Chapter 9. Cut-and-Fill Stoping as Practiced at Outokumpu Oy

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HISTORY

The history of mining in the Outokumpu Co. shows continuous development of small and medium-sized mines, coupled with a permanent improvement in mining methods and mechanization.

Tables 1 and 2 provide a brief outline of the major events over the years of operation. Some of the mines have had relatively short lives as in the case of Nivala, Korsnas, Kylmäkoski, the surface pits of the Kotalahti, Vuonos, and Hammaslahti mines, and some very small pits. The sequence in which the mines started operations is shown in Table 1 and production increases in Table 2.

GEOLOGICAL FRAMEWORK

Most of the ore deposits in Finland (see Fig. 1) are situated in middle Precambrian (1500 to 2300 m.y.) formations corresponding to the Baltic shield. The ores and country rocks are generally firm, with a minimum compressive strength of 60 MPa (8700 psi).

The sulfide ores, of importance to the national economy, can be divided into copper-nickel deposits, associated with basic and ultrabasic rocks (1900 m.y.), and the sulfide ores found in well-preserved Svecokarelidic crystalline schists (1800 to 2300 m.y.) which contain varying amounts of copper, zinc, cobalt, nickel, and lead.

Over 90% of the sulfide ore mined to date in Finland and existing in the known ore reserves belongs to deposits situated in the main sulfide ore belt. This belt extends diagonally across the country over a breadth of 40 to 150 km, from Lake Ladoga to the coast of the Gulf of Bothnia. The main sulfide ore belt includes the Outokumpu copper-zinc, the Kotalahti nickel-copper, the Pyhäsalmi copper-zinc, and the Vihanti zinc ore zones.

Table 1. Sequence in Which Mines Began Operations

1913	Mining started at the Outokumpu mine (now called Keretti)
1928	Large scale systematic exploitation started in the Outokumpu mine
	Opening of mines:
1942	Nivala mine (1942–54)
1943	Yiöjärvi mine (1943–66)
1947	Orijärvi mine (1947–54) (Mining started in 1757)
1948	Aijala mine (1949–58)
1952	Metsämonttu mine (1952–58 and 1964–74)
1954	Keretti's new mine plant
1954	Vihanti mine
1959	Kotalahti mine
1961	Korsnäs mine (1961–1972)
1962	Pyhäsalmi mine
1966	Virtasalmi mine
1967	Kemi mine
1970	Hitura mine
1971	Kylmäkoski mine (1971–74)
1972	Vuonos mine
1973	Hammaslahti mine
1978	Vammala mine

Table 2. Ore Production of the Outokumpu Oy Mines

Year	1000 t of Ore
1913–1928	252
1929–1954	13 075
1955	1 105
1960	1 784
1965	2 627
1970	3 269
1975	5 825
1976	5 445
1977	4 939
1978	5 766
1979	5 905

The Outokumpu ore district occurs in a mica schist area about 60 x 100 km, in association with belts of metamorphic Svecokarelidic quartzites, black schists, dolomites, skarn rocks, and serpentinites. The main ore minerals are chalcopyrite, pyrrhotite, pyrite, and sphalerite. In addition there are nickel and cobalt minerals such as cubanite and cobalt-pentlandite, which have been of economic importance. In this area, Outokumpu Oy exploits the deposits at Keretti and Vuonos. The latter was discovered as an extension of the Keretti ore field about 6 km to the northeast.

The Kotalahti geological formation extends across nearly 400 km. The host rock of these mostly pipelike deposits is generally serpentinite, pyroxenite, or norite. The main ore minerals are pyrrhotite, pentlandite, and chalcopyrite. In this zone, the deposits of Kotalahti, Hitura, and Virtasalmi are at present under exploitation by Outokumpu Oy.

The Vihanti geological formation is located in western Finland and is about 40 km wide and some 200 km long. The rock associations are crystalline schists including dolomites, mica schists, mica gneisses, graywacke, and acidic or basic volcanic rocks, which change generally, in connection with the mineralization, into skarn and cordierite-anthophyllite rocks. The host rocks are dolomite, skarn, graywacke, and quartzitic rock and the principal minerals are sphalerite, chalcopyrite, galena, pyrite, and pyrrhotite. The accessory minerals are mainly cubanite, arsenopyrite, molybdenite, and native gold and silver.

The two largest ore bodies being exploited at present by Outokumpu Oy are the Vihanti mine, which produces zinc, lead, and copper, and Pyhäsalmi, which contains copper and zinc.

Deviating from the sulfide ore types described earlier is the Hammaslahti copper ore located in the southeast-

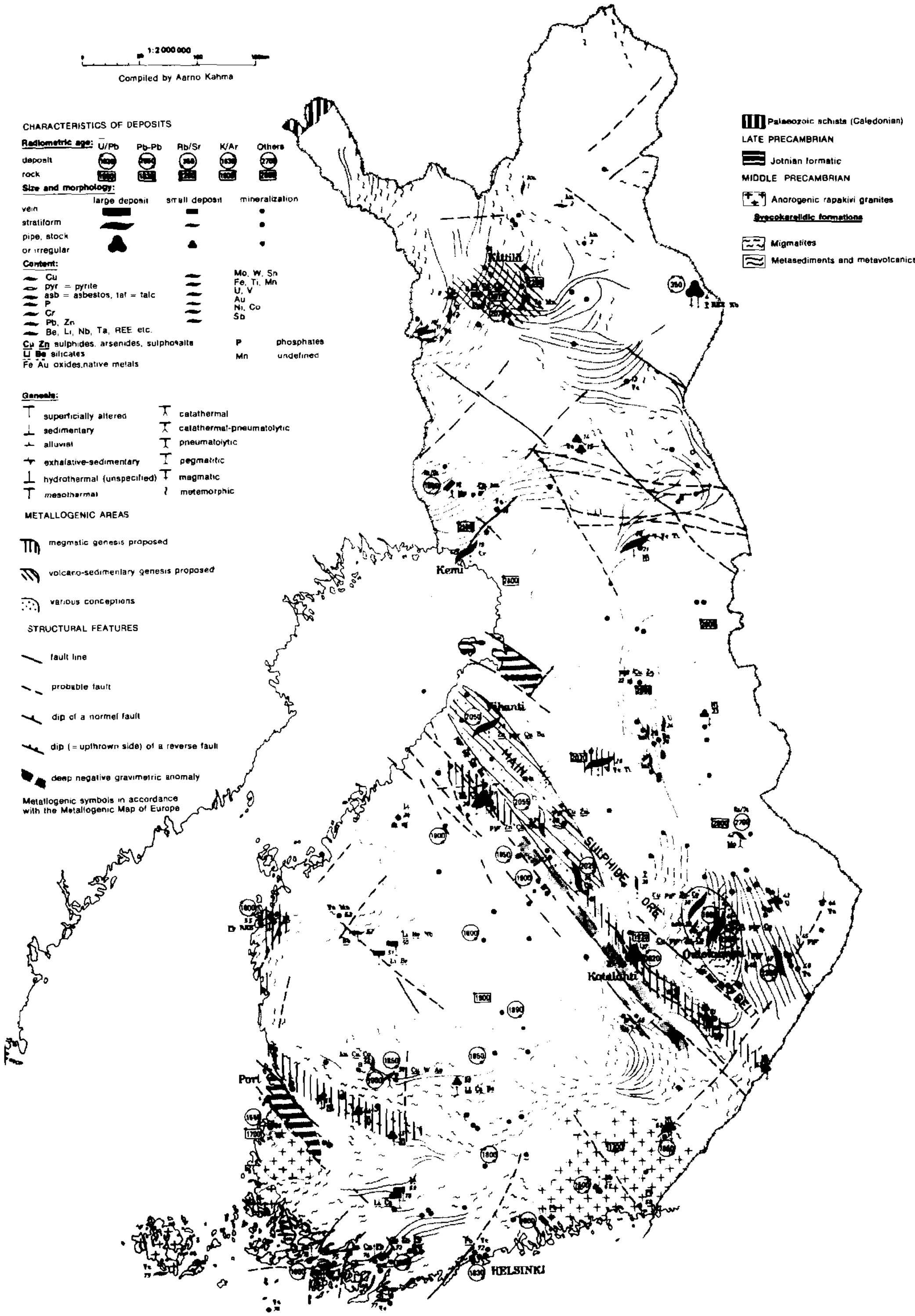

Fig. 1. Metallogenic map of Finland.

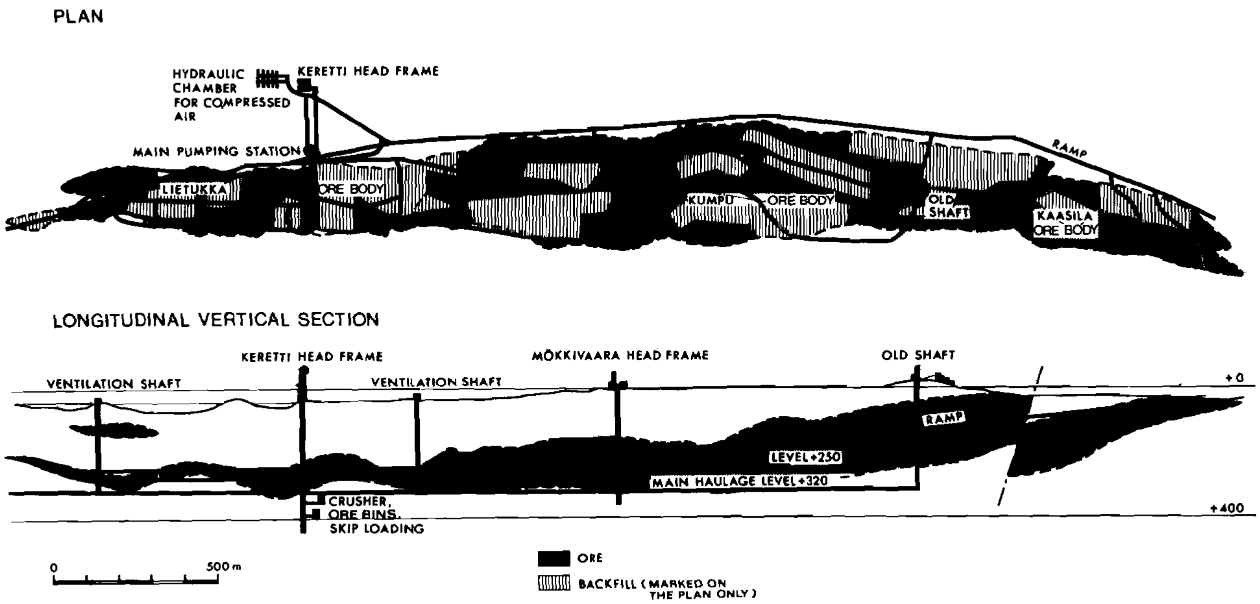

Fig. 2. Keretti mine.

ern part of the main sulfide belt. The rock associations are phyllites, arkoses, and black schists within a shear zone of impure arkose. The host rock is arkose and the main minerals are chalcopyrite, pyrrhotite, and smaller amounts of sphalerite and galena. In contrast to the Outokumpu ore type, Hammaslahti ore contains practically no cobalt or nickel.

OUTOKUMPU MINES

Most of the deposits mentioned occur as steeply dipping ore shoots and as rich veinlike ore bodies. Since the ore and the surrounding rocks are generally rather firm, mining is mainly performed by sublevel stoping with long-hole drilling.

In order to improve recovery, the mined-out stopes are in most cases filled with classified mill tailings, gravel, and waste rock, nowadays often mixed with cement. When the host rocks are less competent, sublevel caving, mechanized shrinkage stoping, and cut-and-fill methods are also applied.

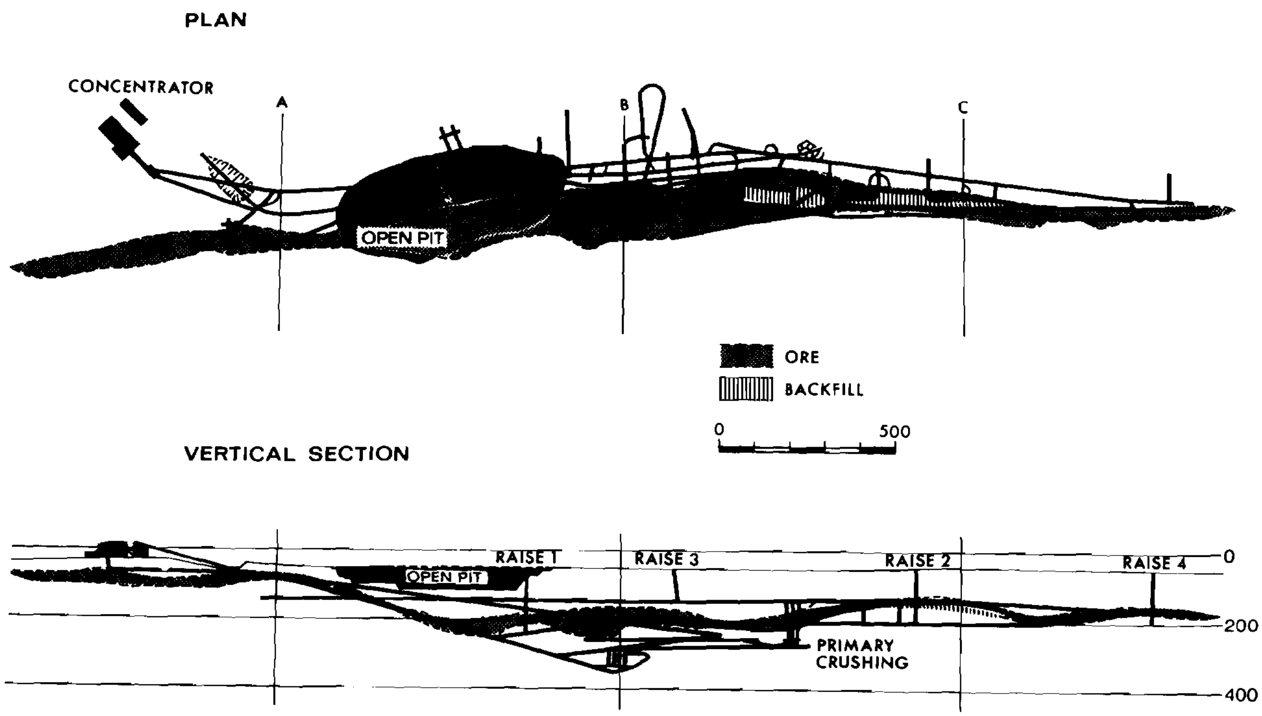

Fig. 3. Vuonos mine.

Table 3. Mining Methods in the Mines of Outokumpu Oy*

Mine	(main products)	Open pit	Sub-level stoping	Sub-level caving	Shrinkage stoping	Room and pillar	Cut and fill methods: Concrete pillar stoping	Cut and fill methods: Inclined wall stoping	Cut and fill methods: Conventional	Back filling: Loose	Back filling: Cemented
Vuonos	(Cu)	(x) (Ni)		(x) (Ni)		x	x	x		x	x
Vihanti	(Zn, Cu)		x		(x)				x	x	x
Pyhäsalmi	(Cu, Zn)	x	x	x	x					x	x
Kemi	(Cr)	x									
Kotalahti	(Ni)	(x)	x						x	x	x
Keretti	(Cu)			(x)	(x)	(x)	x	x		x	x
Hammaslahti	(Cu)	(x)	x							x	
Hitura	(Ni)	x									
Virtasalmi	(Cu)	(x)	x								
Vammala	(Ni, Cu)	(x)	x							x	x

*x = Currently used; (x) = previously used.

Table 4. Ore Production, 1979

Mine	Mill feed, 1000 t	Ore Quality, %						
		Cu	Zn	Ni	Pb	Cr_2O_3	Au g/t	Ag g/t
Vuonos								
copper ore	551	2.1	1.2				0.1	10
talc ore	230			0.2				
Keretti								
u/g ore	330	2.8	0.5				0.6	10
old tailings	137	0.4						
Hammaslahti	420	1.2					0.3	12
Vihanti	936	0.6	3.8		0.3			
Pyhäsalmi	1 039	0.7	1.8				0.4	14
Kemi	689					26		
Kotalahti	490	0.2		0.6				
Hitura	463	0.2		0.5				
Virtasalmi	303	0.7						
Vammala	317	0.3		0.6				
	5 905							

Two exceptions to the steeply dipping ore bodies are the almost horizontal deposits of Keretti (see Fig. 2) and Vuonos (see Fig. 3). These two ore bodies are exploited using locally developed mining methods. These are concrete pillar stoping at Keretti, inclined wall stoping at Keretti and Vuonos, and conventional room-and-pillar at Vuonos.

The exploitation of outcropping ore bodies normally starts with an open pit. The possibility of a quick start to production and its associated benefits in cash flow are the main advantages.

Table 3 shows the mining methods employed at the Outokumpu Oy mines in Finland. The ore production and operating figures for the various mines are shown in Tables 4 and 5, respectively, and total production of ore in 1979 is shown in Table 4.

MINES USING CUT-AND-FILL METHOD

Keretti

Geology: The ore body is an oblong plate cut by faults, 4 km long, 300 to 400 m wide, and usually less than 1 m thick though thickness may be 30 to 40 m. The mineralization is homogeneous and the host rock is generally strong. The ore body outcrops at one end and is 300 m deep at the other. The ore averages 3.5 to 4% copper, 24 to 36% iron, 23 to 25% sulfur, nearly 1% zinc, and 0.3% cobalt.

Layout: The mine has been under exploitation since 1913 in the eastern, central, and upper sectors, corresponding to the old shaft and the Mökkivaara shaft. As a result, most of the mine has already been worked out. Nevertheless, substantial ore reserves still

Table 5. Average Operating Figures for Main Underground Operations, 1979

	Keretti	Vuonos	Kotalahti	Virtasalmi	Vihanti	Pyhäsalmi	Hammaslahti	Vammala
Ore hoisted, t	330 000	551 000	490 000	303 000	936 000	1 039 000	420 000	317 000
Waste rock hoisted, t	—	21 000	9 000	4 000	—	58 000	11 000	104 000
Metal, t								
copper	8 900	11 000	600	2 000	4 000	6 300	4 800	—
nickel	—	220	2 700	—	—	—	—	1 200
zinc	570	2 900	—	—	33 000	15 600	—	—
lead	—	—	—	—	1 400	—	—	—
cobalt	650	330	—	—	—	—	—	—
Pyrite	—	—	—	—	—	186 000	—	—
Water pumping, m^3	1 700 000	1 000 000	900 000	110 000	760 000	600 000	160 000	400 000
Compressed air consumption, m^3/h	8 500	6 000	4 500	3 800	7 000	9 000	6 300	6 700
Electric power consumption, MWh	10 600	11 200	7 600	2 400	9 400	11 300	6 500	4 200
Ventilation air inflow, m^3/h	483 000	600 000	250 000	160 000	356 000	480 000	400 000	120 000
Total manpower (supervision included)	225	183	120	19	170	130	68	45
Productivity (1)	7	19	20	48	28	25	26	32

(1) Tonnes of ore hoisted per total shifts including mine department, engineering services and contractors.

remain as pillars in the older sectors and in the outcropping Kaasila section.

The principal mining area is presently located near the bottom in the southwestern sector of the Lietukka ore body.

The mine comprises five shafts, a ramp, three main levels, and an underground crushing station.

The Keretti shaft is the main shaft and has been operating since 1954. It is 408 m deep with a section of 3 x 10 m. It is provided with separate hoists for personnel, materials, and ore hoisting, and compartments for ladders and pipes.

The Mokkivaara shaft was completed in 1939 to a depth of 383 m. Today it is used only for ventilation, and the surface installations are used for the preparation of cemented backfill and other services.

The old shaft, completed in 1928 to a depth of 330 m, also serves only as a ventilation shaft. Two additional ventilation shafts are also operating. No. 1, located between the Keretti and the Mökkivaara shafts down to a level of +280, serves as a return for polluted air, and No. 2, situated near the western end of the mine to level +320 m, is for the intake of fresh air.

The main levels are located at depths of +250, +285, and +320 m. The main transport level is the +320 level which is provided with an electric railway serving the whole mine. Tracks are also laid on the other levels, which are used mainly for waste and some ore transport, and services.

The underground crushing station is located adjacent to the Keretti shaft, between levels +320 and +400. Crushing takes place in two stages to a maximum size of 130 mm. The crushed ore is then hoisted to the surface.

A ramp was recently opened from the easternmost end of the ore body (Kaasila sector) to level +285. It is 3500 m long with an inclination around 1:10 to 1:12 and a section of 20 m². It is surfaced with gravel. The ramp follows approximately the ore body's footwall edge from the Kaasila to the Keretti shafts. The main uses of this ramp are to provide good access to the older sectors of the mine for pillar recovery, to improve the underground traffic, and to ease connections between Keretti and the nearby Vuonos mine.

Vuonos

Geology: The ore body is similar in occurrence to Keretti, but somewhat smaller in size. It is plate-shaped, 3.5 km long, 50 to 150 m deep, 50 to 200 m wide, and with an average thickness of about 5 to 6 m. It contains on average 2 to 2.5% copper, 1 to 1.5% zinc, 22% iron, 15% sulfur, and some cobalt and nickel (0.2%). The rocks are generally strong.

Layout: The Vuonos mine was developed to make the most effective use of large load-haul-dump (LHD) equipment. An inclined ramp connects the surface with the underground workings (down to level +370). The section is 5 x 4.1 m and the length is 2500 m with an inclination of 1:8.5. The floor is surfaced with concrete down to level +220. Electric heating is provided for the pavement at the entrance to the ramp to prevent ice formation in the floor during wintertime.

The two main levels are the +160 and the +220. The development openings are driven in the footwall and connected to the inclined ramp. The sections are 4.5 x 3.7 m. Their floors are surfaced with concrete along 1200 m with the rest being leveled with gravel.

A third main level, the +280, has been developed below and near the center of the ore body. It is used primarily for exploration and also as an auxiliary level for ventilation, communications, and water handling.

The mine has three orepasses on the +160 and

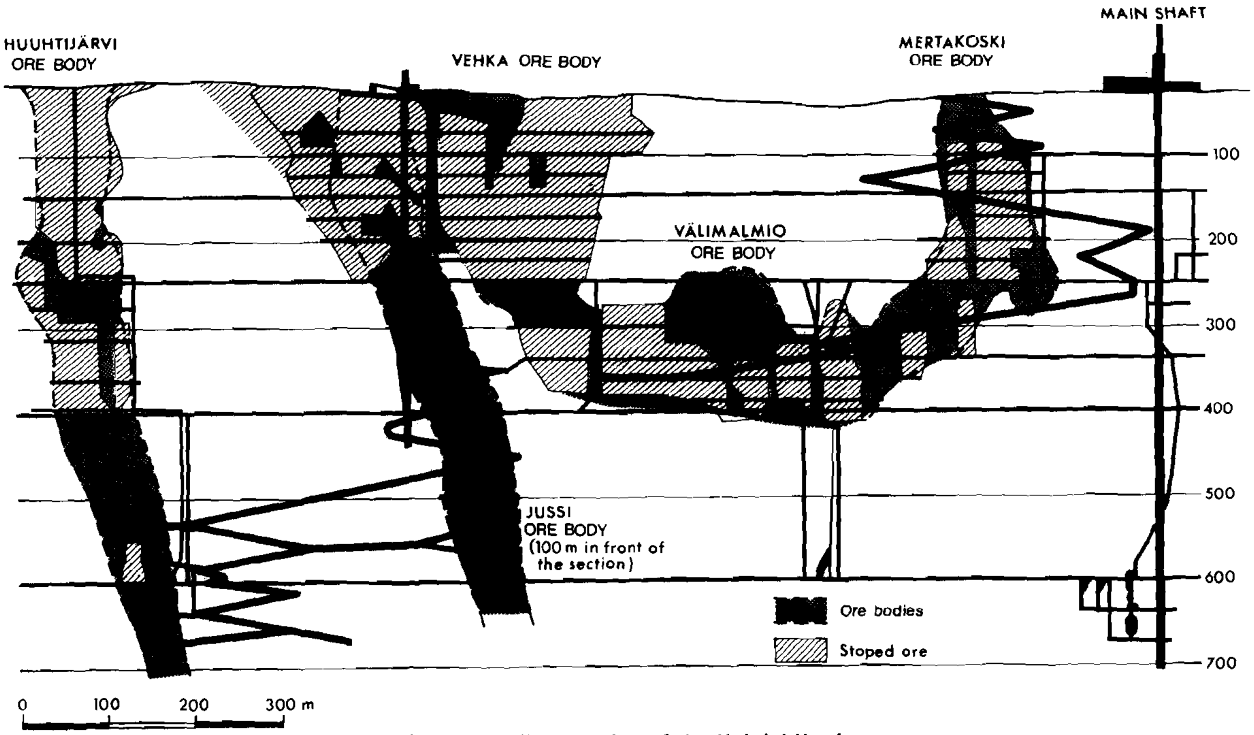

Fig. 4. Longitudinal section of the Kotalahti mine.

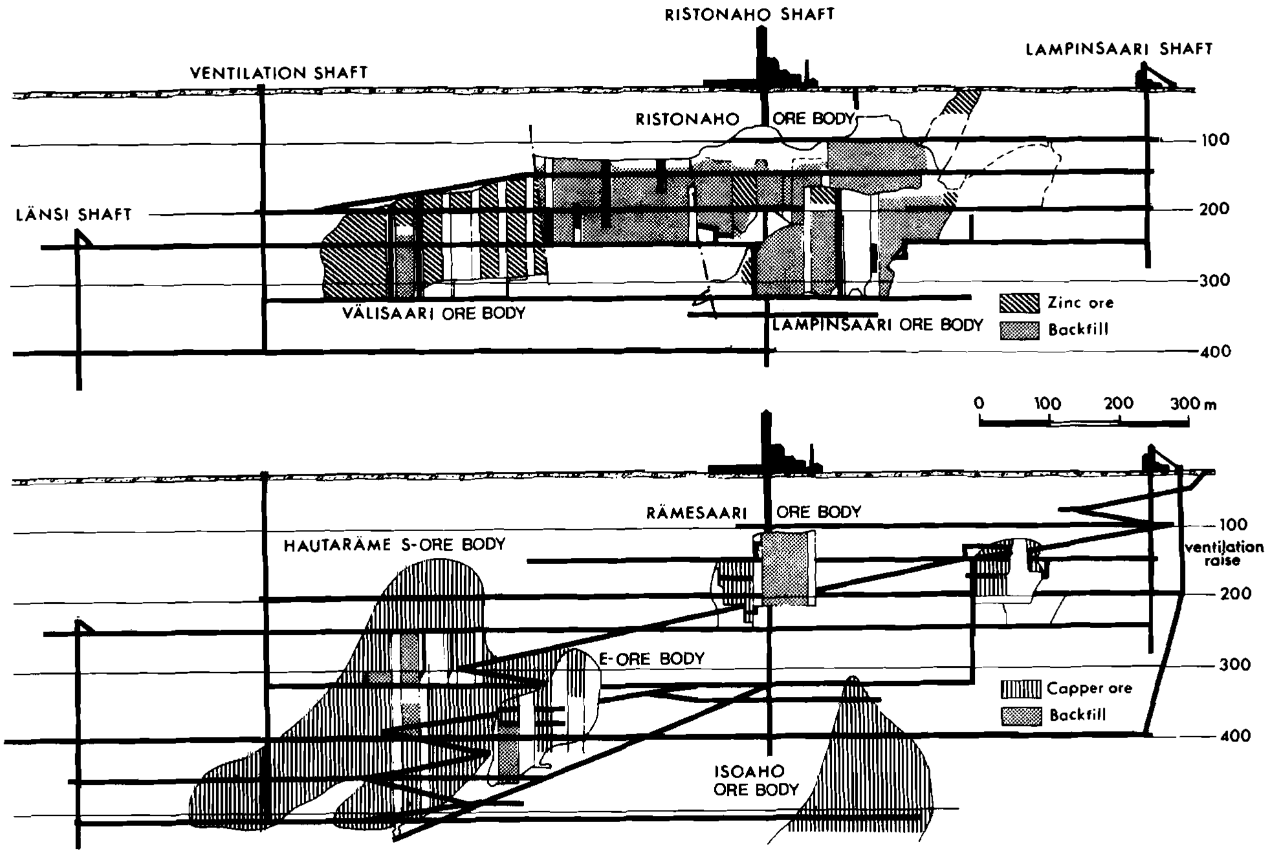

Fig. 5. Longitudinal sections of the Vihanti mine.

+220 levels, which connect to the underground crushing station opened at level +320. The crushed ore is carried to the surface by conveyor belts through a system of two ramps (total length 1550 m), and inclined at 1:3.6 and 1:4.5 respectively.

Other existing connections are four ventilation raises located at regular intervals along the ore body.

Kotalahti

Geology: The deposit is made up of several steeply dipping ore shoots. The mineralization is variable; the amount of sulfides and metal content vary even within the same ore shoot. Dissemination is the typical mode of occurrence in certain locations, whereas in others a breccia type with massive sulfides is predominant. The length is about 1.3 km with a dip towards the northeast. The rocks are usually firm, but in places they are weakened, partly by frequent jointing. The ore averages 0.7% nickel and 0.28% copper.

Layout: Five vertical ore bodies are being exploited (see Fig. 4): Mertakoski from levels +250 to +400; Huuhtijärvi below level +250; Välimalmio from +250 to +400; Jussi from +250 to +700; and Vehka, where pillar recovery is being finished.

The mine has two shafts, a ramp, four haulage levels, and a crushing station.

The main shaft is located at the northern end of the ore body, reaching a depth of 700 m. It has a section of 4.5 x 4 m with separate compartments for personnel lifting and ore hoisting, ladders, and pipes. Vehka shaft is located in the footwall of the Vehka ore body, and is 420 m deep, with a section of 2.1 x 3.5 m. It is employed for the intake of fresh air for ventilation. In addition there is a short raise connecting the empty stopes of Huuhtijärvi ore body with the surface for the intake of fresh air.

The main levels are located at +250, +340, +400, and +600 m, and all are provided with rail tracks. Level +250 is used for the transport of waste rock required for filling. Level +340 serves the Välimalmio and Mertakoski ore bodies, and level +400 serves the Jussi, Välimalmio, and Mertakoski ore bodies. Level +600 is the main haulage level, serving all ore bodies, taking ore to the crushing station.

The crushing station is located beside the main shaft between +600 and +675 m. Crushing takes place in two stages to a maximum size of 250 mm.

The ramp was completed in 1977, and serves the mine down to +800 m.

Vihanti

Geology: The known length of the complex is roughly 2 km and the maximum width is 500 m. The trend is approximately east-west with dips fluctuating between 0.61 and 1.57 rad (35 and 90°) to the south and southwest. The depth is in excess of 700 m.

There are zinc and copper ore shoots with very variable grades. The structure of the ore is very complicated due to folding and replacement.

The comparison of the zinc ore is 5 to 15% zinc, 0.4 to 1% copper, and 0.3 to 0.7% lead with some gold and silver. The copper ore contains 0.4 to 1.8% zinc, 0.2 to 0.5% copper, and 13 to 30% sulfur.

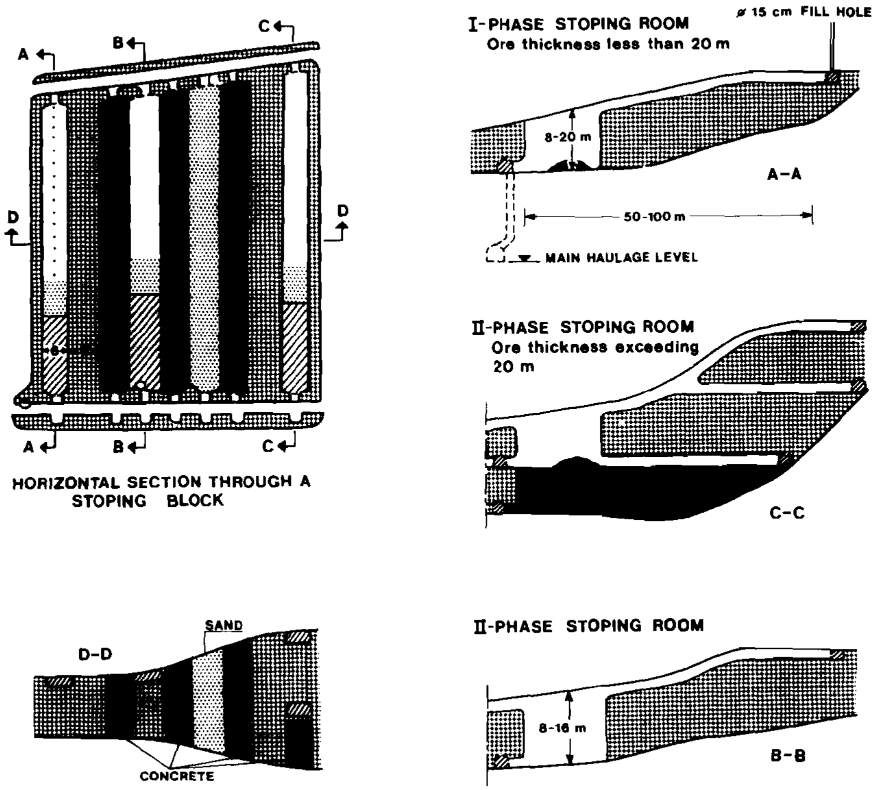

Fig. 6. Concrete pillar stoping at the Keretti mine.

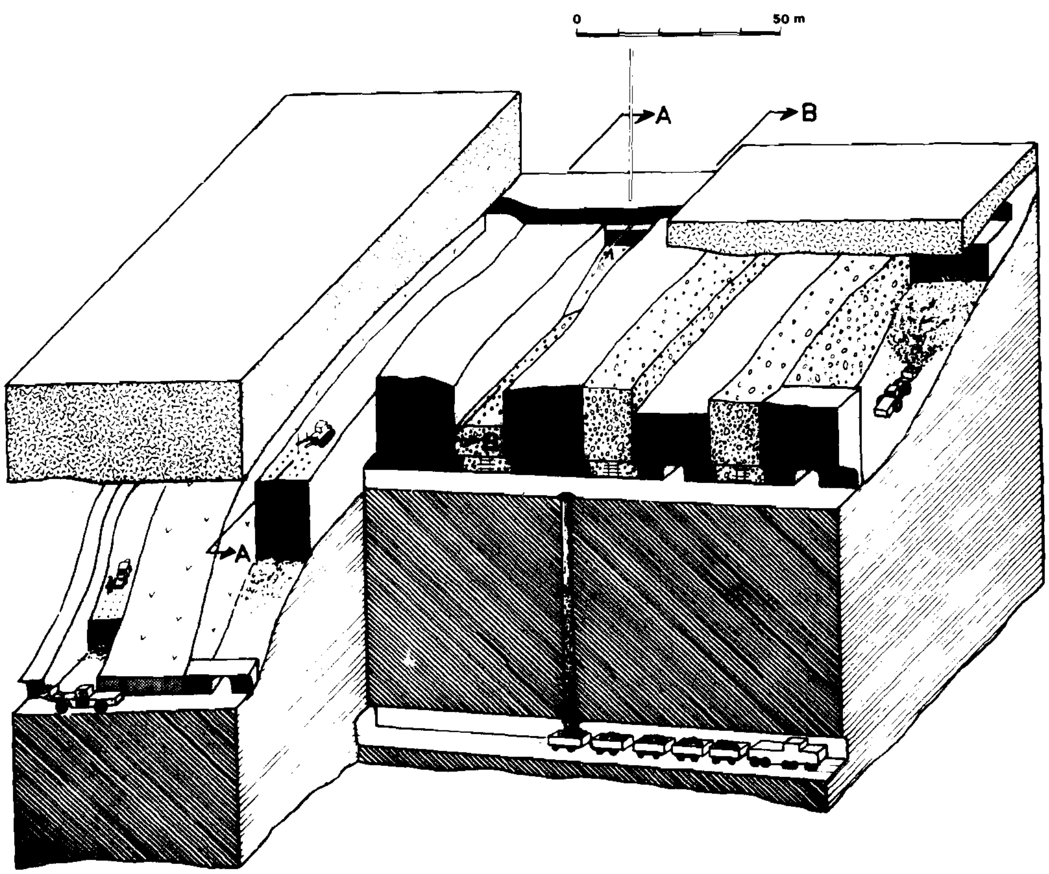

Fig. 7. Concrete pillar stoping at the Keretti mine.

Layout: The following ore shoots are presently being exploited (see Fig. 5): Välisaari, mostly for zinc ore; Ristonaho and Lampinsaari, in pillar recovery of zinc ore; E ore body, Rämesaari, and Eastern for copper ore; and Isoaho, in development.

The mine comprises four shafts, an inclined ramp, main transport levels, and two crushing stations underground. The Ristonaho shaft is the main shaft, and is located at the footwall of the Ristonaho ore body. It is 421 m deep with a section of 3.9 x 6 m. There are separate compartments for personnel lifting, ore hoisting, pipes, and ladders.

The Lampinsaari shaft, located near the eastern end of the ore body, is 260 m deep, and is used mainly for waste hoisting and services. It is connected to levels +100, +150, +200, and +250.

The underground Länsi shaft is located near the western end of the ore body between levels +250 and +515. At present it is utilized for waste rock hoisting and services between these levels.

A downcast ventilation shaft is located near the western end of the ore body, 515 m deep, and is connected to levels +200, +250, +325, +400, and +515. A raise was driven at the eastern end of the mine for exhaust air.

The main levels are situated at 50 to 75-m intervals. At present the main rail haulage levels in operation are: level +250, serving the Ristonaho ore body and waste haulage from the Länsi shaft to the Lampinsaari shaft; level +325 serving the Välisaari and Lampinsaari ore bodies, and level +515 for waste rock haulage.

Two underground crushing stations are installed; the main one is located between levels +325 and +400, beside and connected to the Ristonaho shaft; the second one, located at level +515, was built to receive the ores from levels below +325. The crushed ore is transported by conveyor along a ramp to the station at level +325-+400 for hoisting through the Ristonaho shaft.

A main ramp connects all main levels and ore bodies from the surface down to level +600. Its inclination varies between 1:10 and 1:5. It is mostly surfaced with concrete and macadam. The plans provide for an extension down to level +700, in order to explore the deeper portions of the ore body.

MINING METHODS

Concrete Pillar Stoping

Around 1950, planning was begun for a new mining method which would satisfy the following conditions: safety, high recovery, small dilution, and absence of

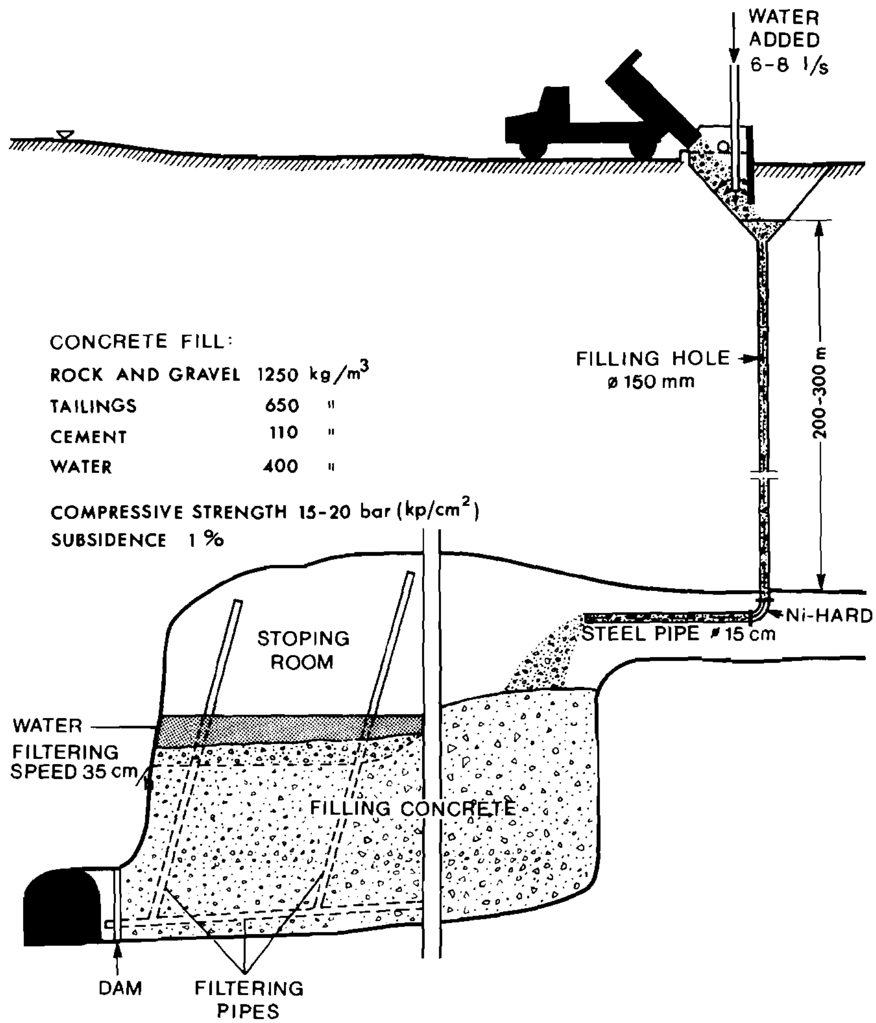

Fig. 8. Filling of stopes with concrete fill at the Keretti mine.

cave-ins. Several years of experimentation produced concrete pillar stoping.

This system has been developed in Outokumpu and it has been the main stoping method at Keretti since 1954 (Figs. 6, 7, and 8). The Keretti ore (3 to 4% copper) can be exploited safely and with good recovery using this method.

The mining block is divided alternately into 6- and 8-m wide parallel rooms with vertical walls. First the 6-m wide rooms are stoped and filled with concrete; in the second phase the 8-m wide ore pillars are taken away. These stopes are filled with classified tailings and natural gravel.

The development is started by driving a ramp which provides access both to the hanging wall and to the footwall.

In all stopes a top heading measuring either 6.0 x 3.5 m or 8.0 x 3.5 m is driven in the ore along the hanging wall contact. As the heading proceeds, the roof is supported by bolting or, when necessary, by guniting. Depending upon the thickness of the ore, drifts are also driven along the foot of the ore. Long-hole drilling is then used first to drive a slot raise at the head of the stope and then to drill the stope itself. Whenever feasible the stope is drilled upward; this serves to keep the holes open, which facilitates charging.

When the thickness of the ore exceeds 20 m, the stope is divided by subheadings into 20-m high sections which are excavated upwards individually.

Reinforcement: For rockbolting 16- to 20-mm diam rebar is normally used in 2.4-m lengths, although 6-m long bolts have been used. The bolts are fed into the holes for their entire length and are bonded with a mix of classified tailings from the concentrator and cement in the ratio 1:1 with water and 1% bentonite added. The bolts are not prestressed and washers are not used; instead the ends are bent 1.57 rad (90°).

Guniting is performed by the semiwet method using Aliva 600 equipment. The dry concrete is prepared above ground at a concrete mixing station and is transported to the mine in trucks. A special vehicle is used for the guniting. The nozzle is attached to a hydraulically operated boom and the operation is remote controlled from a pressurized cabin to improve working conditions.

Fill: The concrete required for the fill is also prepared at a concrete mixing station above ground. Gravel screened through a 20-mm diam screen and classified tailings in the ratio of 2:1 form the aggregate for the fill, and 110 kg of portland cement and 600 L of water are added per cubic meter. The maximum theoretical compressive strength of the concrete fill is 1.7 MPa. In practice however, a strength of only about 0.6 MPa is achieved since the concrete loses its uniformity during application in the stope.

The fill is first poured down 152-mm (6-in.) fill holes from the surface and then through 150-mm diam welded tubes into the stope. The tube bends are Ni-hard cast for protection against the heavy abrasive wear of the fill.

Fill for stage 2 comes straight from the concentrator and is directed to the stopes through 78-mm diam fill holes and 75-mm diam plastic tubes.

Cribbed channels, wrapped around twice with hessian sacking, dewater the fill. Complete drainage and setting of the fill usually takes about six months.

Barricades and through drives are built by erecting cribbed walls which are reinforced and anchored with steel cables. These serve to support a 100 to 200-mm thick gunited layer of concrete.

Drilling and Charging: The drifts in stage 1 are driven with three-boom Tamrock Paramatic jumbos and the drifts in stage 2 with two-boom Paramatics. A special bolting jumbo, the Boltmatic, was developed for bolting the top headings. This jumbo ensures the safe drilling of boltholes under the already reinforced roof.

Production drilling is performed with an Oku jumbo, a two-boom crawler-mounted rig. Four to five holes are drilled per row in long-hole drilling with a row spacing of 1.5 to 2 m, a burden of 1.5 to 2 m, and a hole size of 51 mm. Ammonium nitrate-fuel oil (ANFO) is used as the blasting agent.

The walls of the stage 1 stopes are smooth blasted

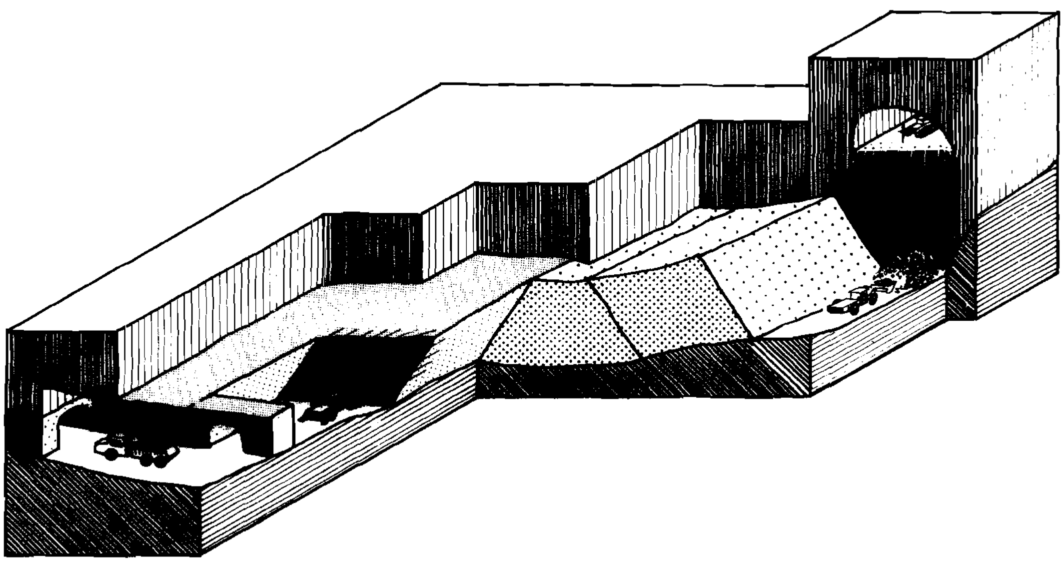

Fig. 9. Inclined wall stoping at the Vuonos mine.

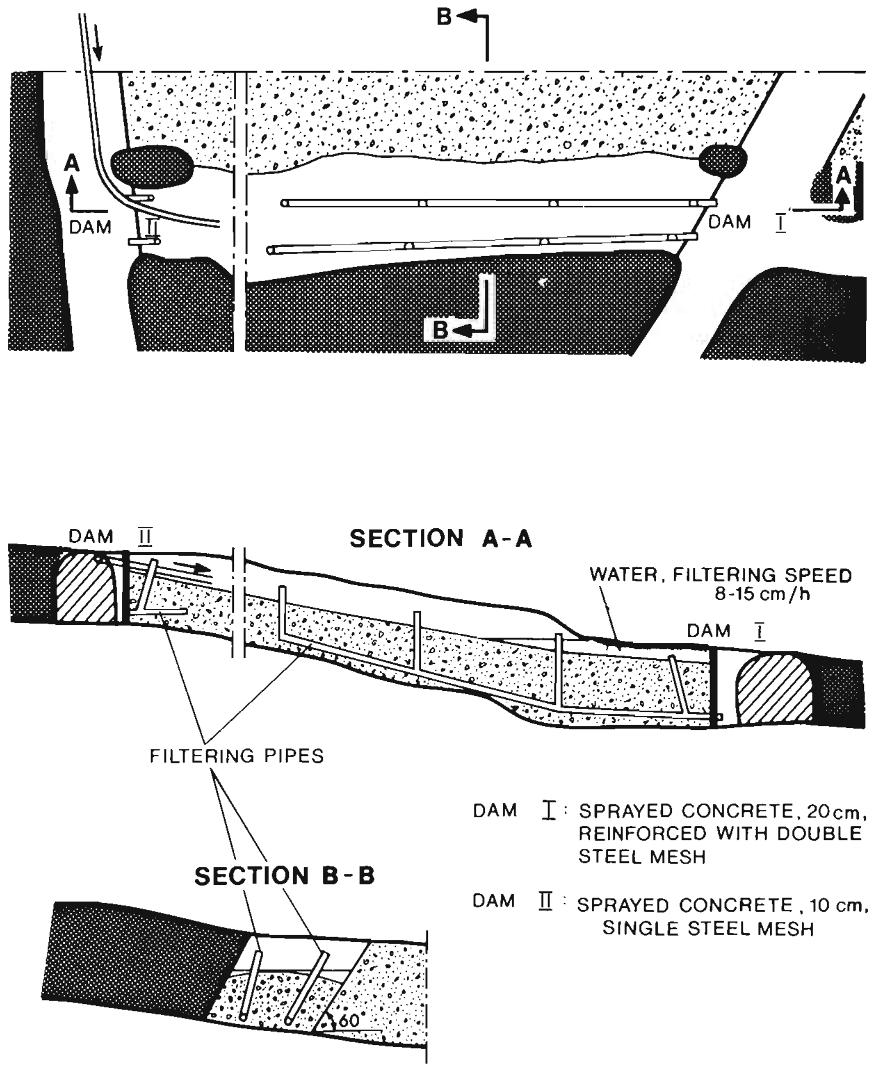

Fig. 10. Filling of stopes with classified tailings from the concentrator during inclined wall stoping at the Keretti and Vuonos mines.

using ANFO weakened with polystyrene prills in the ratio of 1:1.

Loading and Hauling: LHD loaders with 3.8- to 6-m^3 capacity muck out the excavated ore direct to orepasses from which a train hauls the ore to the crusher.

In the newest stoping areas, however, the ore is loaded into dumpers which haul the ore straight to the crusher. The loading distance varies between 50 and 200 m, averaging about 100 m.

An electrohydraulic excavator has also been tested in loading but its limited maneuverability in the mine turned out to be a great drawback.

Inclined Cut-and-Fill

Introduction: Concrete pillar stoping fulfilled the demands placed on it for mining thick (>8 m) ore bodies. About half of Outokumpu's ore, however, lies in areas under 8 m thick. These had to be excavated either by conventional sublevel caving or by leaving pillars, and due to the nature of these methods, ore losses resulted.

Inclined cut-and-fill, a method whereby adjacent stopes are filled only with sand, was developed at Outokumpu at the end of the 1950s. It enables 3- to 8-m thick gently dipping ore bodies to be mined with the

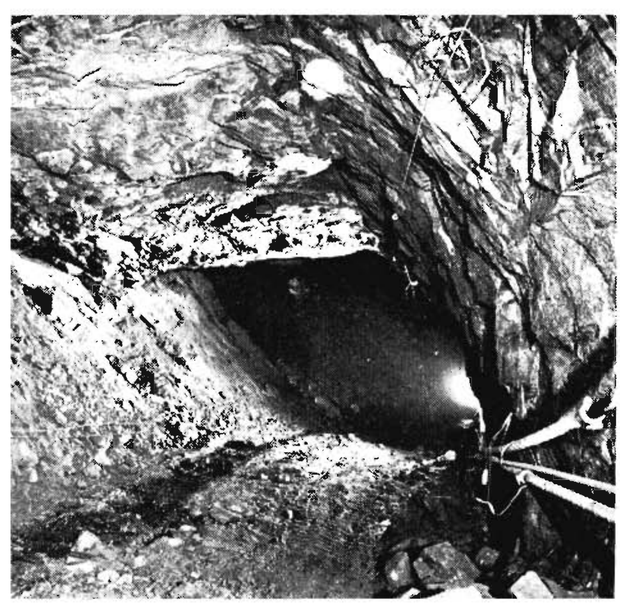

Fig. 11a. Inclined wall stoping at the Vuonos mine.

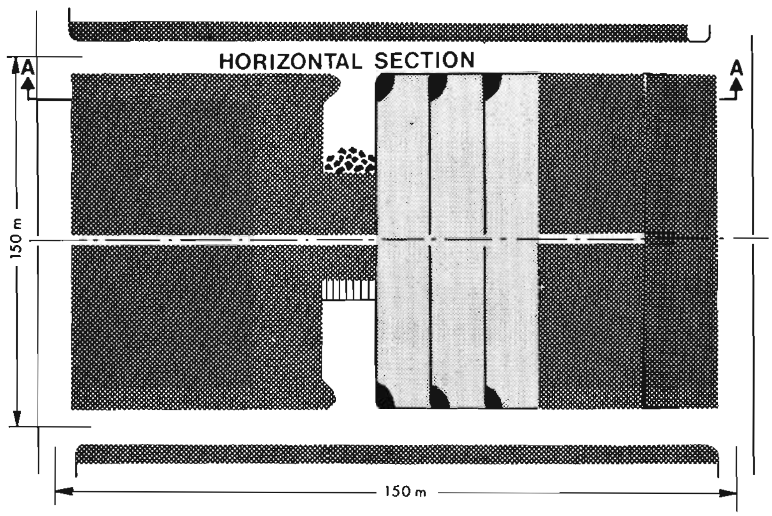

Fig. 11b. Horizontal section.

excavation and filling stages following each other successively without the need for pillars.

It can also be applied to thicker and massive ore bodies starting from the footwall in 8-m layers proceeding upward on the fill. In certain ore zones up to 12 m, the development includes a roof drift 4 m high matching the stope width.

At present this is the main method used in the excavation of Outokumpu's Vuonos copper ore body.

Description: The ore is divided into 40- to 80-m long mining areas as wide as the ore itself, and haulage and connecting drifts are driven at both ends of each area. The area is opened at its lowest point by excavating the first stope across the ore body (Fig. 9). Three methods can be used to excavate the stopes: 3- x 3-m top heading is driven, from which the stope is fan drilled; a top heading is driven and slashed to the stope's width (about 6 m), after which the stope is benched out; or the whole profile of the stope is driven simultaneously. This latter method is the main one employed at Vuonos at present.

The top heading (or roof) is bolted where necessary for reinforcement. Both sides of the first stope are inclined upward. This inclination varies, according to the fill material used, from about [1.13 rad (65°)] for classified mill tailings to [0.78 rad (45°)] for ordinary sand.

Both ends of the stope are barricaded and filling proceeds, usually with classified mill tailings (see Fig. 10) slurried to about 60% solids. The stope is then drained with the same cribbed channel system as in concrete pillar stoping. Drainage takes about three months. The sand has proven firm which is important to avoid both dilution and ore losses. The following stope is opened next to the preceding ore in the form of a parallelogram.

No special opening is required since the whole profile method is used and the rock is excavated against the fill (Fig. 11). The length of round varies between 2.8 and 3.6 m.

Drilling and Charging: Tamrock Minimatic (see Fig. 12), Paramatic, and Zoommatic drill jumbos are used depending on the height of the stopes. The holes are charged only with ANFO using a pressure vessel loading machine.

Normally each round is drilled at full face with horizontal blastholes up to the maximum height of 8 m. Conventional bench drilling is performed in those ore zones up to 12 m high, where a roof drift has been developed.

Loading and Hauling: In the smallest stopes 1.5-m^3 capacity LHD loaders have had to be used. Otherwise loading and hauling are performed in the same way as in concrete pillar stoping.

CONVENTIONAL CUT-AND-FILL

Conventional cut-and-fill (Fig. 13) is used for pillar recovery at Vihanti and for mining a small sized ore body at Kotalahti. In both cases it accounts for a small percentage of the ore production (5% or less). The great advantages of the method are its safety and the good recovery and low dilution of the ore. The disadvantages are the low productivity (9 to 10 t/manshift) and the associated higher cost compared with other methods.

At Vihanti, each cut is about 3 m high. A common drift is opened first along the center of the pillar, transverse to the ore body. Both walls are slashed to the

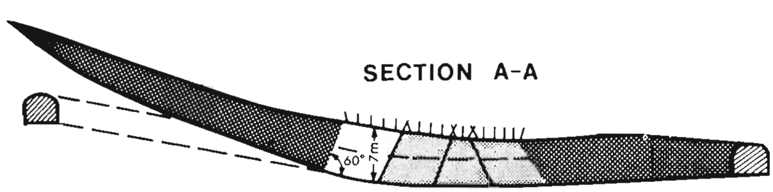

Fig. 11c. Vertical section.

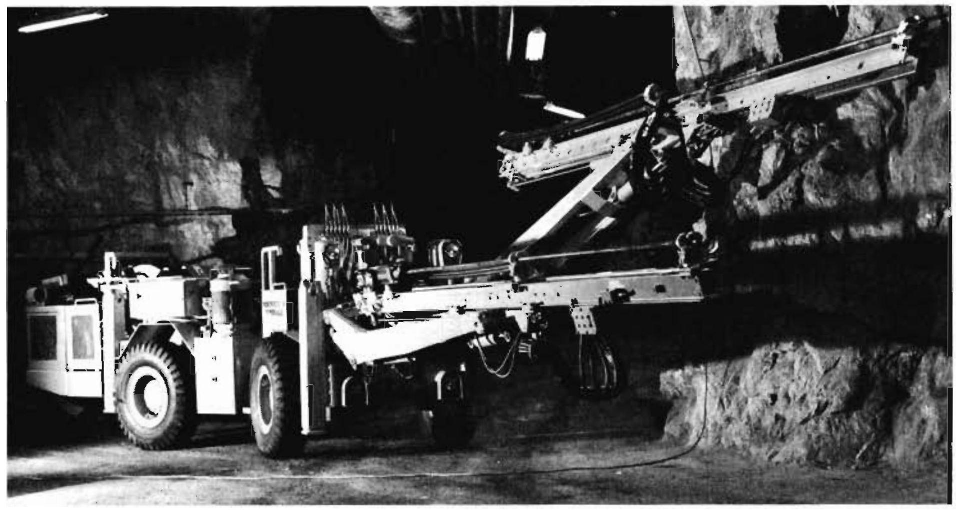

Fig. 12. Tamrock Minimatic drill jumbo, used for driving of stopes.

pillar's breadth, about 10 m. Good ore recovery with minimum dilution is obtained when ore walls 0.5 to 1 m thick are left, as this prevents the surrounding filling material from entering the stope. The ore is mucked by small shovel loaders into orepasses connecting to the main haulage levels. The empty stope is filled with classified mill tailings, and after settling, a new production cycle begins on the fill.

Cut-and-fill at Kotalahti is simpler because the ore body is rather thin (3 to 4 m). Therefore the stope can be driven as a conventional drift, the floor being the previous backfill. The height of each cut is about 4 m and the length 80 to 100 m.

TECHNICAL AND ECONOMIC DATA FOR DIFFERENT STOPING METHODS

The productivity of the stoping methods, including development, are given as follows:

Stoping Method	*Tons of Ore/Manshift*
Sublevel stoping	20-80
Sublevel caving	20-30
Concrete pillar stoping	20-25
Inclined wall stoping	15-20
Cut-and-fill	5-20

Table 6 shows three items of cost for 1979: stoping without development costs, stoping including development costs, and filling costs.

Due to the differences in methods, capacities (Table 7) and costs (Table 8) have had to be calculated separately. Development work, production stoping, reinforcement, and filling have been considered.

In concrete pillar stoping, development work includes connecting drifts, the top heading, and possible sublevels. The slot raise is the final stage in development work. Loading out of the stopes by LHD loaders marks the end of the stoping stage.

Table 6. Items of Cost for 1979

	US$ per ton of ore		
Stoping Method	Stoping Without Development	Stoping, Including Development	US$ per Filled m³
Open pit mining		1.00 - 1.50	
Sublevel stoping	0.75 - 2.00	1.75 - 3.50	Filling with lean concrete 6.00 Classified tailings 1.50
Sublevel caving	2.00 - 2.50	3.00 - 4.25	
Concrete pillar stoping	2.00 - 2.50	Stoping 4.00 Filling 4.00 8.00	Concrete 22.00-27.00 Classified tailings 6.50
Inclined wall stoping	3.50 - 5.00	Stoping 4.50 - 7.00 Filling 2.25 6.75 - 9.25	Classified tailings 6.50

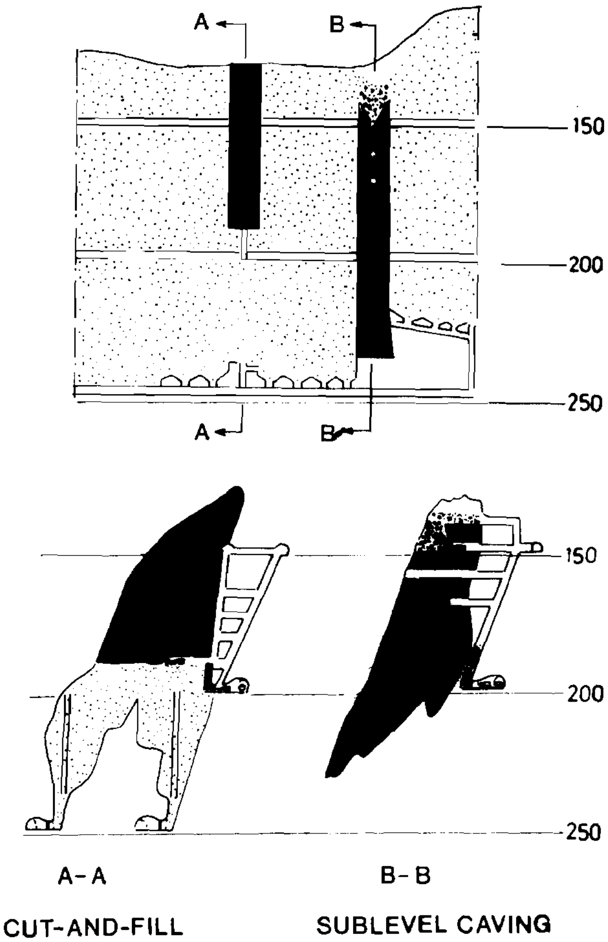

Fig. 13. Pillar recovery at the Vihanti mine.

In inclined cut-and-fill, development work includes connecting and haulage drifts and sometimes a top heading. The relatively very high efficiency is due to the new, fully mechanized drilling equipment used in the Vuonos mine, and the heavy reinforcement needed is caused by weak roof rock in certain stoping areas.

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Table 7. Rates Achieved with Cut-and-Fill Stoping in Finland in 1974

Work Phase	Unit	Concrete Pillar Stoping: Pillar	Concrete Pillar Stoping: Stope	Inclined Cut-and-Fill
Development work				
t/manshift		26.2	19.6	50.5
m³/manshift		7.4	5.5	16.0
explosives	kg/t	0.74	0.67	0.93
explosives	kg/m³	2.63	2.38	2.94
Stoping				
t/manshift		54.4	45.5	56.4
m³/manshift		15.2	12.7	17.3
explosives	kg/t	0.24	0.20	0.41
explosives	kg/m³	0.85	0.73	1.33
Reinforcement				
manshift/1000 t		8.9		1.1
manshift/1000 m³		31.9		3.6
Fill				
concrete	m³/shift	165		
sand	m³/shift		92	92
Total				
t/manshift		39.7		53.8
m³/manshift		11.1		17.0
explosives	kg/t	0.29		0.59
explosives	kg/m³	1.03		1.85

Table 8. Costs for Cut-and-Fill Stoping in Finland 1974

Work phase	Costs: Fmk/t	Fmk/m³	%
A. Concrete Pillar Stoping			
Development work	14.18	50.75	49.3
pillars	5.84	20.91	20.3
stopes	8.34	29.84	29.0
Reinforcement	2.03	7.28	7.0
pillars	0.51	1.83	1.8
stopes	1.52	5.45	5.2
Stoping	5.59	20.00	19.4
pillars	2.30	8.25	8.0
stopes	3.29	11.75	11.4
Filling	7.01	25.10	24.3
concrete	5.18	18.56	18.0
tailings	1.83	6.54	6.3
Total	28.81	103.13	100.0
B. Inclined Cut-and-Fill			
Development work	4.62	14.98	32.0
Stoping	7.22	23.38	49.9
Filling	2.62	8.52	18.1
Total	14.46	46.82	100.0