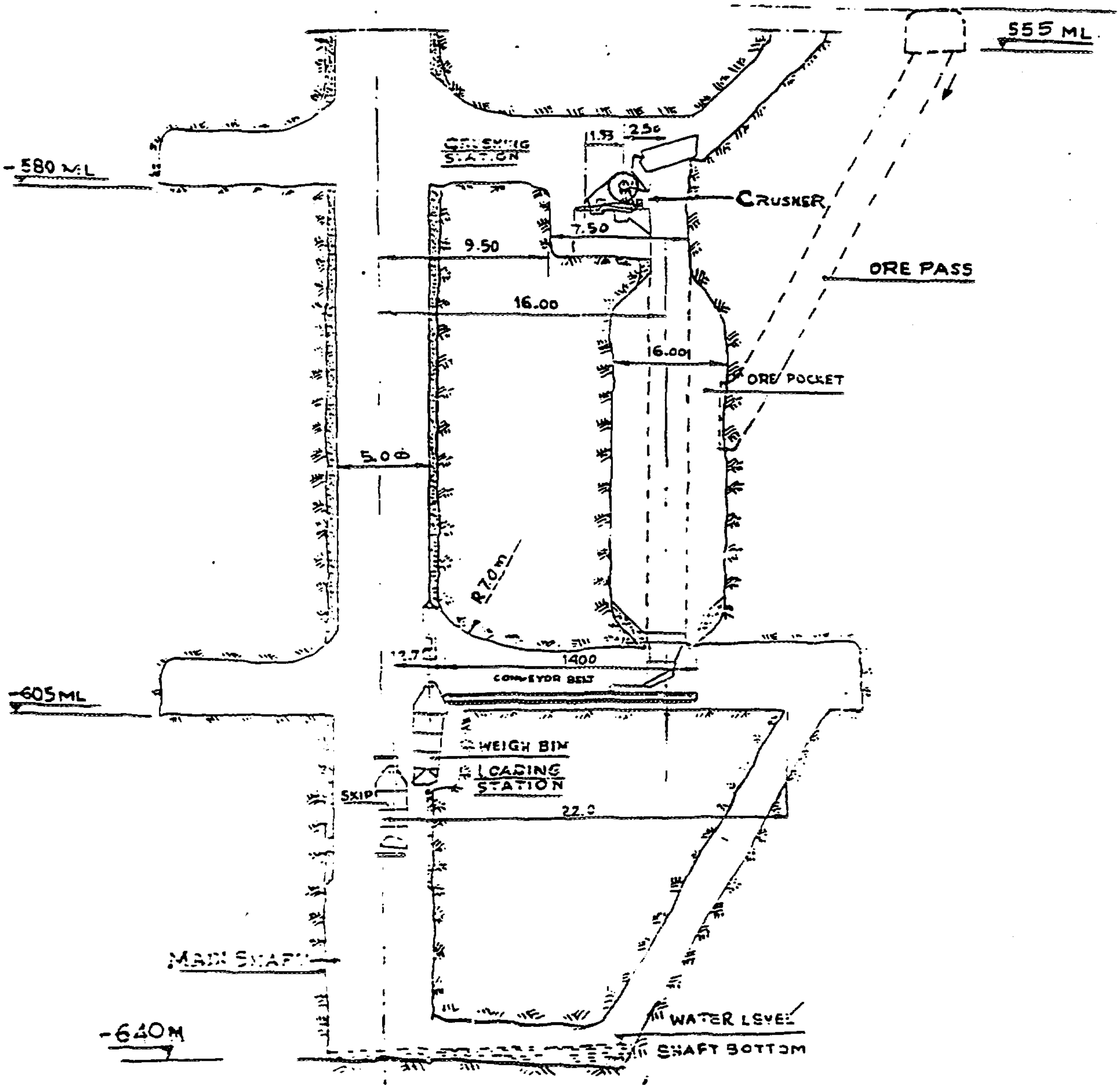

FIG. 5. Crushing and hoisting station.

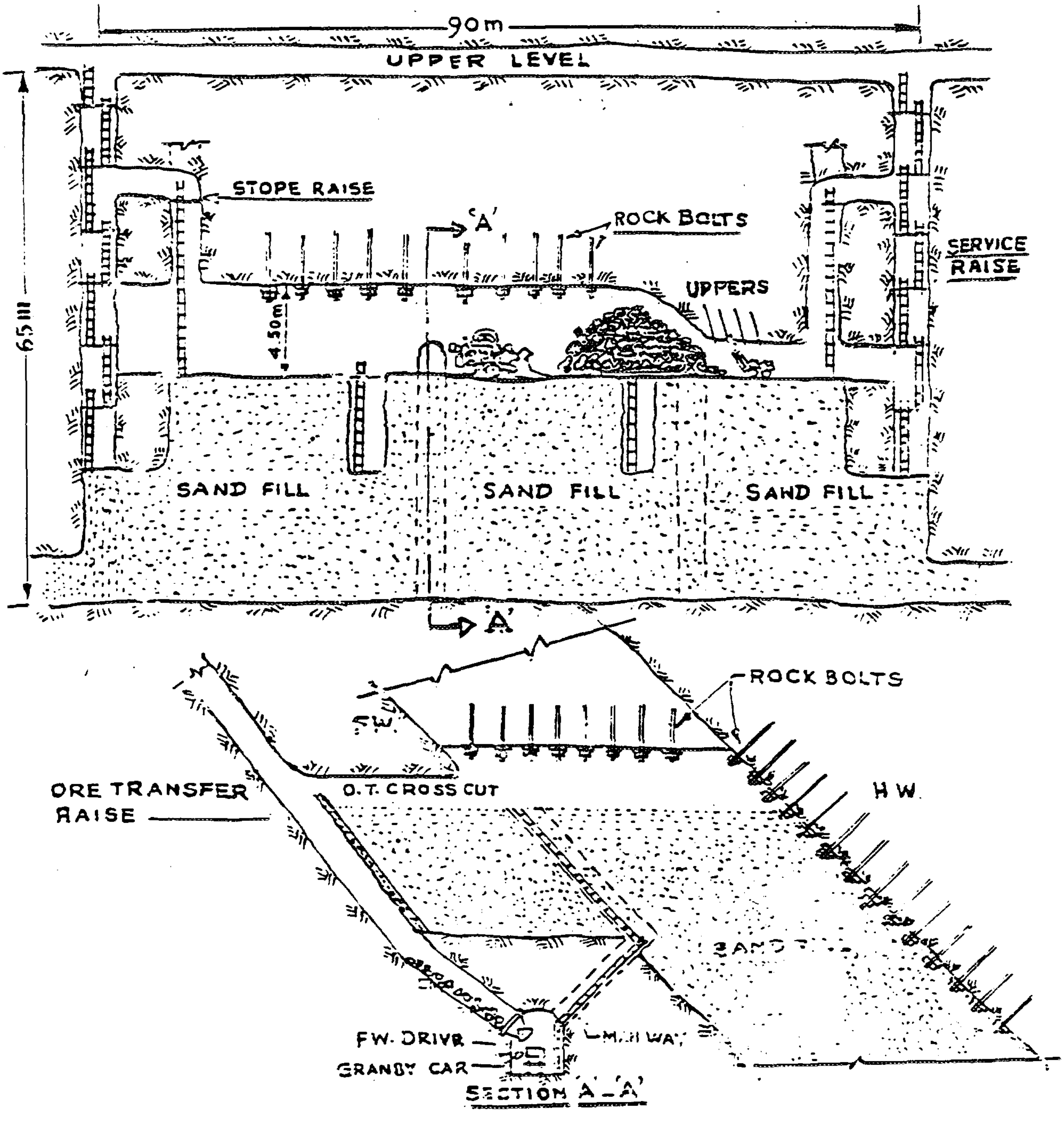

FIG. 6. Cut and fill stope at Jaduguda.

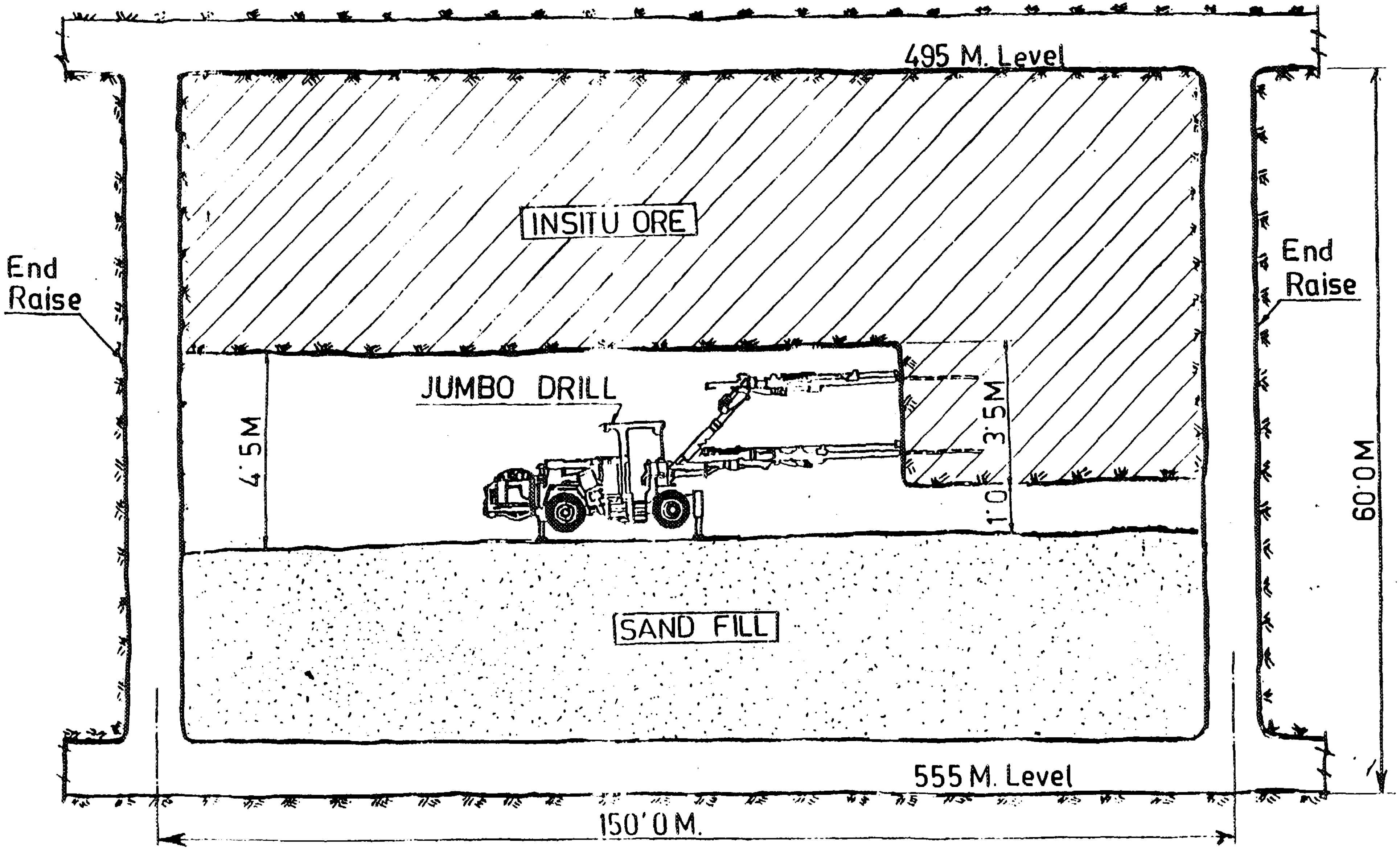

FIG. 7. Vertical longitudinal section; mechanized EO-W5 stope.

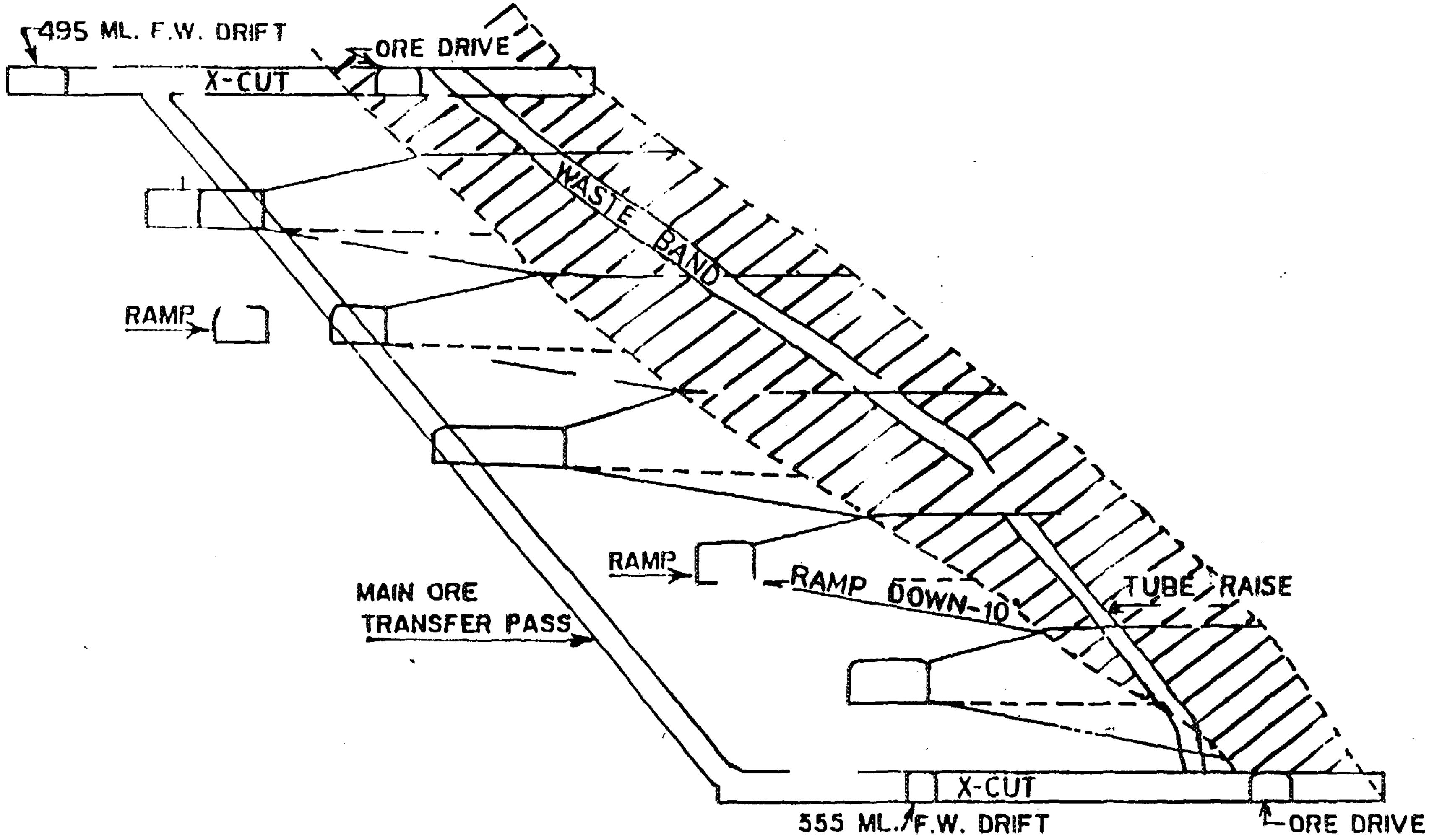

FIG. 8. Transverse section showing the general arrangement of HCF stoping.

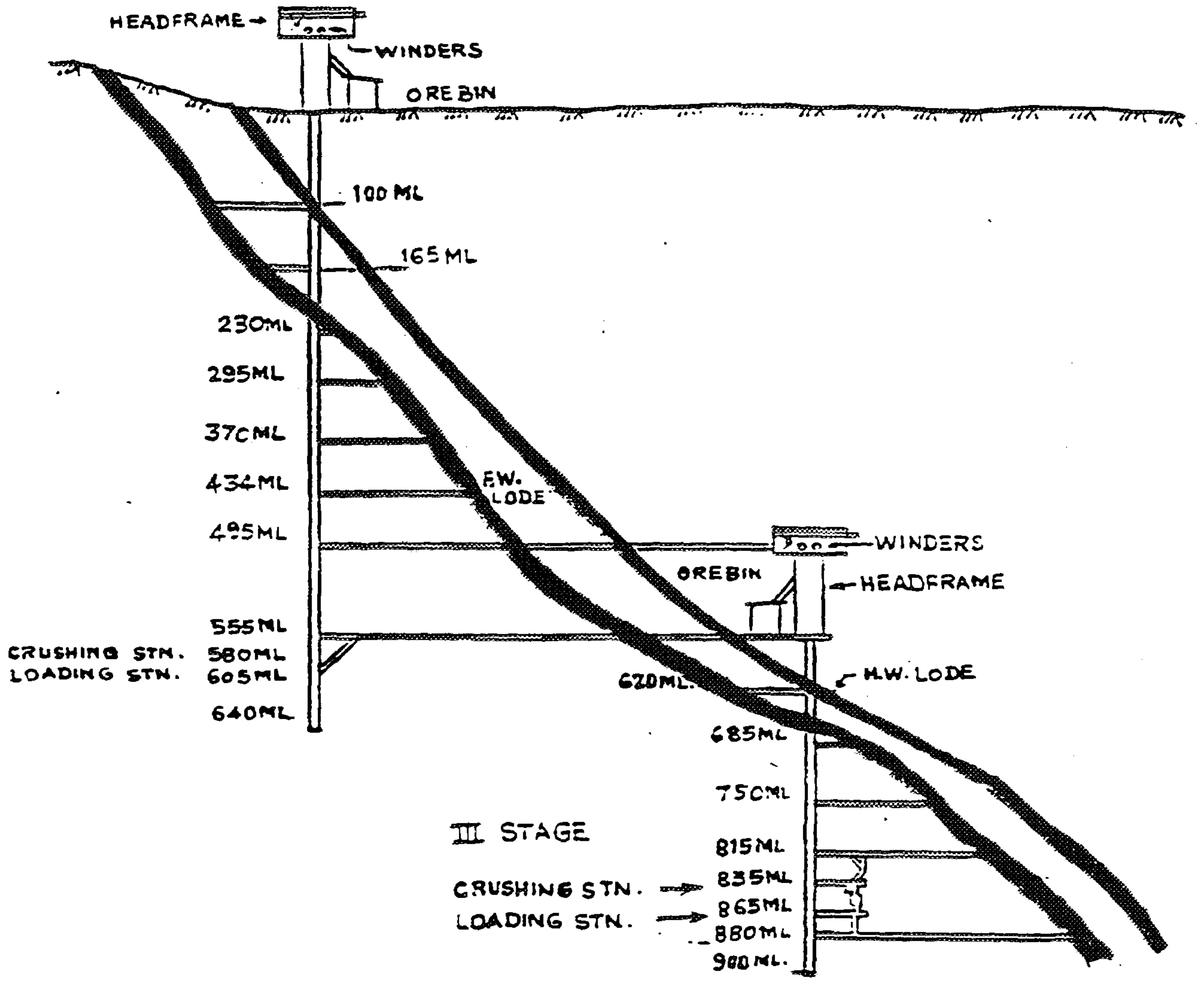

FIG. 9. III-stage shaft sinking.

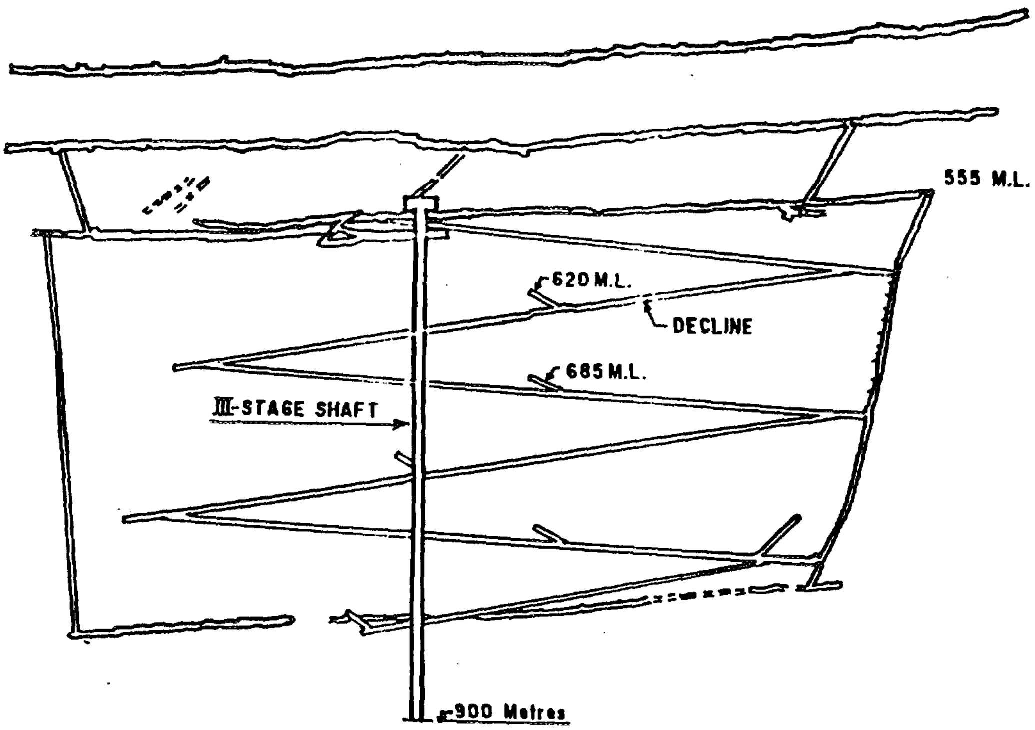

FIG. 10. Development below 555 m.l.

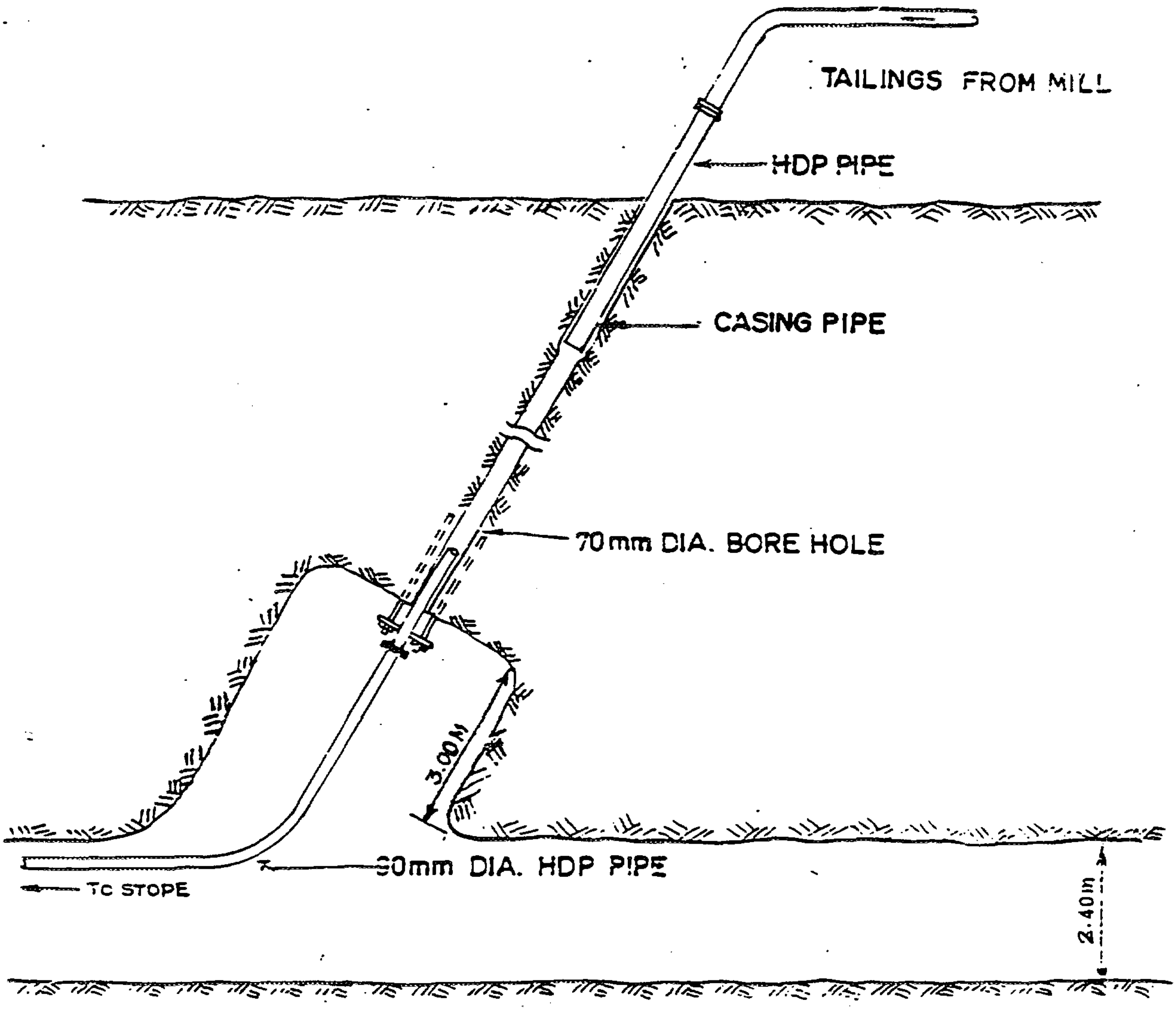

FIG. 11. Sand stowing borehole.

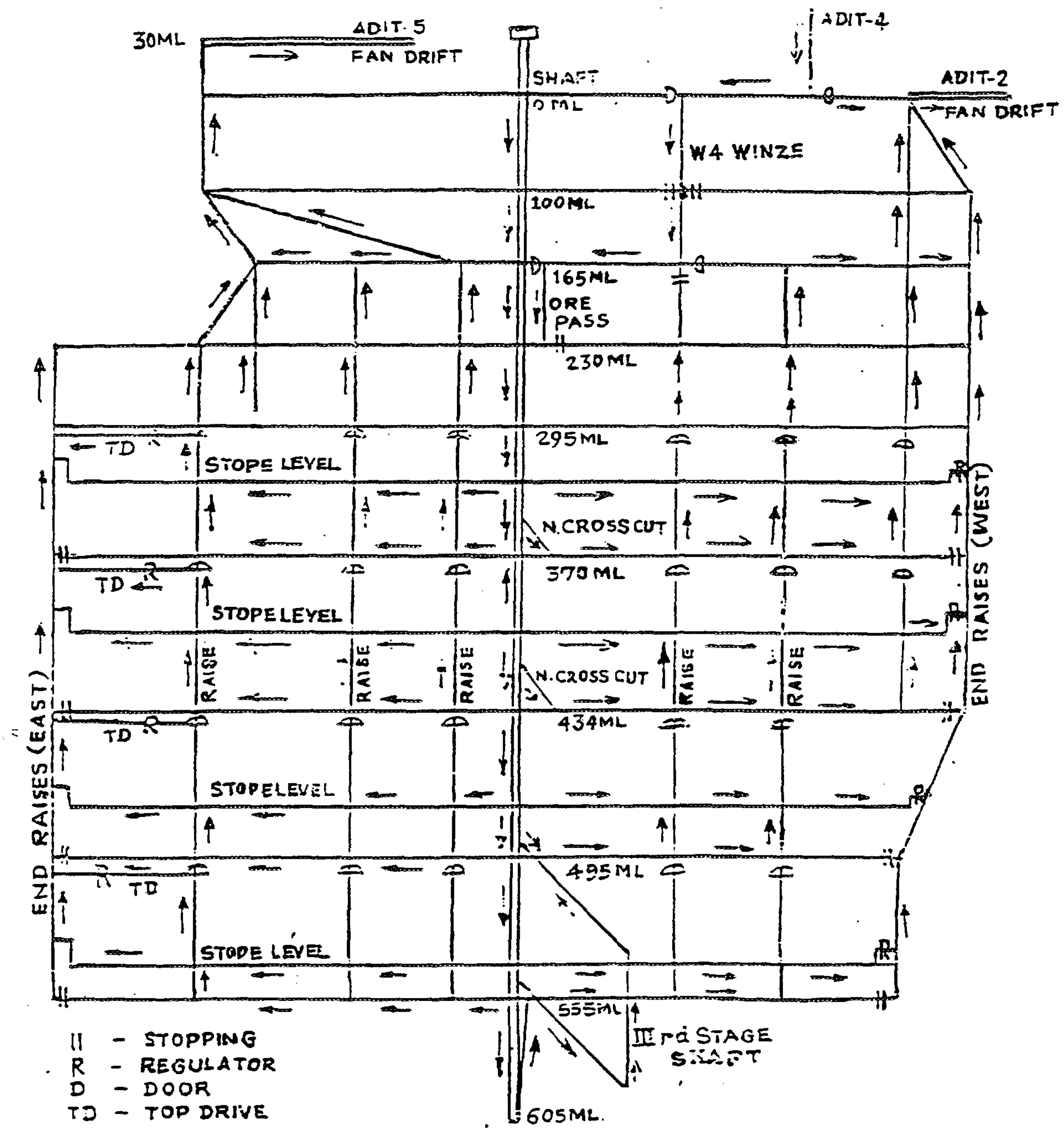

FIG. 12. Schematic diagram of proposed ventilation network of Jaduguda mine.

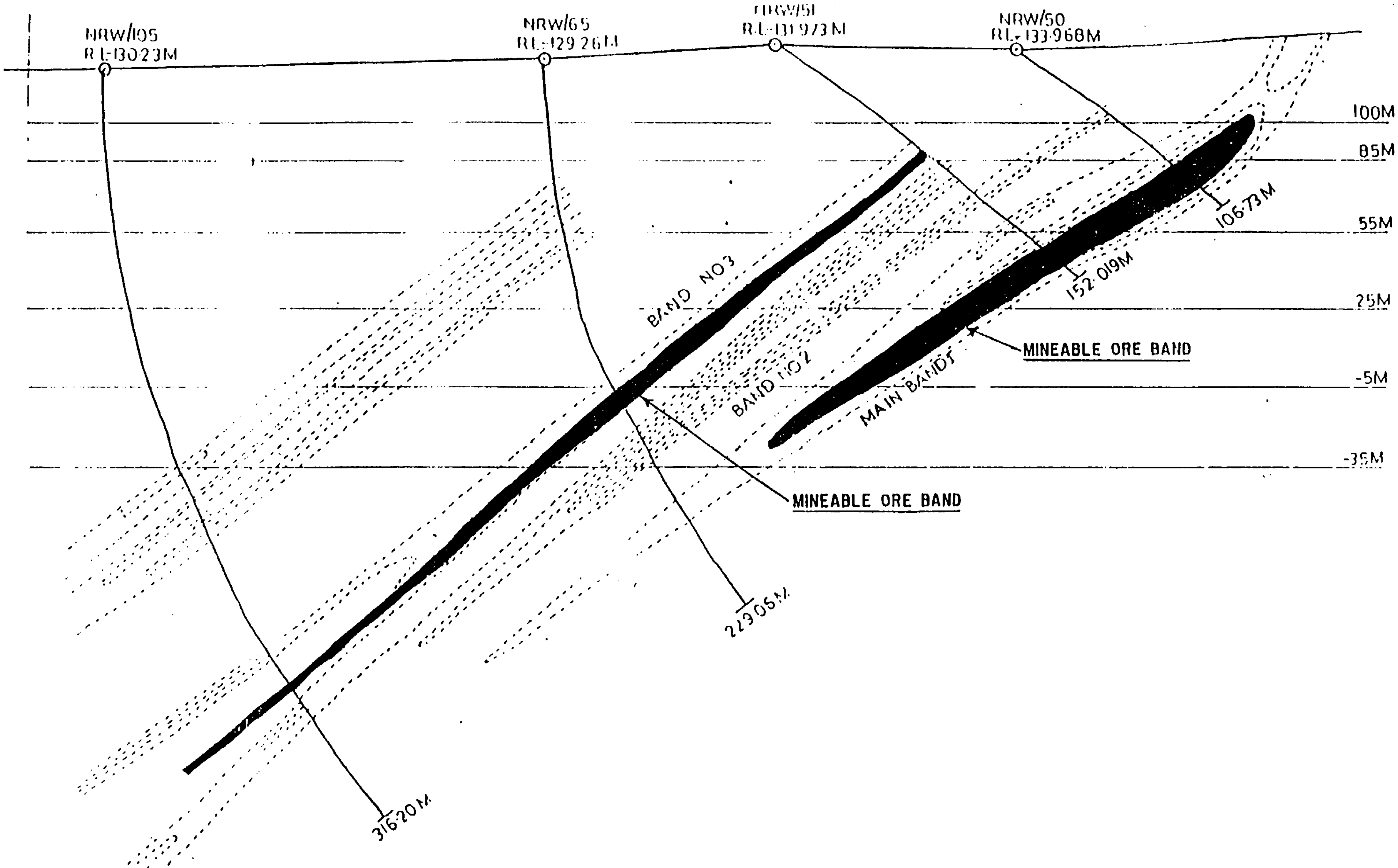

FIG. 13. Borehole section, Narwapahar deposit.

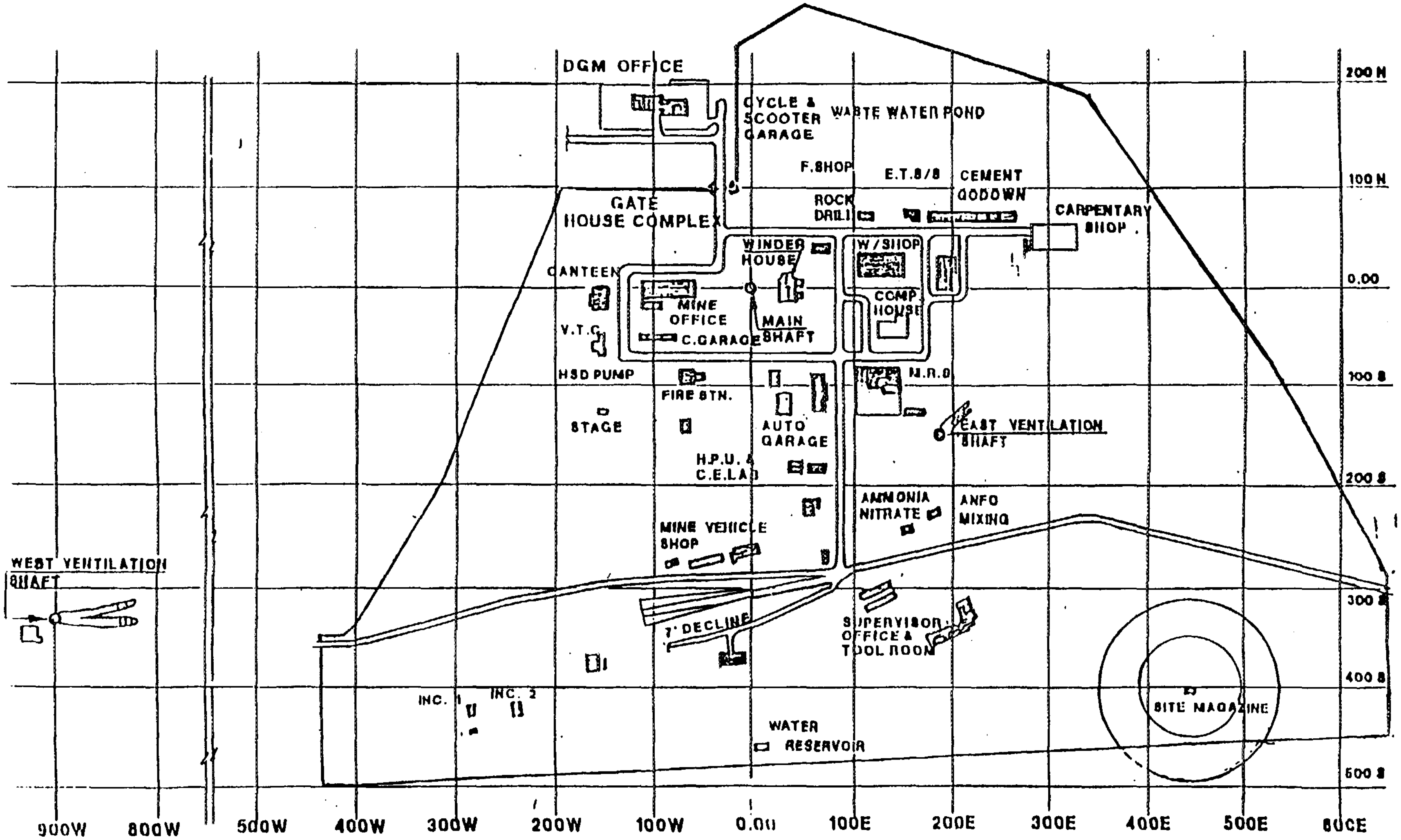

FIG. 14. Narwapahar mining project; surface plan.

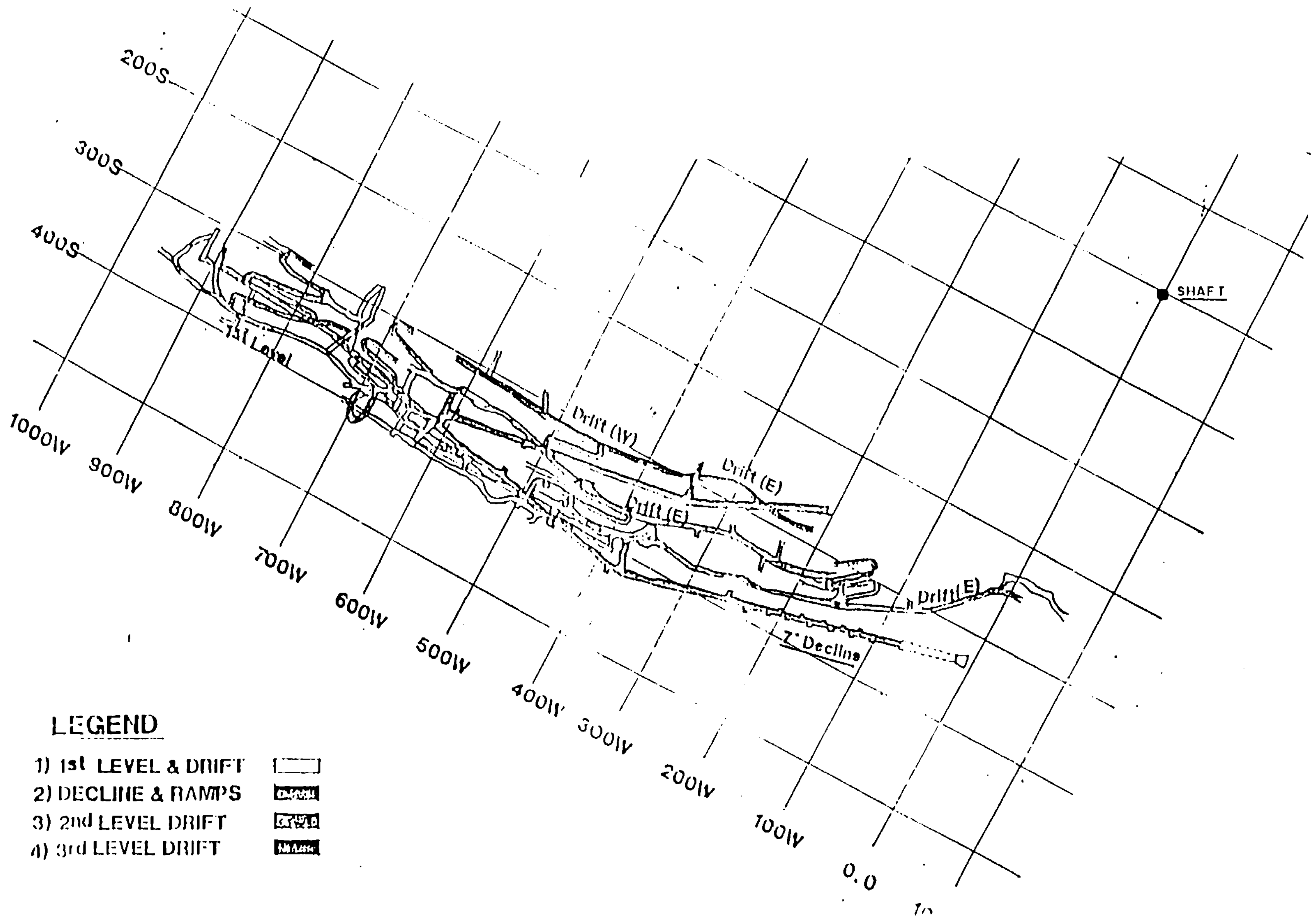

FIG. 15. Narwapahar mining project; underground plan showing present development through decline.

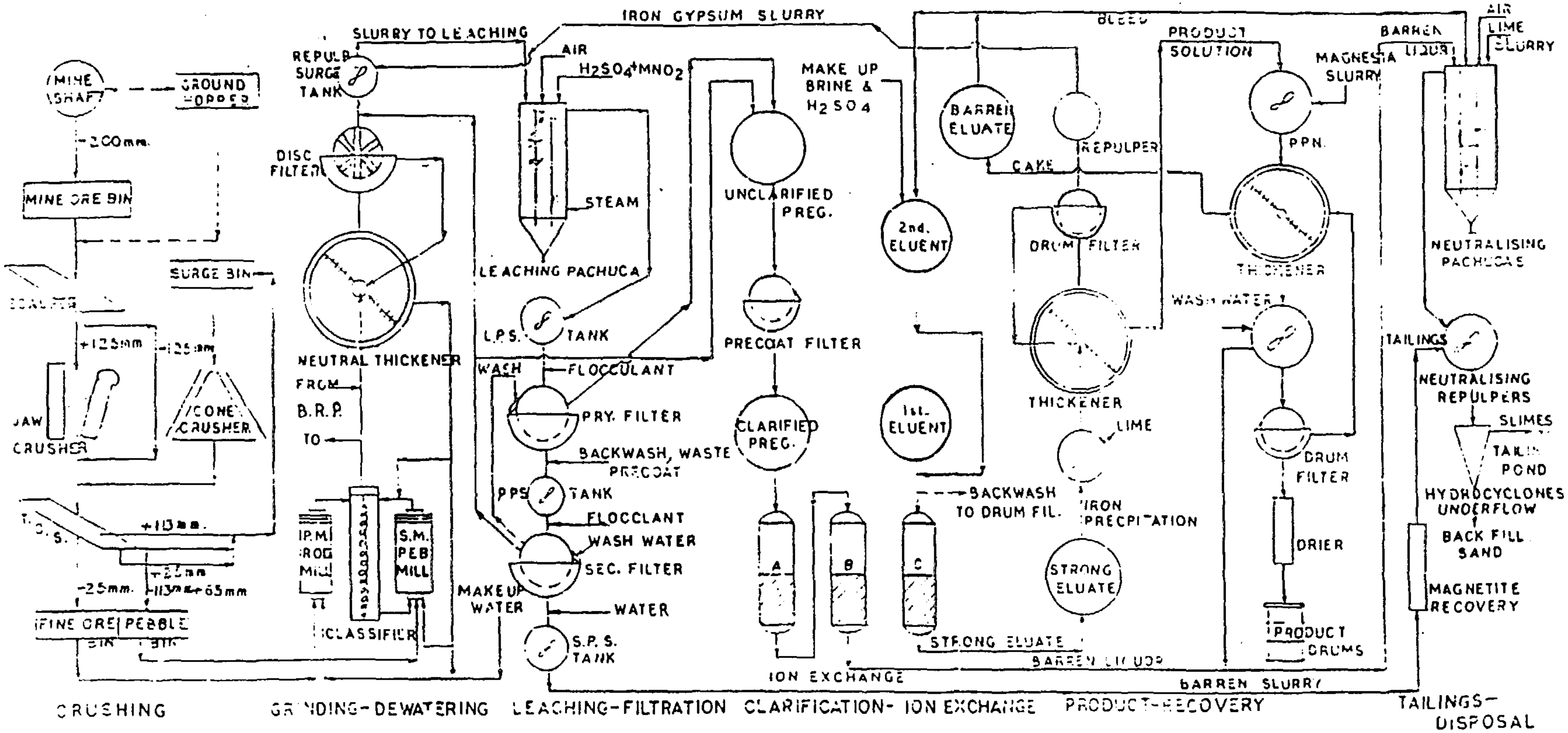

FIG. 16. Uranium ore processing flowsheet.

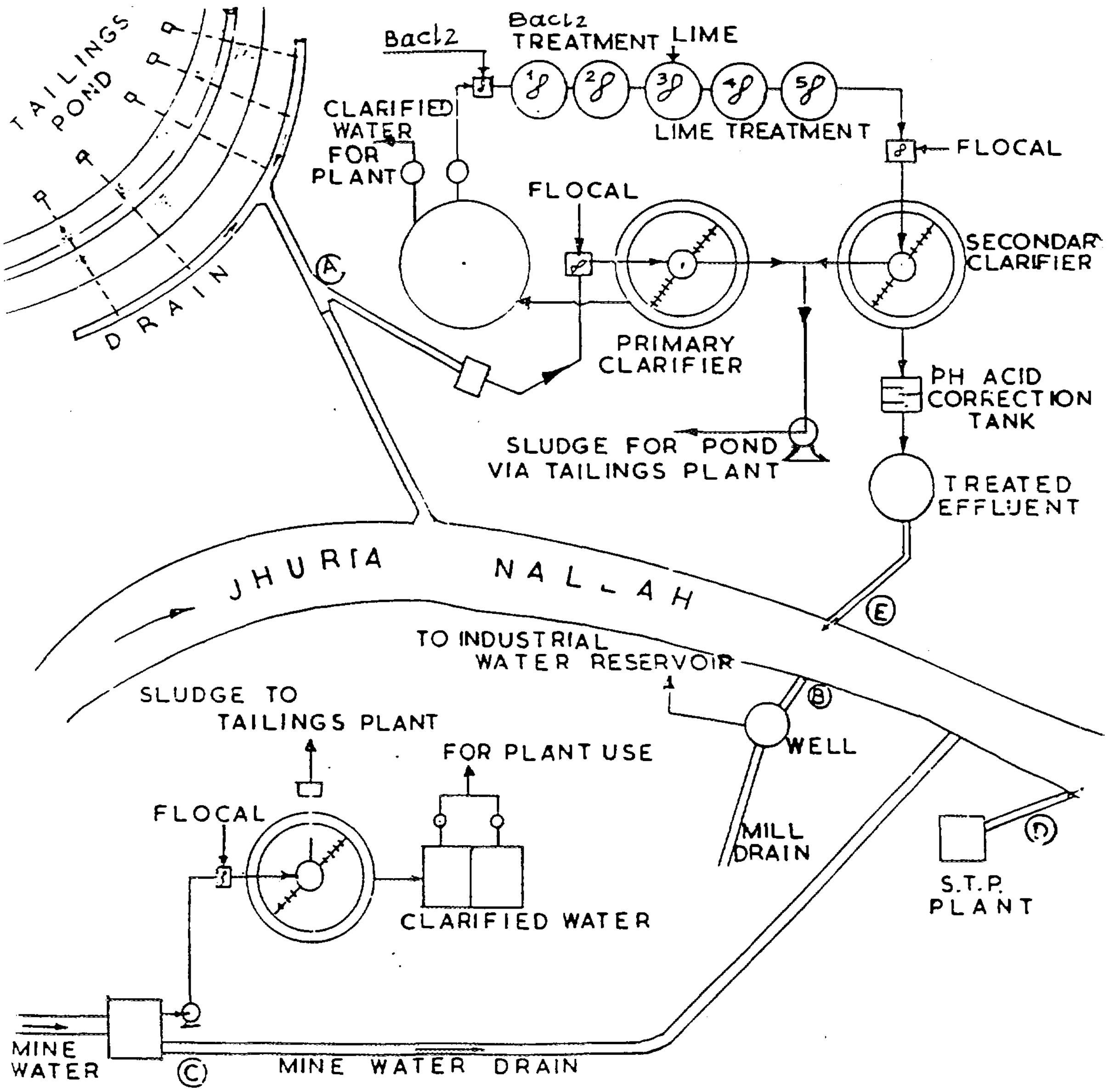

FIG. 17. Flowsheet of effluent treatment plant

	FLOW		Ra (Bq/M3)		Mn (gm/M3)	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTET
INDUSTRIAL EFFLT.	6360	600	710	80	3·0	0·2
S.T.P. EFFLUENT	3000	3000	50	50	—	—
TOTAL EFFLUENT	9360	3600	500	55	2·0	<0·1

FIG. 18. Anticipated results in lean period, i.e. mid-October to mid-June

6.11. Magnetite recovery

The uranium ores of Singhbhum contain about 3% magnetite minerals. These are separated after the recovery of sulphide minerals and uranium by electromagnetic separation. It is ground to 90% -300 mesh. The magnetite produced is 95% magnetics and find its use in coal washeries.

7. FUTURE PLANS

To meet the ever increasing requirement of uranium for the nuclear power programme, there is a constant search for viable uranium deposits in the country. One such deposit has been located at Domiasiat in Meghalaya state in the north-eastern part of the country. This was the result of extensive drilling and exploratory mining. The estimated ore reserve is expected to be 9.22 million tonnes with an average grade of 0.1% U_3O_8. The ore occurs at shallow depth of 45 m from the surface. The ratio of ore to ore burden is 1: 6.7 which makes the deposit amenable to exploitation by open cast mining method. The only difficulty is the remoteness of the area whereby the heavy open cast mining machinery will have to be transported. The mill will have to be installed at site to process the mined ore. The raw materials required for processing will have to be supplied constantly and all this will add to the cost of the finished product.