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NR 14

CHILEAN MINING

TECHNOLOGICAL AND GEOMECHANICAL ASPECTS

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Spis treści

Nie masz kraju, który by mniej był podobny do naszego [...]
same skały, pustynie i morze; ni lasów, ni obszernych łanów
zbożem zazielenionych, ni łąk naszych, ni wsi...
(Ignacy Domeyko)

Słowo wstępne

Chile to jeden z nielicznych krajów na świecie, gdzie słowo Polska — Polonia znane jest przede wszystkim dzięki pracy uczonych i badaczy polskiego pochodzenia. Przykład Ignacego Domeyki — rektora Universidad de Chile w Santiago, człowieka wielce zasłużonego dla rozwoju nauk geologicznych i oświaty, nie jest przykładem odosobnionym. Duży rozgłos zyskali sobie także botanik Józef Warszewicz, Henryk Babiński — odkrywca złóż węgla w Chile i inni. Ignacy Domeyko związany był również z miastem La Serena. Pracując w kolegium górniczym w Coquimbo dał początek kolekcji skał i minerałów, która obecnie znajduje się w murach młodego i prężnego Uniwersytetu La Serena. Obydwaj autorzy przedstawionych wykładów są pracownikami tej właśnie uczelni.

Alfonso Carvajal, absolwent studiów magisterskich na Wydziale Górniczym AGH, jest ambasadorem uczelni i polskiej nauki w Chile, zaś Federico Brunner — przyjacielem i sympatykiem Polski. Z prawdziwą przyjemnością pragnę zaproponować zapoznanie się z dwoma wykładami prezentującymi niektóre problemy górnictwa rud w Chile — kraju posiadającym największe zasoby rud miedzi na świecie i jedne z najwyższych wskaźników w rozwoju górnictwa. Wszak to właśnie na terenie Chile — zdaniem niektórych specjalistów z zakresu geologii gospodarczej — znajduje się „Miedzionośna Zatoka Perska".

Polska mająca duży dorobek w dziedzinie nauk górniczych może być dla Chile interesującym partnerem. Mam nadzieję, że coraz liczniejsze kontakty polsko-chilijskie, a także ten skromnny zeszyt staną się wyrazem obiecujących początków szerszej współpracy.

Przewodniczący Komitetu Organizacyjnego
Szkoły Eksploatacji Podziemnej

Jerzy KICKI

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Technology of mining in Chile and perspectives

Key words
Chilean mining-organization-production-geology-technology-perspecitves

Abstract

The paper describes the Chilean mining, especially copper mining. The historical outline of mining development in Chile is presented. The organization, rate of production and resources of extractive industry are discussed. The National Copper Corporation (CODELCO) is characterized in more details. The requirements in the field of environmental protection in mining sites, lawful regulation for foreign investors, and the structure of foreign investments during 1974—1993 are also presented. The typical geological structure of the copper deposit, classification of exploitation methods including block caving and typical exploitation technology are exposed.

The paper presents also main directions of mining development till 2000.

1. Introduction

When the Spanish came to Chile, our aborigines already had a mineral of their own, which, was used as cooking utensiles, arrowheads, ornaments, etc.

In 1838, the Polish engineer Ignacio Domeyko arrived in Chile, starting the first courses of mining in La Serena city. .Between 1830 and 1870, coal became the most important mining product and the VIIIth Region of the country played a major role in the Chilean economy; from about the end of the XIXth century to 1930, Chile received the benefits of a „White Gold" (Nitrate).

Later on, world development generated a higher demand for copper, thus producing an important increase in copper extraction which is reflected in the operation of copper producing center such as El Teniente, Chuquicamata and others which started to be mined at a later stage.

At present, due to the presence of 26 Canadian mining companies, and over 10 American, English and Australian ones, the development and potential of the mining has become very optimistic.

With this potential, Chile will continue to grow and will remain as the main copper supplier, besides gold, lithium, nitrate, iodine and molybdenum.

The State is promoting a process of modernization and an improvement of the productive management and the institutional structure, with the purpose of turning Codelco, Enami, Enap, Cochilco and Sernageomin into efficient state companies.

The decrease in metal grade and the increase in the depth of the principal copper deposits has forced the state into an important technological development in its mining enterprises.

2. Location

Chile is located West and South of South American Southern cone, extending down to the Antarctica and reaching West to Easter Island in Polinesia.

The main geographical features of the country are: To the North, the Atacama Desert; to the East, The Andes; to the South, the Antarctica; and to the west, 5000 km. of the Pacific Ocean.

With a continental and insular area amounting to 756.6 thousand square kilometers and 1,250 square kilometers of Antarctica, the varied geographic scenery that the country offers is very attractive for tourists and visitors.

Of the 13.2 million inhabitants, 84.9% is urban population with a density of 17 inhabitants per square kilometer.

3. Chilean copper mining

The Chilean Copper Mining is divided into three categories:

Large Scale Copper Mining

Here we find the companies that exceed 75,000 metric tons of copper bars per year.

Medium Scale Copper Mining

All companies with production under 75,000 metric tons per year and with capitals exceeding 70 minimum income, rang A of the Department of Santiago are included in this group.

Small Scale Mining

Here we find companies with a capital stated in their articles of incorporation under 70 minimum income, rang A of the Department of Santiago, which are excempted from the provisions in decree with Force of Law (D.F.L.) N° 251.

According to the origin of their capitals, mining is classified as following:

Privately Owned Mining

This sector is made up of private small — or medium-scale mining companies and is represented by SONAMI (Sociedad Nacional de Minería).

State Owned Mining

Into this sector, we find CODELCO, constituted by four copper mines: Chuquicamata (open pit), El Teniente and El Salvador (underground), and Andina (open pit and underground).

Another company is ENAMI (Empresa Nacional de Minería) whose action is promoting small — and medium — scale activities.

ENACAR (Empresa Nacional del Carbón) groups the principal underground coal mines, and ENAP (Empresa Nacional del Petroleo), the National Petroleum Enterprise, exploits some deposits and carries out exploration projects.

4. Resources

Besides copper, nitrate, iodine and molybdenum, Chile has interesting resources of selenium, iron, lead, manganese, zinc, sulphur, baritine, calcium carbonate, sodium chlorhide, puzolane, gypsum, clays, marble, diatomites, feldspar, quartz, guano and ulexite.

Table 4.1. Production and Reserves as percentage of the world position
Tabela 4.1. Produkcja i rezerwy wyrażone w procentach w stosunku do pozycji światowej

	Category	Production	Reserves
Copper	1	20	27
Natural nitrate	1	100	100
Lithium	2	36	58
Iodine	2	33	13
Moybdenum	2	19	21
Silver	7	9	3
Gold	9	2	1,5

Table 4.1 shows the reserves and production as percentages of the world position.

The National Geological and Mining Service (Sernageomin), reports that the total area of the country covered by mining concessions up to the end of September increased 12,5% compared to the same period in 1994, reaching 15 712 403 hectares.

Exploration concessions reach 916 089 hectares, representing a 14% increase for the same period 1994.

Exploitation concessions reach 796 314 hectares with a 10% increase compared with the same period 1994.

The Second Region, with 6 395 390, is the favorite; the First Region with 3 050 085 hectares running in second place and the Third Region with 2 617 142 hectares, in third place.

In 1994, more than 875 000 meters of diamond drilling took place, with the expectation of discovering new reserves.

5. Codelco Chile

Chiles National Copper Corporation (CODELCO), is made up of four operating divisions producing copper and by-products: Chuquicamata, Salvador, Andina and El Teniente. Two other divisions (the Rancagua-based Mining Support Division and Tocopilla Division, an electric power producer serving the Chuquicamata Division and the northern Chilean power grid) round out Codelcos corporate structure. See Fig. 5.1 and Tab. 5.1

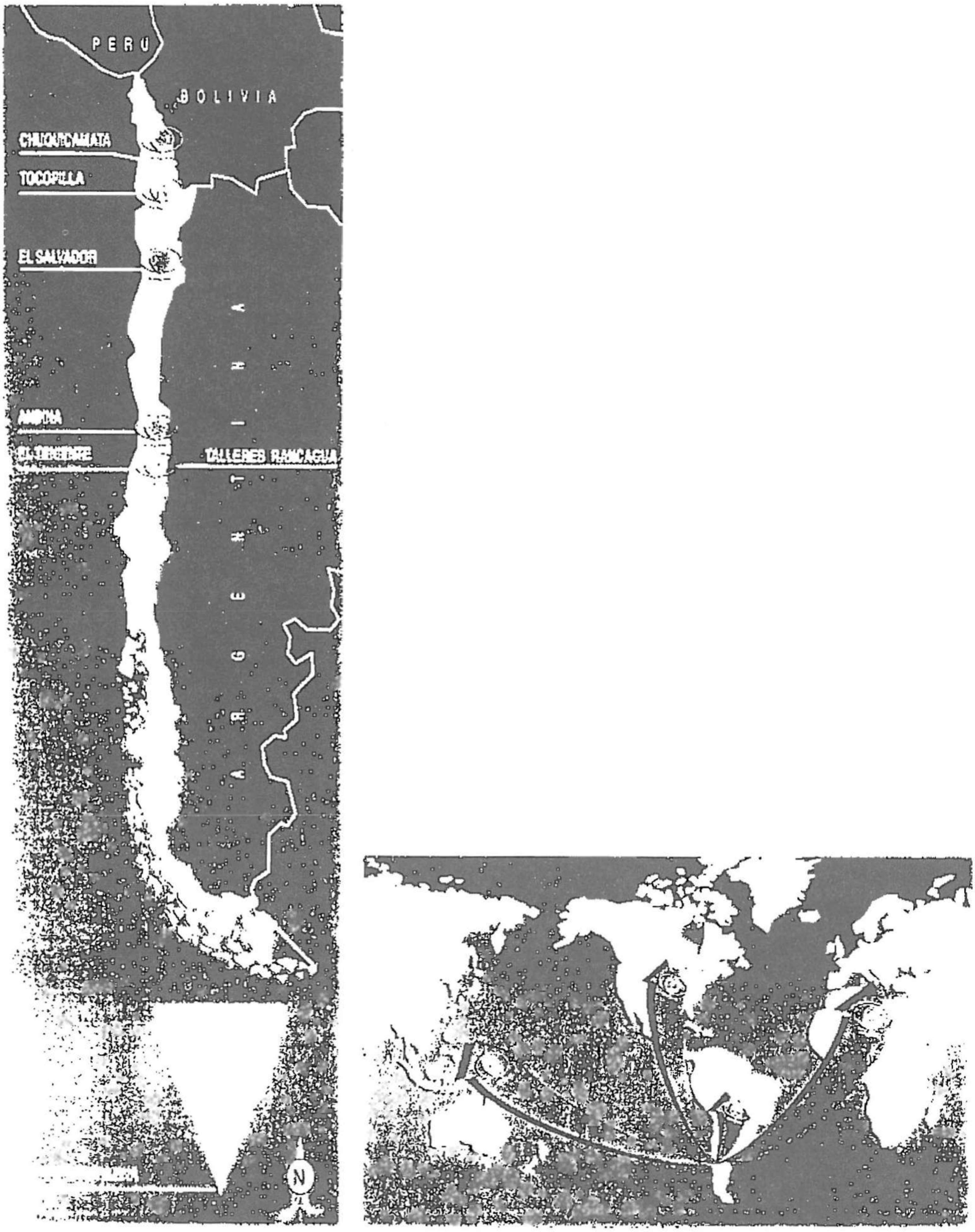

Fig. 5.1. Map of Chile and location of Codelco Chile Divisions
Rys. 5.1. Mapa Chile i mapa lokalizacji oddziałów CODELCO

Table 5.1. Divisions of Codelco Chile
Tabela 5.1. Oddziały CODELCO

	Chuquicamata	Andina	El Salvador	El Teniente
m.s.n.m (meters)	2 800	3 700	2 600	2 500
Proven Res. (mill. metr. tons. fine copper)	45	17	3	15
Yearly Prod. (metr. tons fine copper)	620 000	130 000	85 000	300 000
Yearly Prod. (metr. tons molybd. concentrate)	10 000	1 500	800	2 000

At present its proven resources amount to 7000 million metric tons of fine copper with an average of around 0,9%. This resources represent 20% of world reserves.

Codelco's commercial products are:

Copper products
Wire bars
H.G. cathodes
Fire refined copper
Copper concentrates
Blister copper

By Products
Molybdenum trioxide
Ferrum Molybdenum
MO_3 Pellets
Antimonium perrenate
Metal Dore
Selenium pellets and others

The major markets for Chilean copper are located throughout Europe, America, and Asia.

Codelco has created 2 subsidiaries: Codelco-Kuppferhandel GmbH (C.K.) and Codelco-France, S.A.R.L., through which it has a share in two wire bar producing companies.

With the current operation levels, its permanence in the market is assured for at least one hundred years.

The distance between the mines and the skipping port are always closer than 240 km.

The Domestic consumption is very low and in practice almost the whole production must be exported.

6. Environment

For the Mining Ministry, the sustainable development requires special considerations towards the environment. Thus, in the mining sector, important enviromental managment is necessary:

— Short-term solution of the main environmental problems.

— The creation of a special advisory、unit to support the Ministry of Mining on environment issues.

— Diagnosis of environmental impact from the mining sector.

— Supreme Decree N° 185 and the drafting of Environment Basis Law represent the environmental regulations which control the mining sector.

— For any new project, the presentation of studies about environmental impact is a compulsory requirement. These studies must present the solutions, cost, and time limits for the enforcement of the regulations.

7. Laws on foreign investments

Chapters XIV and XIX of the Compendium of Norms on International Exchanges of the Central Bank of Chile are part of the current regulations of foreign investments in the country.

The former regulates the inflow of foreign currency and foreign credits. The latter refers to the conversion mechanism for the Chilean foreign debt, which can be used by any foreigner.

The main law is the Decree law 600, which has been modified at various times. Through a contract the rights and obligations of the parties (the foreign investor and the Chilean State), it gives the maximum securities and guaranties during the development of their project.

Thus the investor has the right to send profits abroad when he/she considers it necessary without a date limit.

The investor can opt for a tax invariability regime with a 42% effective rate, for a 10 year period. The value added Tax (VAT) is not considered when is the importation of machineries and equipments is necessary.

Finally, the law guarantes no discrimination for the foreign investors.

For investments equal or above US$ 5 000 000, the authority has the power to grant various time limits and special rights.

For the foreign investments, the income tax corporate rate is 15% and 35% for profit remittances abroad, with a 15% (additional tax) credit.

8. Investments in mining

The 47.9% of the foreign capitals invested in mining between 1974 and 1993 came from the United States. In the same period, Canada represented 20.3%, followed by Australia 9.6%, England 6.4% and New Zeland 5.3%. Smaller shares came from Japan, South Africa, Finland, Papua New Guinea and several international organisms (see Fig 8.1).

For period 1993—1997, foreign investments of about US$ 21,000 millions are expected for Latin America. 25% should be concentrated in our country.

Brazil expects 20% of the whole investments, Perú 17%, Mexico 10% and others, alower percentage (see Fig. 8.2).

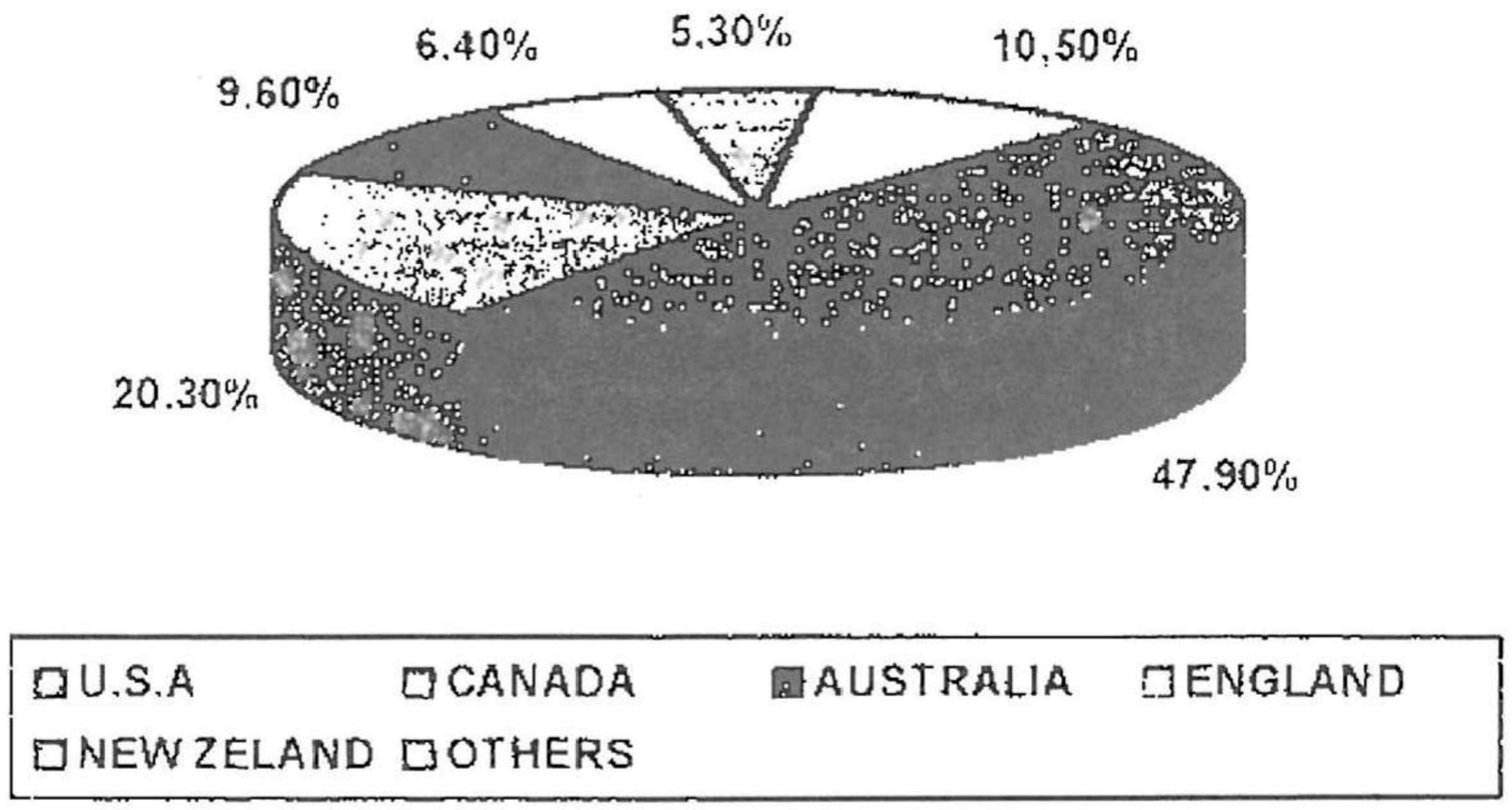

Fig. 8.1. Foreing Investments in 1974—1993
Rys. 8.1. Inwestycje zagraniczne w latach 1974—1993

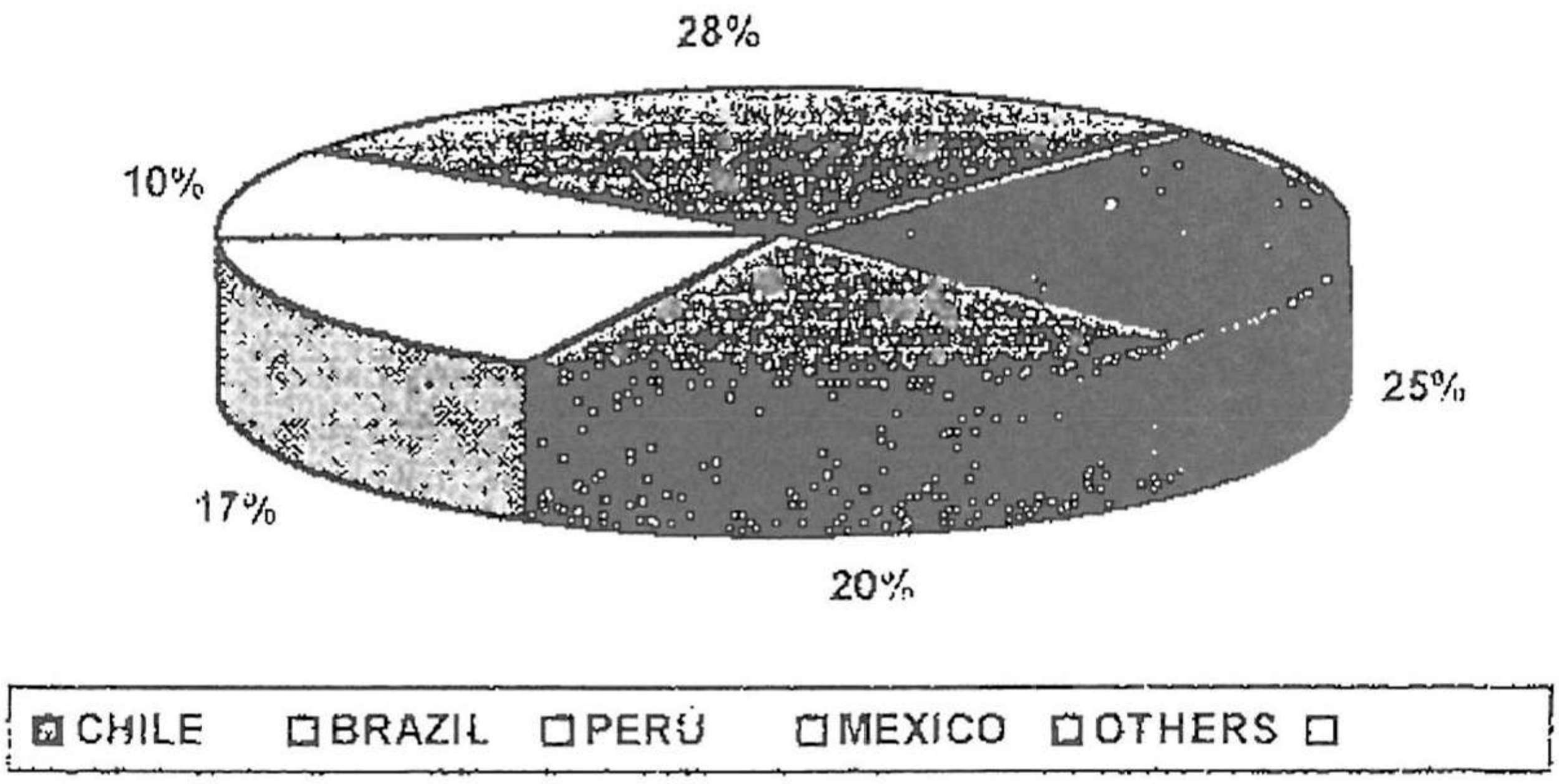

Fig. 8.2. Investments of Latin America in 1993—1997 (US$ 21 000 millions)
Rys. 8.2. Inwestycje krajów Ameryki Łacińskiej w latach 1993—1997 (21 000 mln USD)

9. Geology

Most orebodies where the copper production is high are classified as porphyry copper deposits. These are huge deposit containing various million tonnes of ore reserves (see Fig. 9.1).

The formation of the orebodies is associated with volcanic activity arising from movement of tectonic plates in the earths crust. Because of the progressive advance of the plates, large parallel fault were generated. Later on, these faults were filled with the magma fluid, thus giving rise to the segregation and concentration of minerals.

The distribution of mineralization and associated rock alteration processes is arranged as concentric zones, with the porphyritic rocks typifying the deposit at the core.

For the Andina mine, the applied geologic model features two zones of economic interest: a central zone of the porphyry copper at depth, characterized by the presence

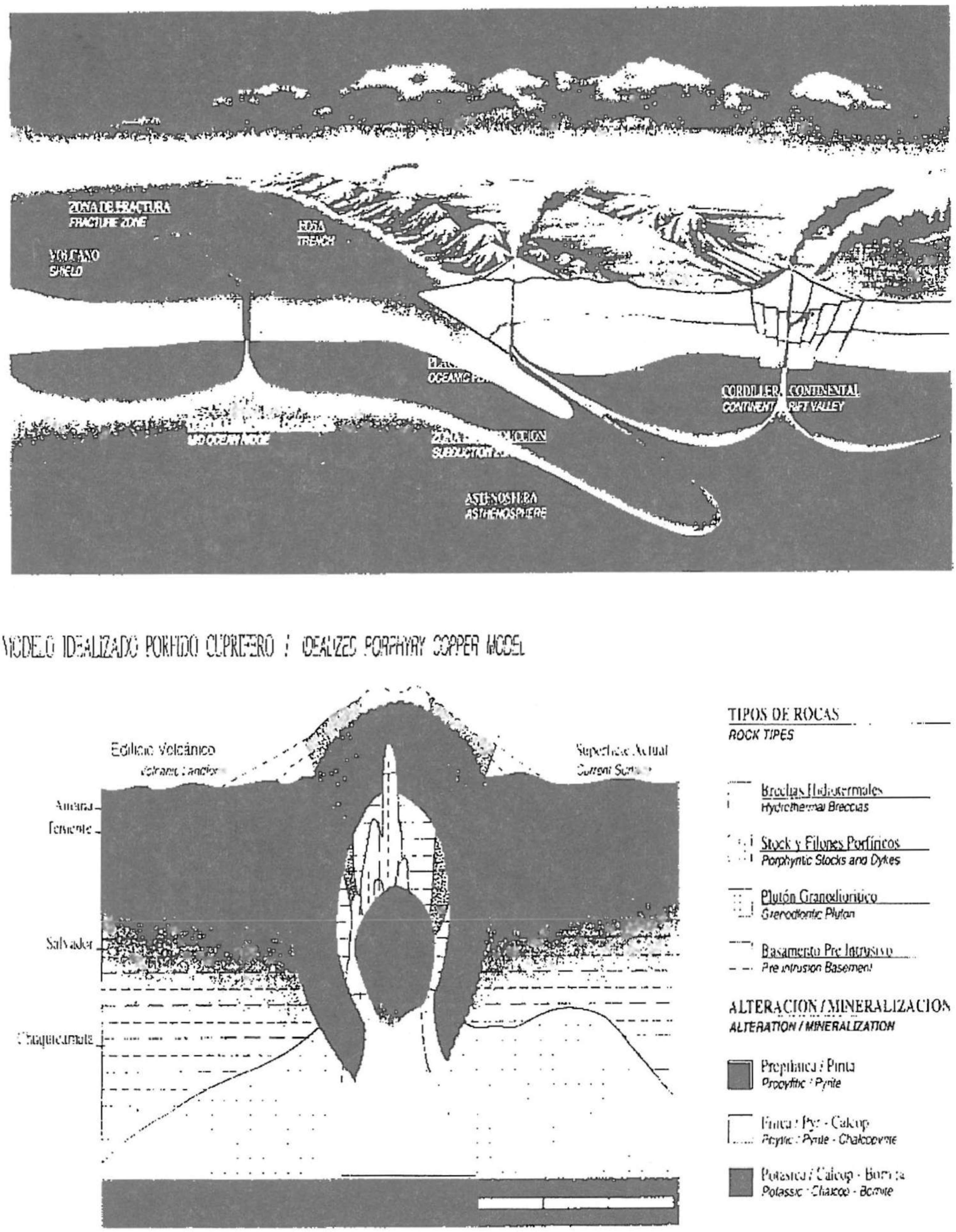

Fig. 9.1. Porphyry Copper Model (from Andiana Manual)
Rys. 9.1. Model porfiro-miedziowy

of chalcopyrite — bornite mineralization, and an upper level intruded by volcanic necks with fragmented rock showing high concentrations of chalcopyrite and lesser chalcocite — covellite mineralization.

In the El Teniente mine, the central part has a lower concentration the copper ore (0,4% Cu) than the periphery (over 1% Cu). The latter forms a mineralized ring of around 700 m. wide which is being extracted up to this date.

The other porphyry copper deposits are very similar. Among these we have El Salvador, Chuquicamata, La Escondida, El Abra, etc.

The following lithologic unit in this deposits are observed:

— Andesite
— Granodiorites
— Quartzmonzonite
— Monzonites
— Breccia
— Dacite

A great number of veins from the central part of the country to the North are found in the high mountain range (Los Andes) and in the coastal mountainous range. In the Southern part some interesting orebodies have been discovered such as El Toqui mine, which is formed by various strata of zinc, lead and gold.

At present, an increment in the exploration activity in the southern part of the country is observed.

Some orebodies near the coast are exploited and they correspond to a special deposit classified as Skarn.

Coal deposits are located in the south near and under the sea as in the case of Lota mines.

10. Methods of exploitation

Because orebodies exist along the whole country and are found in diverse hydrogeological conditions, the explotation systems employed are quite different.

These methods can be analyzed from the ranking proposed by Nicholas (Tab. 10.1).

Table 10.1. Ranking of geometry — grade distribution

Tabela 10.1. Klasyfikacja optymalnych systemów eksploatacji wg warunków geologicznych

MINING METHODS	GENERAL SHAPE			ORE THICKNESS				ORE PLUNGE			GRADE DISTRIBUTION		
	M	T/P	I	N	I	T	VI	F	I	S	U	G	E
OPEN PITS	3	2	3	2	3	4	4	3	3	4	3	3	3
BLOCK CAVING	4	2	0	–49	0	2	4	3	2	4	4	2	0
SUBLEVEL STOPING	2	2	1	1	2	4	3	2	1	4	3	3	1
SUBLEVEL CAVING	3	4	1	–49	0	4	4	1	1	4	4	2	0
LONGWALL	–49	4	–49	4	0	–49	–49	4	0	–49	4	2	0
ROOM & PILLAR	0	4	2	4	2	–49	–49	4	1	0	3	3	3
SHRINKAGE STOPING	2	2	1	1	2	4	3	2	1	4	3	2	1
CUT & FILL	0	4	2	4	4	0	0	0	3	4	3	3	3
	M = Massive T/P = Tabular or Platy I = Irregular			N = Narrow I = Intermediate T = Thick VT= Very Thick				F = Flat I = Intermediate S = Step			U = Uniform G = Gradational E = Erratic		

Ranking	Value
Preferred	3—4
Probable	1—2
Unlikely	0
Eliminated	–49

Nicholas, incorporates a ranking of rock mechanics characteristic of ore zone, hanging wall and foot wall.

Block caving method

Basically block caving is a mining system that is normally used to extract deep seat, massive, low grade deposits of copper, molybdenum and iron where stripping ratios for open pit mining are economically prohibited. The caving system is limited in its selectivity. It is a mass production type of underground ore extraction that under favorable conditions is one of the most efficient, low cost mining systems in the world today. It is capable of producing ore at a rate of 10 000 to 100 000 ton per day from large deposits, such as El Teniente mine. The costs are comparable with many open pit mining systems with a high waste to ore ratio.

There are three basic method of draw commonly used:

— Gravity draw

— Slusher draw

— L.H.D. draw

Fundamentally the type of draw used must be compatible with the physical charactetristics of the deposit to be extracted and the economical position of the mining operation (see Fig. 10.1).

The type of draw chosen has direct relation with the size of the ore, configuration (design of draw point mesh), depth, strength and fracture pattern of the deposit.

Conventional block caving requires manual operations of the draw points in order to control the flow of the ore down to the haulage level below.

The use of grizzlies or grates may be adjusted to control the size of the broken ore passing through. In Andina mine, ore is transported to the ore passes by conveyor belt.

In Panel caving System, to transport of the ore from the draw points to the ore passes L.H.D. are used; for the security of the miners such as adverse geomechanic conditios with rockburst, remote control L.H.D. is incorporated (El Teniente). Other situations, such as the secondary reduction by big hydraulic hammers located more than 500 m away, are controlled and handled through T.V. screens (El Salvador).

Block caving with grizzly-truck extraction requires the use of low-profile underground tram units for the haulage of the ore from the draw points to the ore passes.

In Andina Mine, the adverse climatic conditions require that the entire ore comminution and flotation process be conducted in underground facilities. Ore is transported between the different stages of crushing by conveyor belts, with the largest being the N° 5 belt, which is 5335 meters long and takes crushed ore to the concentrator plant.

The ore grinding facilities are located 150 meters below the surface in an enormous underground cavity opened in highly competent rock.

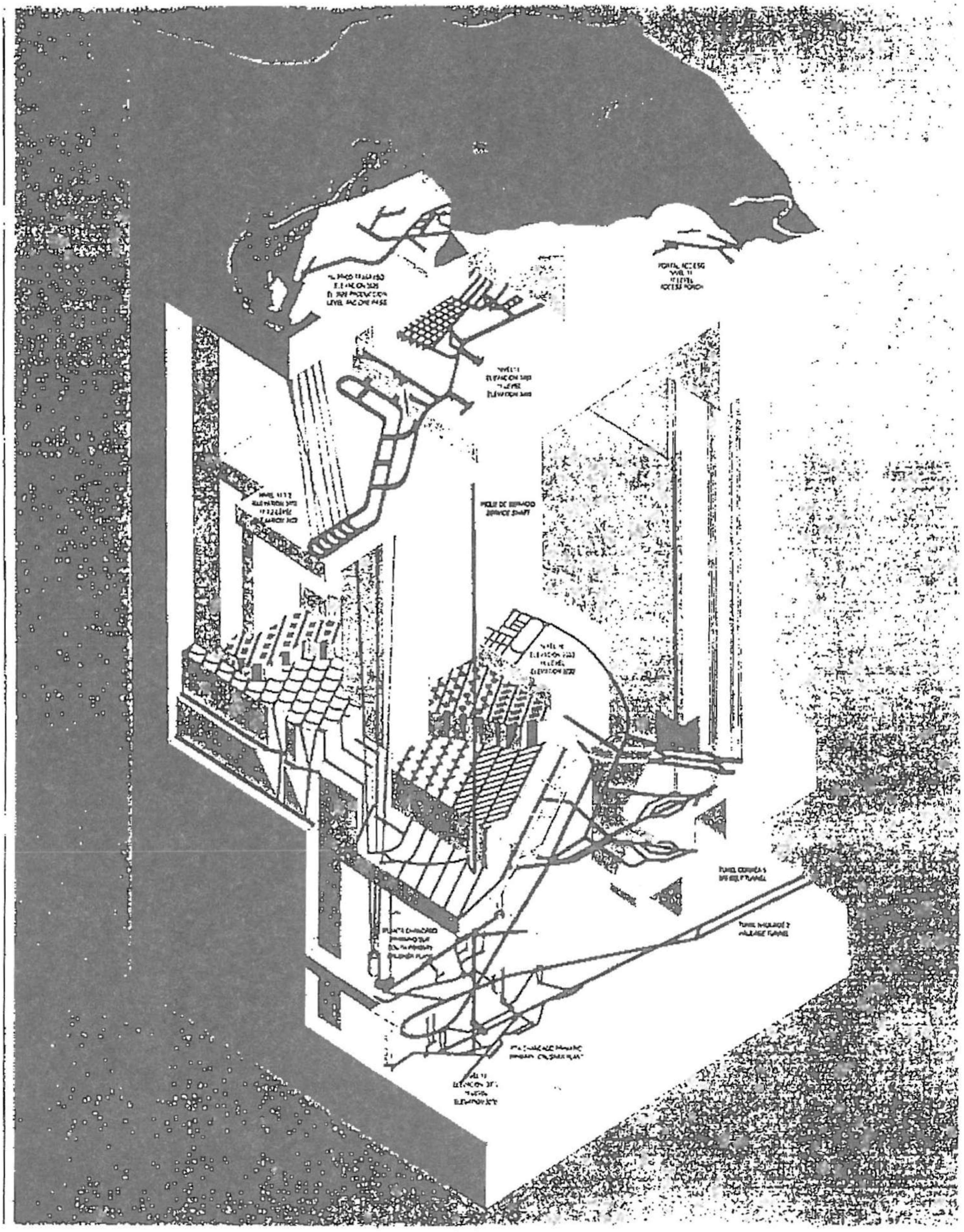

Fig. 10.1. Block Caving Method (from Andiana Manual)
Rys. 10.1. Metoda wybierania stropowego z zawałem (Andiana Manual)

The flotation tailings make up 96,5% of the ore rock put through processing. This material is sent to thickeners, where water is recovered, and taken to The Leones tailings pond, located at 2125 meter above sea level in The Leones Valley. This facility has the capacity to store 106 millions cubic meters of tailings material.

In El Teniente case, an enormous crushing plant is located in an underground place. The capacity of the unit is 6000 ton per hour. The flotation plant is located on the surface. The tailing pond is 150 km far and it was necessary a big investment for the construction of the canoe channel from the mountain to the valley.

In general, the climate for the mines located in the high mountains is very adverse and combined with the rugged topography of the area, promote frequent avalanches and make winter operations difficult.

Other methos of exploitation are used for vein orebody:

Sublevel caving

This method, although considered most suitable for low grade ores, has been successfully used for mining intermediate or higher grade base metal sulphide ore.

The method is known to be very flexible and it can be adapted to different orebody configurations under varying rock strengths and wall rocks. It is adaptable to mechanization and standardization. Higher grade ores can stand more dilution and hence obtain better recovery.

Sublevel caving is used in Pelambre mine and in special areas in El Teniente mine (marginal Breccia).

Sublevel stoping

This system is the best suited to steeply inclined orebodies, with simple structures and with a strong footwall and hangingwall.

At present, as more complex folding and flatter dipping orebodies have been used, considable varations have been applied. The daily production from a stope face varies from 300 to 1000 tons. El Soldado mine applies this mining system.

Cut and fill

Cut and Fill mining is accepted as the process in which a stope is produced by removing ore in a series of horizontal slices and placing waste material in the void created to enable the process to continue. Both flat-back and up — hole drilling are used to define the block to be fired. Under different rock condition the cut and fill varies (See Fig. 10.2).

The method is well suited for selective stoping where it is desirable to keep the ore qualities separate. Futhermore, the method provides for stable surface conditions without the risk of ground collapsing and slides.

The principal underground gold mine in Chile, El Indio is mined under this system of exploitation. The selectivity here has been well used in special sectors in the mine. The average grade reached 3000 gr of gold per ton. years ago. At present, it is not difficult to find sectors with 200 gr per ton.

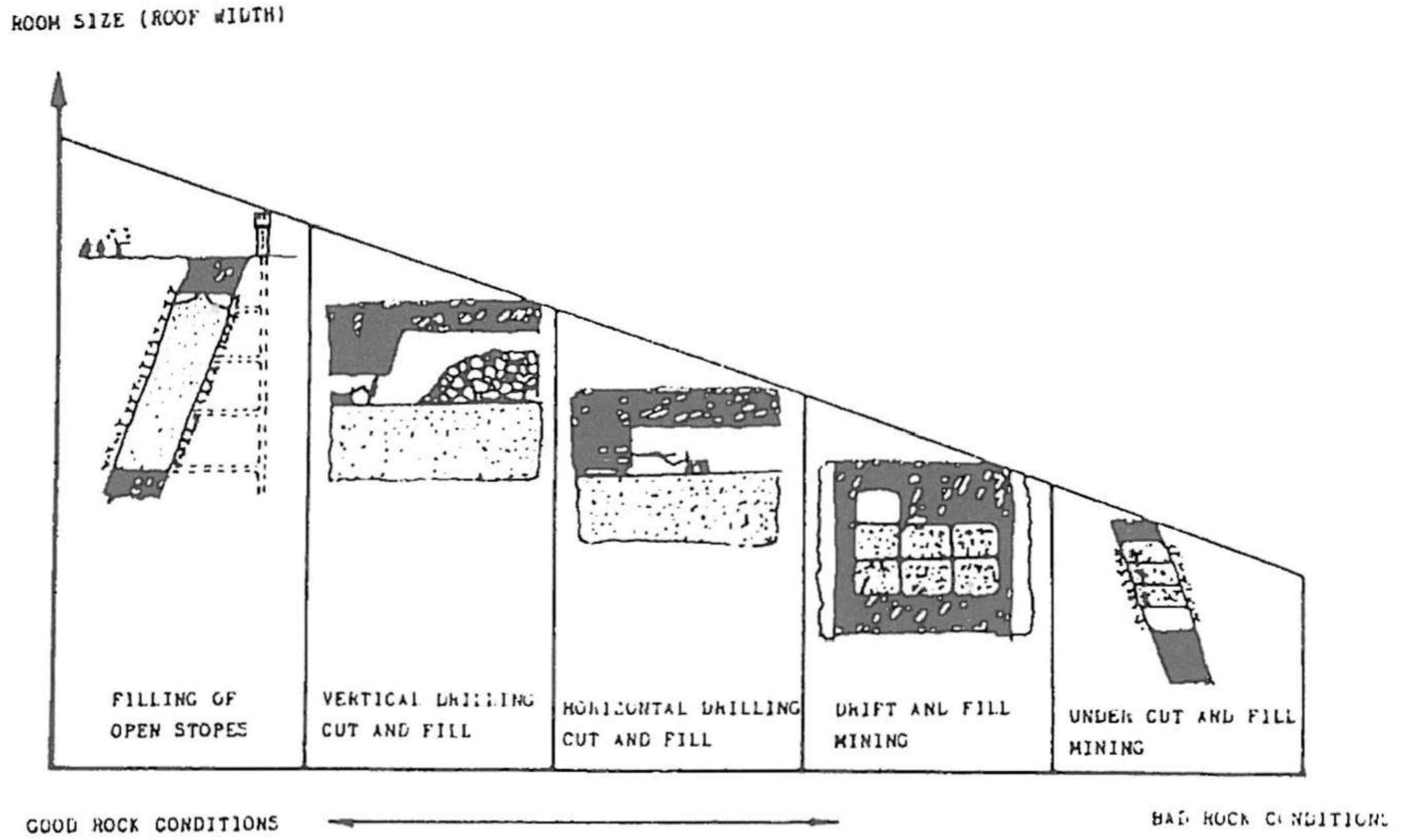

Fig. 10.2. Cut and Fill Methods for varying rock conditions
Rys. 10.2. Metody drążenia i podsadzania w różnych warunkach skalnych

11. Operation techniques

All the operations have an acceptable technological level compared with other countries where mining is an important activity. However, more research is required. Information transfer to small-scale mining is especially necessary. This sector usually has no possibilities to reach modern technologies and beside the low level of production allow no other investments except the necessary ones.

Basic operations such as support, drilling and blasting and haulage, are similar to the techniques used throughout the world.

For support systems, roof and rock bolt, friction bolt, thred bars, metallics or non-metallics rib bolts, cable bolts, „W" straps and butterflies, chemical anchors, organic and inorganic pumpable grouts, steel arch, steel sections radius bending, shotcret, mesh and others are usually used.

In blasting technique, the commonly used explosives are: ANFO, emulsion, slurry, etc. Blasting accessories are: NONEL, electric detonator, plastic igniter cord, etc. The control of Vibrations, overlap between delayed detonators, measurements of particule velocity, detonation velocity of the explosives, and monitoring systems are extensively used.

In contour blasting, techniques as presplitting and smooth blasting are used to a great extent both in underground and open pit.

In Chile as well as around the world, drillling has experimented an important degree of mechanization. The productivity of underground mines has increased rapidly during recent decades. Mechanized drilling, hydraulic rock drills as well as tunnel driving or production drilling with different trademark and models are used; Atlas Copco, Tamrock, Ingersoll Rand, etc.

12. Perspectives for the year 2000

Actions of the state

The Chilean government has the following objectives for the year 2000:

— Modernization of the management of the principal state entities such as, CODELCO, ENAMI, ENAP and SERNAGEOMIN.

— Strengthening of the supervisory function of the Comisión Chilena del Cobre (Codelco) and development of technical studies and information methodologies for the copper industry.

— Consolidation of the second stage of the program „Chile exporta Minería" in the field of services, and development of the industry elaborating capital goods, along with their promotion abroad.

— Promotion of the consolidation and improvement of technical assistance to micromining activities through PAMMA program.

— Encouragement and strengthening of the environmental management in the mining sector through the action of the Environmental Unit and National Environmental Commision.

— Lobbying for the introduction of bills related to modifications to the Code of mining and the issue of superimpositions of concessions.

Action of Private Mining

Among the new mines, Zaldivar, with 125 000 tons of fine copper, Candelaria, which will contribute 108 000 tons fine copper; Cerro Colorado with 40 000 tons, Quebrada Blanca with 75 000 tons, Escondida expansion, enabling it to reach 700 000 tons of fine copper, etc, plus an interesting development of medium scale ones, such as Las Luces, Rio Cobre and Pelambres, lead us to claim that the private mining sector will reach the year 2000 a production over 2 350 000 tons of fine copper per year.

It is expected that the private mining industry will double state-run mining by the year 2000.

13. Conclusions

— Chile has experimented an important development in the mining sector for last 15 years.

— Our country has reached a high level in production, but it is necessary to raise the research level for both medium scale and small scale mining.

— The great resources in copper and other minerals give a security for the development in the mining sector for the years to come.

— Private Mining played an important role and will continue contributing to the Chilean economy.

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Technologia górnictwa chilijskiego i perspektywa rozwoju

Streszczenie

W opracowaniu scharakteryzowano chilijskie górnictwo, a w szczególności górnictwo miedzi. Przedstawiono historyczny rozwój górnictwa w Chile. Omówiono organizację, wielkość produkcji i zasoby przemysłu wydobywczego. W sposób bardziej szczegółowy scharakteryzowano National Copper Corporation (CODELCO).

Przedstawiono również wymagania w zakresie ochrony środowiska na terenach górniczych, regulacje prawne dla inwestorów zagranicznych oraz strukturę zagraniczych inwestycji w latach 1974—1993. Omówiono także typową budowę geologiczną złoża miedzi, klasyfikację metod eksploatacji, w tym bardziej szczegółowo system komorowy oraz typową technologię eksploatacji.

Przedstawiono wreszcie główne kierunki rozwoju górnictwa do 2000 roku.

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Geomechanical aspects of hard rock mining in Chile

Key words
Stress-strain-joint-fracture-mining method-numerical model-roof support

Abstract

A wide range of geomechanical problems regarding underground exploitation has been presented in the paper. Considering rock mass structure with joints and fracture sets and water influence on mining conditions stability of excavations were analyzed. Both numerical analysis and in situ measurements of stresses and strains have been applied to solve the basic problems.

A special attention has been paid to the El Teniente Mine, the biggest copper mine in the world where a lot of geomechanical investigations were carried out.

1. Introduction

Application of rock mechanics principles in mining engineering is based on simple and, perhaps, self-evident premises. Firstly, it is postulated that a rock mass can be ascribed a set of mechanical properties which can be measured in standard tests. Secondly, it is asserted that the process of underground mining generates a rock structure consisting of voids, support elements and abutments, and that the mechanical performance of the structure is amenable to analysis using the principles of classical mechanics. The third proposition is that the capacity to predict and control the mechanical performance of the host rock mass, in which mining proceeds can assure or enhance the economic performance of the mine.

The ultimate objective in the design of a mine structure, is to control rock displacement into and around mine excavation. Rock displacements of engineering consequence may involve such processes as fracture of intact rock, slip on a geological feature such as a fault, or instable failure in the system. (This latter process is expressed physically as a sudden release of stored potential energy, and significant change in the equilibrium configuration of the structure).

These potential modes of rock response, immediately define some of the components of a methodology intended to provide a basis for geomechanically defensible excavation design. The methodology includes the following elements. The strength and deformation properties of the orebody and adjacent country rock must be determined together with the „In Situ" stresses. The geological structure of the rock mass, ie, the location and the geometrical properties of the main fractures and the „Rock Fabric" (design fracture sets). The groundwater pressure distribution in the mine domain must be established. Finally, analytical techniques are required to evaluate each of the possible modes of response of the rock mass, for the given mine site conditions and proposed mining geometry.

2. Rock mass strength

One of the major problems confronting designers of engineering structures in rock is that of estimating the strength of the rock mass. This rock mass is usually made up of an interlocking matrix of discrete blocks. These blocks may have been weathered to varying degrees, and the contact surfaces between the block may vary from clean and fresh to clay covered and slickensided.

Determination of the strength of an in situ rock mass by laboratory testing is generally not practical. Hence this strength must be estimated from geological observations and from test result on individual rock pieces or rock surfaces which have been removed from the rock mass.

Hoek et al. (1980, 1988), developed an empirical failure criterion for jointed rock masses. Also, Hoek (1983) proposed that the rock mass classification systems, can be used for estimating the rock mass constants required for this empirical failure criterion. Although practical application of this failure criterion in a number of engineering projects has shown that these estimates are reasonably good for disturbed rock mass, further work is required to improve this criterion and others failure criteria for jointed rock masses.

3. Rock fabric determination

The elements and geometrical properties of the „Rock Fabric" of a rock mass, can be obtained using the methodologies of Detail Line and Cell Mapping Call (1976); which are systematic spot sampling techniques. The principal characteristics and geometrical properties of the discontinuities to be measured in either technique are as follows:

a) Location

b) Orientation

c) Waviness. All geological discontinuities have an inherent surface roughness and ondulations about a mean planar surface; both contribute to shear resistance.

d) Strength of fillings and fracture surfaces

e) Groundwater

f) Length (Continuity). This parameter indicates the portion of a rock mass where material continuity is interrupted.

g) Spacing.

Fractures falling within the mapping zone are described and the information is recorded on a tabular data sheet.

The first stage in data reduction in the fabric analysis is to choose the joint sets used in the design. Schmidt lower hemisphere point plots or contoured percent plots are constructed for each sampling site. If a point plot is used for treatment of the measurements of joint orientations in a cluster, the mean orientation and value of dispersion about this mean can be obtained. For defining the joint fracture sets in a design sector which is formed by a finite number of detail lines or cells; correlations within and between joint sets in the different detail lines or cell are necessary for obtaining the joint fracture sets for design.

The analysis for obtaining the joint fracture sets is performed as follows:

1. The mean vector for each joint set is plotted in a Schmidt equal-area projection.
2. Adjacent mean vectors are compared with the Fisher distribution.
3. The F-test is then compared to the ratio obtained from the mean vectors tested to the theoretical frequency distribution with the same degrees of freedom, and inspected for closeness of fit for a certain risk value.

Once the joint fracture sets have been determined, the various characteristics from the joints falling within the design set limits can be combined to form distributions.

Repeating this process within and between sectors of design in a structural domain, the joint fracture sets of design are determined and the structural domains are optimized.

The final step will be to fit new distributions for the geometrical characteristics of the joint fracture sets of design.

4. Rock stresses

The stability of deep underground excavations depends upon the strength of the rock mass surrounding the excavations, and upon the stresses induced in this rock. These induced stresses are a function of the shape of the excavations, and the in situ stresses which existed before the creation of the excavations. The magnitudes of pre-existing in situ stresses have been found to vary widely, depending upon the geological history of the rock mass in which they are measured (Hoek et al. 1980).

Theoretical predictions of these stresses are considered to be unreliable and, hence, measurement of the actual in situ stresses is necessary for main mining projects.

In situ rock stress determinations can be separated into three categories: The determination of applied stress (absolute or field stress); the determination of concentrations of the field stress near openings; and the determination of changes in rock stress as load bearing material is removed. Various instruments and techniques have been developed to determine applied rock stress and stress changes in rock.

4.1. Absolute Stresses

a) Borehole Deformation Gages.

The method basically consists of drilling a pilot borehole, positioning the deformation gage in the pilot borehole and diamond drilling a concentric borehole over the gage and recording the change of length of the pilot borehole diameter. Readings in three boreholes are required to calculate the complete three dimensional stress field.

b) Strain Cells.

The Doorstopper (Leeman 1964).

It consists of a strain gage rosette plotted in the base of a low modulus cylindrical solid. The Doorstopper is glued to the end of the borehole which has been ground flat and smooth with a flat-faced diamond-impregnated bit. The strain gages in the doorstopper are mounted close to the end face and readings taken before and after overcoring give a measure of the stress relief. Readings in three boreholes are required to calculate the complete three dimensional stress field.

c) CSIR Triaxial Strain Cell.

Its consists of three groups of three strain gages mounted on the circumference of a tubular body (Leeman 1969). This device is glued to the wall of a pilot borehole and overcored in a manner similar to that used with the borehole deformation gage.

d) CSIRO Hollow Inclusion Cell.

The CSIRO hollow inclusion cell is similar in construction and concept to the CSIR triaxial strain cell.

Other methods applied for in situ stress measurements are: Flat Jack, Hydraulic fracturing etc.

5. Groundwater

Groundwater may affect the mechanical performance of a rock mass in two ways. First by the effective stress law; which is a function of the applied stress and the pore water pressure ($\sigma' = \sigma - u$) and second, water under pressure in the joints defining rock blocks reduces the normal effective stress between the rock surfaces, and therefore reduces the potential shear resistance which can be mobilized by friction. In both cases, the effect of pore water under pressure is to reduce the ultimate strength of the mass rock. A more subtle effect of groundwater on rock mechanical properties may arise from the deleterious action of water on particular rocks and minerals.

The implications of the effect of groundwater on rock mass strength are considerable for mining practice, and it may be essential in some cases to maintain close control of groundwater conditions in the mine area.

6. Geomechanical aspects of hard rock mining in Chile — with emphasis in el teniente mine

6.1. What Makes a Block Caving Orebody?

Theoretically, any block of ore will cave given a wide enough undercut. The objective, however, is to developed an orebody that will upon caving, produce rock blocks sufficiently small to make extraction and transport possible without excessive secondary breakage.

Block caving is a dynamic process in which rock failure must occur continuously within the stope. Any time rock stresses exceed rock strength failure will occur. Unfortunately, this progressive failure process is not just restricted to the stope. Often workings beneath and on the periphery of the stope are subject to similar failure. Ideally, rock within the stope should be weak enough so that failure is virtually incipient. Generally speaking, massive orebodies of highly fractured rock are most amenable to mining by Block Caving. The capping must also cave readily, but fragment coarser than the ore. Coarse fragmentation of the capping is necessary to limit the probability of premature ore dilution. Rock within which development workings are driven should be as competent as possible to limit the failure process.

6.2. Location

El Teniente Mine is located at 50 km to North-East of Rancagua, Cachapoal province VI Región. Rancagua city and the mine is joined by the „Carretera El Cobre" road. The geographic coordinates of the mine are:

34°05′ Latitude South

70°23′ Longitude West

The orebody is positioned at an altitude from 1400 to 2700 meter above sea level. Actually the working lower level at the mine (Teniente 8), is located at 1983 meter above sea level, and the higher level (Teniente 1) at 2630 meter above sea level.

6.3. General characteristics of the orebody

The orebody is a porphyry copper, with byproduct of Mo, and following dimensions: Length 3 km; wide 1.5 km and depth over 1 km.

The mineralization is located around a breccia chimney (Braden formation), with a 800 meter diameter of inverse cone shape, and low contents of Cu and Mo.

6.4. General geology description

The advance of geophysical engineering related to gravity, paleomagnetic and seismic knowledge; joined to geologic and geomorphological aspects occurred in the last two decades, has provoked a true revolution in the different geological disciplines and with special emphasis in the structural geology. Thus, it must actually be understood that the occurrence of an ore deposit as El Teniente, required of a previous existence of structural geological situation; and that this situation, is the resultant of the regional tectonics which is related to the mobile edge of the Southamerican plate.

This geodynamic conception oriented the study of the geological structures at the mine scale. Taking in consideration the aspects before mentioned, the followings geological studies were performed:

i) Categorization and systematization of the geological structures in the mine.

ii) Integration of all geological information summarized.

These studies thrown the following results for the El Teniente orebody:

1. The orebody is emplaced in a complex distrital zone of strike-slip faults.

2. This zone (strike-slip faults), is defined by two conjugated fault systems with strikes N60°E and N50°W and subvertical dips respectively.

3. Both fault systems are constituted by strike-slip faults. At the mine scale, these systems are characterized by zones with thicknesses between 20 m and 400 m respectively.

4. The strike-slip faulting, present, several branches and irregular traces. This characteristic joined to the arrangement of this structures in particular zones, indicates a greater shearing.

5. Both fault systems were actives before, during and after the orebody formation.

6. With this summarized structural-geological conception it was defined six main structural domains. Figure 1 and Table 1.

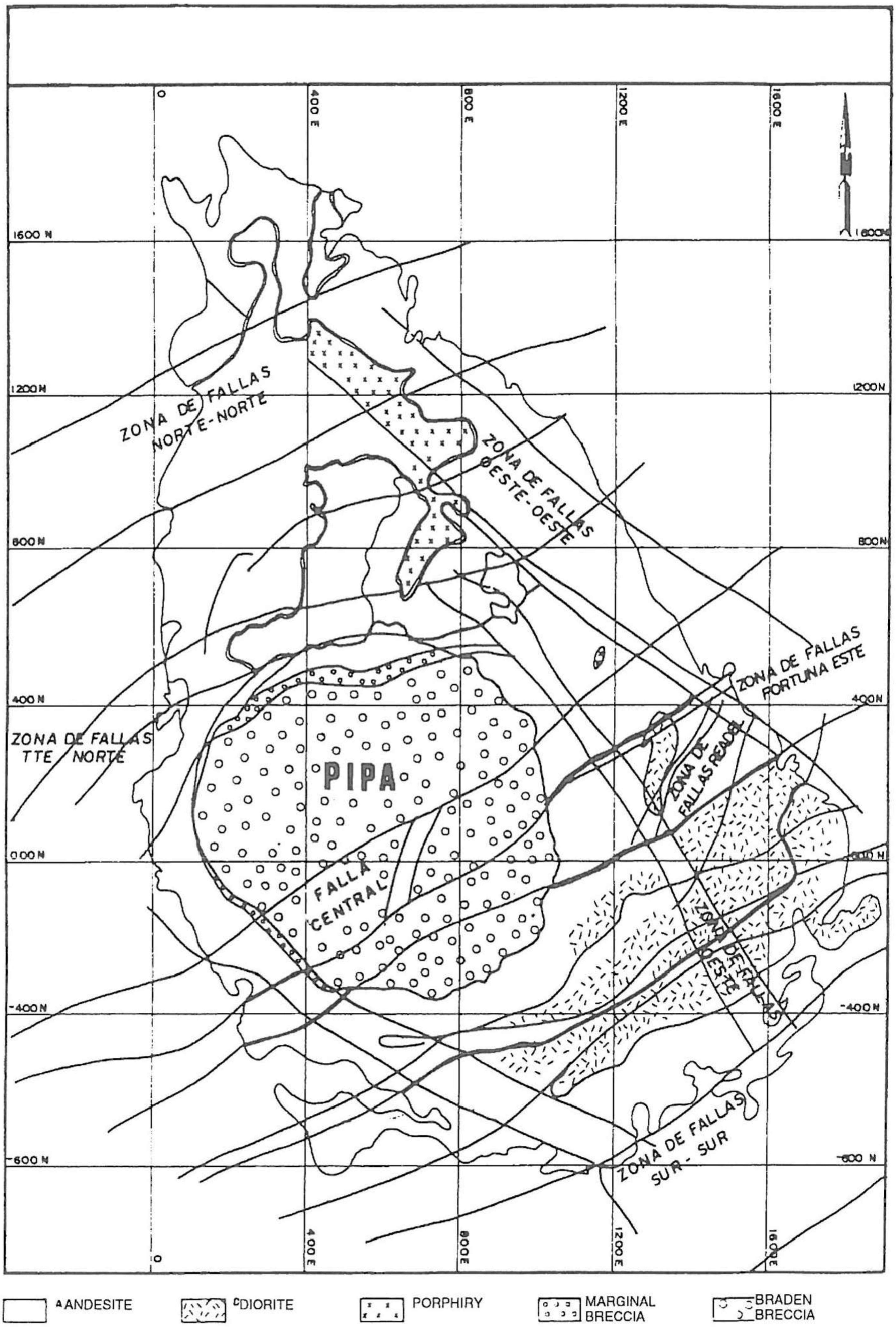


Fig. 1. General structural geology El Teniente orebody

Rys. 1. Zarys geologii strukturalnej złoża rudy El Teniente

Table 1. Structural domains at El Teniente orebody
Tabela 1. Obszary strukturalne w złożu rudy El Teniente

Domain	Zone	Principal joint set	Secondary joint set
D1	Faults zone (South Teniente)	N 50°—70° E	N 0°—20° E N 40°—60° W
D2	Northwest faults zones	N 30°—50° W	N 10°—30° E N 40°—60° E
D3	Riedel zone	N 30°—50° E	N 10°—30° E N 10°—30° W N 40°—50° W N 70°—90° W
D4	Outside Fault zone	N 30°—50° W N 50°—70° E	N 10°—30° E N 10°—30° W
D5	Intersection of NW faults zone with Fortuna faults zone	N 30°—40° W	N 0°—10° E N 30°—40° E
D6	Intersection faults zone (South Teniente) with Riedel zone	N 30°—40° E N 70°—80° E	N 0°—10° E N 40°—50° E

The rock properties for the intact rock are sketched in Table 2.

Table 2. Rock strength properties at El Teniente orebody
Tabela 2. Własności wytrzymałości skał w złożu rudy El Teniente

GEOLOGIC UNIT	GEOTECHNIC PARAMETERS					
	UCS [MPa]	TS [MPa]	YM [GPa]	P.R.	RQD [%]	F.F. [ff/m^3]
Andesite (Primary)	130	4.5	55	0.27	65	7
Andesite (Secondary)	58	20	24	0.24	>25	10
Diorite	150	6	58	0.25	80	5.5
Braden Formation (Breccia)	99	5	26	0.22	95	2
Marginal Breccia	110	4	33	0.23	--	-
Dacite	170	7	50	0.25	80	4

UCS — Uniaxial Compressive Strength
TS — Tensional Strength
YM — Young Modulus
P.R. — Poisson Ratio
RQD — Rock Quality Designation
F.F. — Fracture Frequency

UCS —
TS —
YM —
P.R. —
RQD —
F.F. —

6.5. Method of exploitation and mining production

Actually the mining production is about 92 000 ton, with an average grade of 1.15%; where 51% of the mine production it concerns with primary ore and the remain to secondary ore production.

The mining systems used are: 1) Standard Block Caving, gravitational caving, with direct transport and drill control Figure 2 and 2) „Panel Caving" Figure 3.

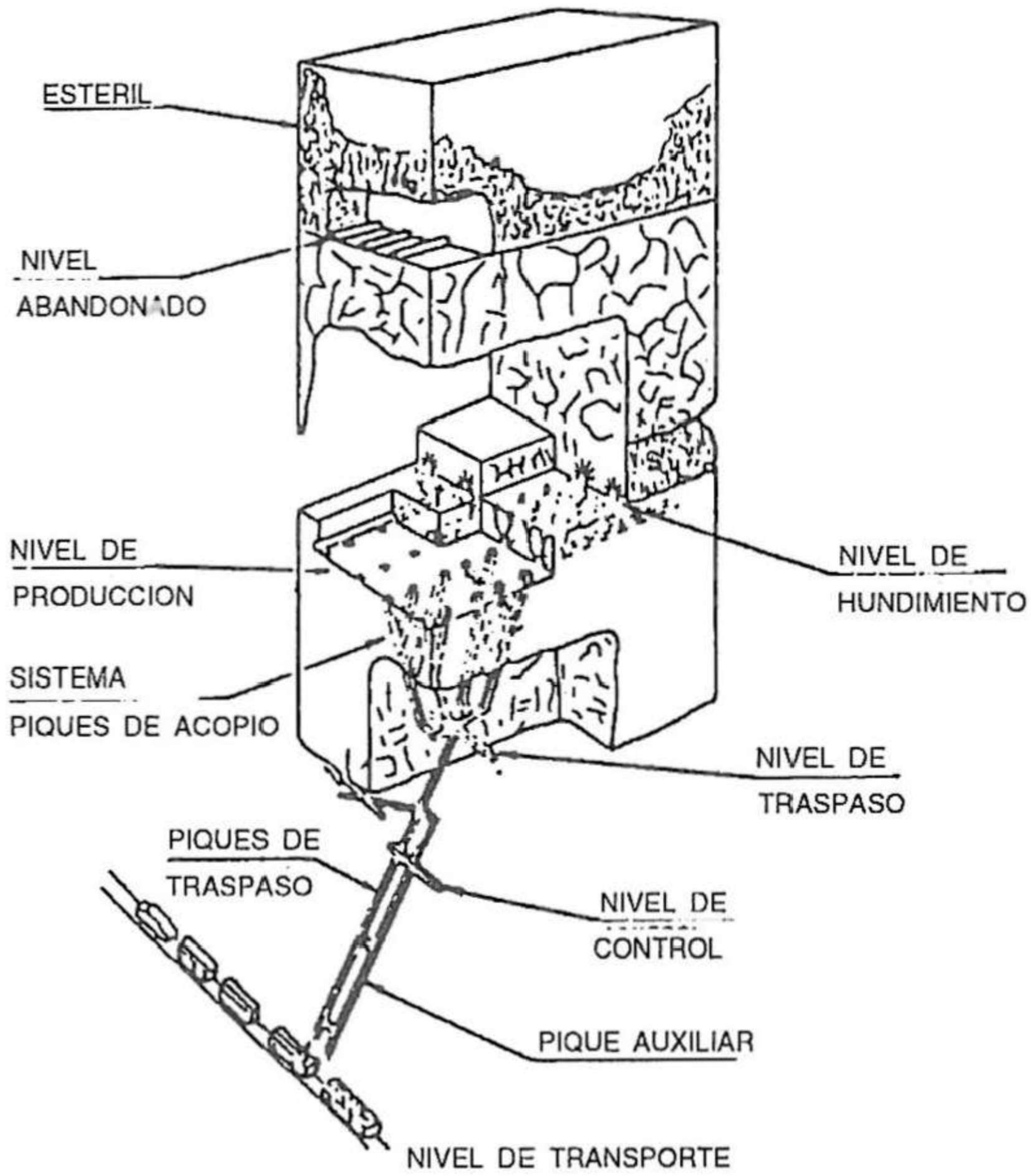


Fig. 2. Block caving with direct transport and drill control

Rys. 2. Eksploatacja systemem blokowym z bezpośrednim transportem i wierceniami kontrolnymi

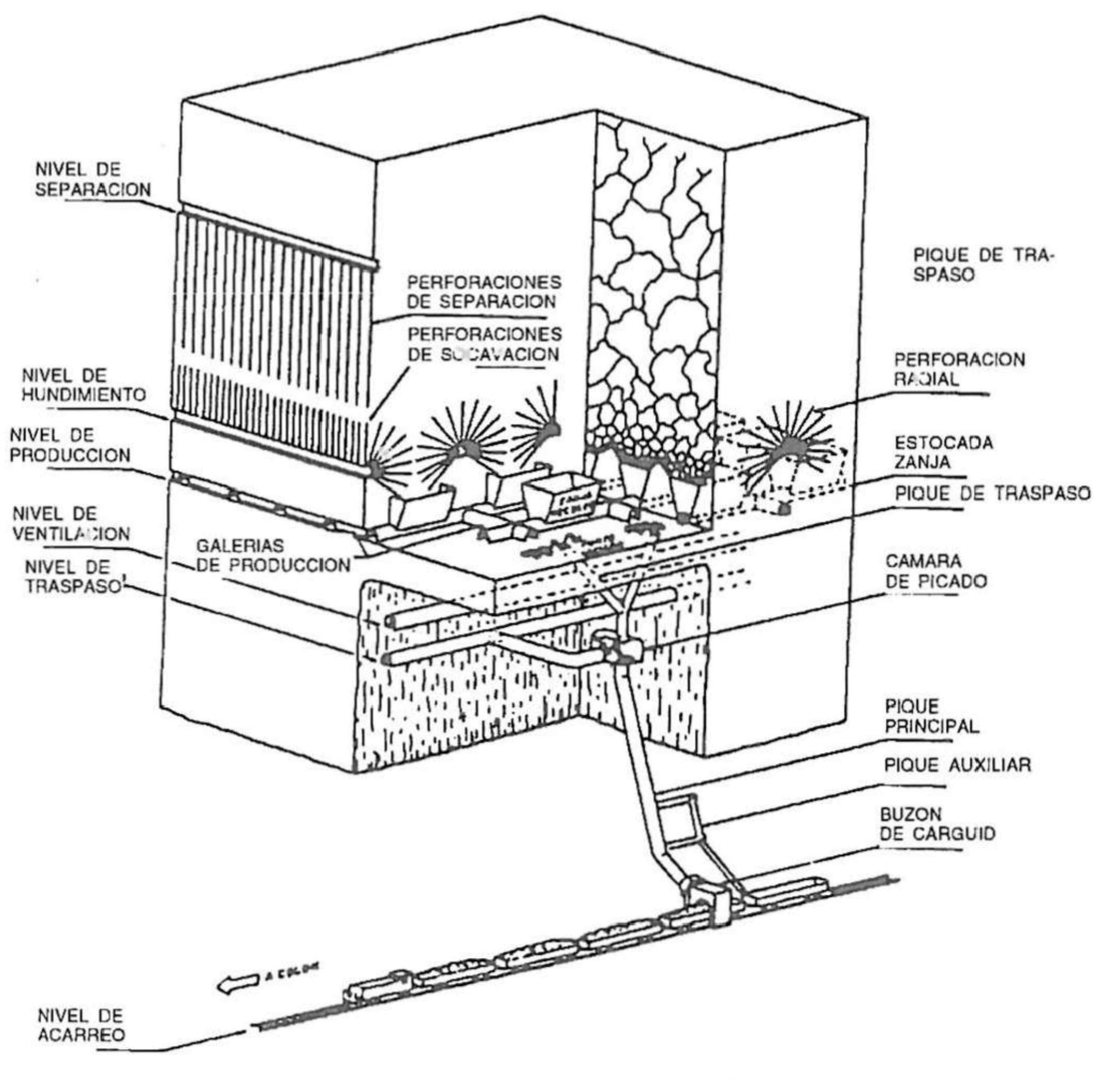


Fig. 3. Panel caving with L. H. D.

Rys. 3. Eksploatacja systemem komorowym z zastosowaniem maszyn ładująco-odstawczych

6.6. Rock stress

A great deal of attention has been directed toward the understanding of natural and mining induced stresses within the primary ore zone. This concern is understandable in light of rock burst and stress related overbreak problems, experienced during early periods of mine development and extraction. Stress measurement programs are common in the mine: Some measurements made in the primary ore near future mining areas have arrived at the following results.

1-) The maximum principal stress trends roughly north-northwest and plunges approximately 45° to the North-West and with an average magnitude of 50 MPa.

2-) Although the magnitude of the intermediate and minimum principal stresses are somewhat conjectural, the orientations appear to be similar; one tending North-West and plunging roughly 45° to the southwest with an average value of 34 MPa; the other tending E-NE lying almost in a horizontal plane with an average of 22 MPa. Under all circumstances, the north west trend of the maximum principal stress, was either measured as the maximum or intermediate principal stress. The existence of this pervasive stress is further substantiated with the consistency with which overbreak occurs in mine drifts.

Beside the vertical stresses measured at the places also appear to be anomalous relative to measurements taken at other locations. The stresses within primary ore can be characterized as high and under most circumstance, highly anisotropic (directional in nature).

6.7. Mine analysis of overbreak and drift stability

Throughout mine development in primary ore, workings have been subjected to overbreak. This overbreak occurs at the time that the drift is driven. This has created a hazard to men and equipment operating in the area, and efforts have been made to prevent falls of ground by using rock bolts with wire mesh, to retain the loose rock. The overbreak characteristically occurs along the springline on the north side of east-west tending drifts, and on the west side of north-south tending drifts.

At many sites, breakage is also visible in the floor diametrically opposite to the configurations described, and areas subjected to caveline induced loads appear to be the most dramatically affected as evidenced by the intersection of extraction (calle) and drawpoints (zanja) drifts Figure 4.

Studies were undertaken to measure the overbreak at select locations throughout the primary ore zone. This was done for the purpose of quantifying observations to determine if there exist any directional qualities of this phenomenon. It is readily apparent, that the overbreak conforms to some pattern that not only is spatially correlative, but consistent between mine levels. This pattern can be explained in terms of a high stress field that is anisotropic. It is important to mention that a total of 87% of all sites exhibiting overbreak, produce breakage in a direction consistent with the hypothetical stress direction Figure 5. This indicates that these probably exists a preferred direction in which to orient mine openings to optimize drift stability.

In order to analyze the overbreak, rock stress and drift orientations, the three dimensional stress field was resolved into secondary principal stresses, to simulate two dimensional

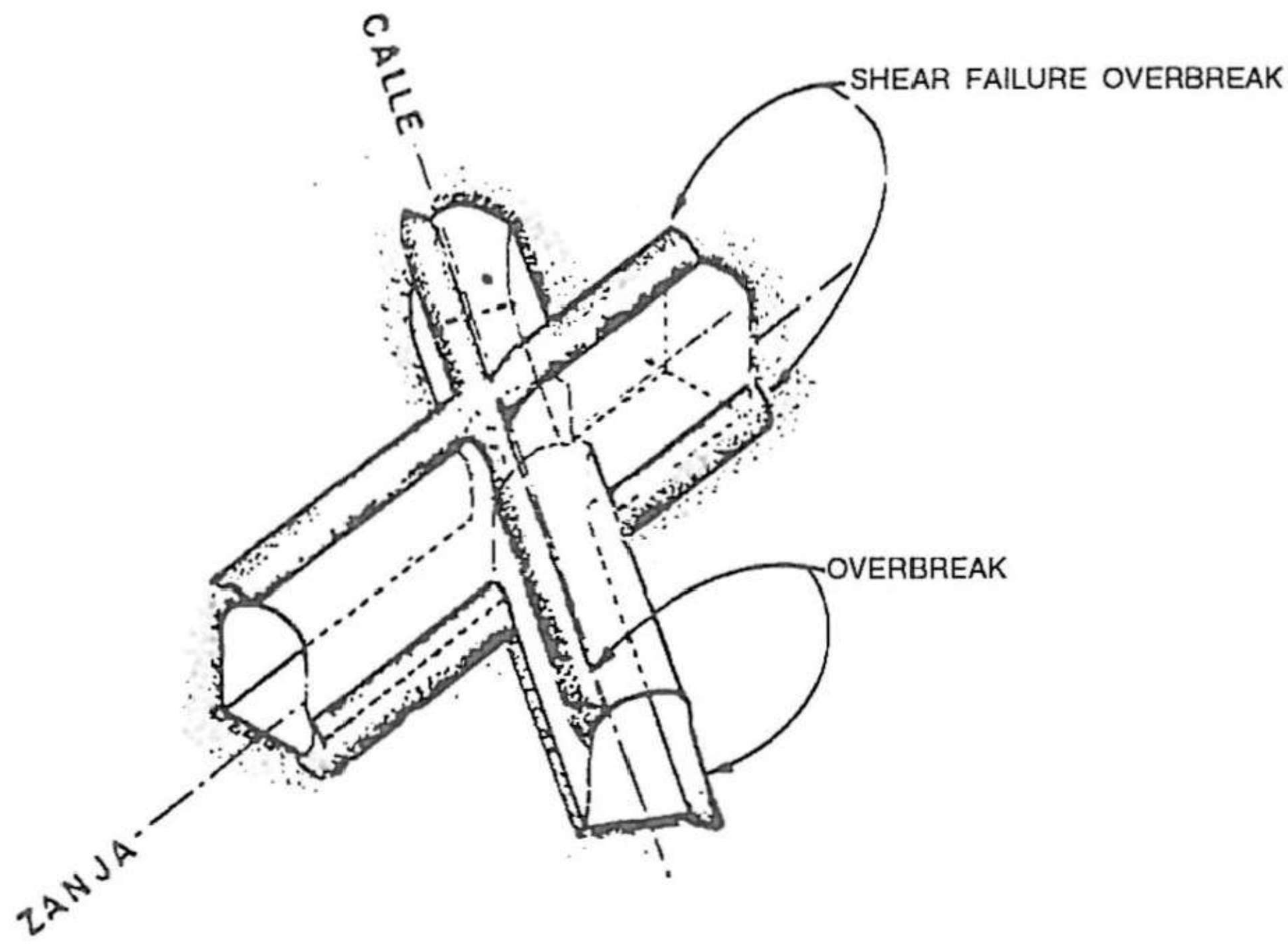


Fig. 4. Schematic diagram of shear failure at the intersection of the extraction and drawpoint drifts
Rys. 4. Schematyczny diagram pęknięcia poślizgowego na skrzyżowaniu wyrobisk w sąsiedztwie lei wypuszczania

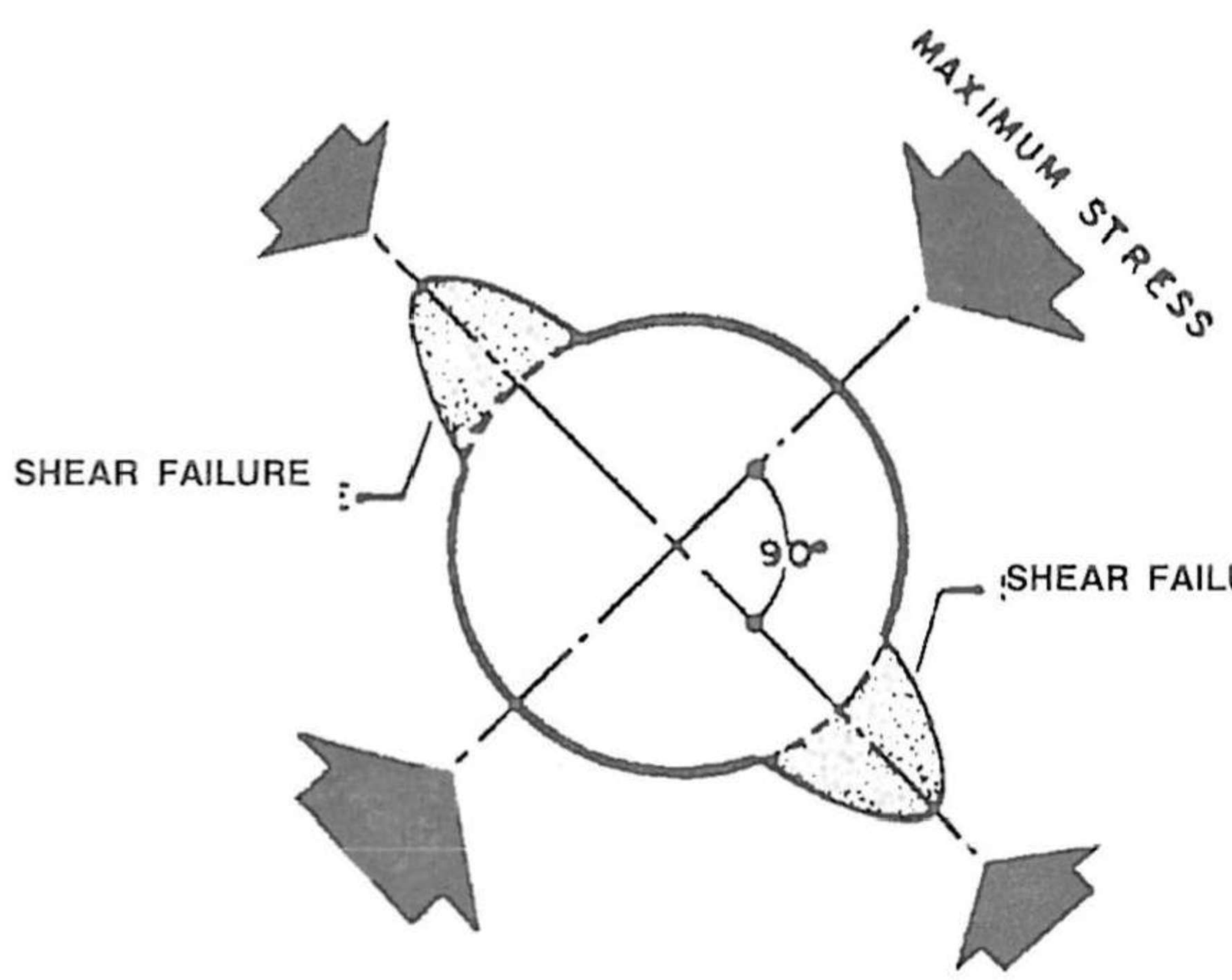


Fig. 5. Shear failure from inclined applied stresses
Rys. 5. Pęknięcie poślizgowe wskutek naprężeń skośnych

stress around an opening. Secondary principal stresses were calculated for vertical sections oriented from 0° to 180° degrees at intervals of 10 degrees. A hydrostatic condition is said to exist when the secondary principal stresses are equal.

Rock failure as observed at El Teniente appears to occur roughly perpendicular, to the direction of the maximum secondary principal stress when viewed in section. This implies that the mode of rock failure is shear. The mechanism of shear failure at El Teniente appears to be most related to the existence of high stresses, and it is not influenced by the presence of structural features (joints etc).

Numerical modelling was used to understand the overbreak phenomena at the development drifts at El Teniente. The studies were made to satisfy the essential objective of to investigate the mechanism of rock failure and compare the results of model studies to field observations.

6.8. Numerical methods — analysis and results

A 2 D computer program was used to calculate stresses and deformations about an underground opening (east-west oriented), subjected to an inclined stress field. Rock properties and stress data used for this analysis are given in Table 3.

Table 3. Rock properties and stress field used in analysis
Tabela 3. Własności skał i pole naprężeń wykorzystane do analizy

Parameter	Haulage drift (Calle)		Extraction drift (Zanja)	
	Actual	Modified	Actual	Modified
Azimuth	23°	0°	83°	120°
Maximum Stress (MPa)	53	40	60	49
Minimum Stress (MPa)	26	29	24	29
Angle of Inclination	37°	37°	34°	33°
Elastic Modulus (MPa)	13 700		13 700	
Cohesion In situ (MPa)	10		10	
Angle of Friction	44°		44°	
Poisson's ratio	0.24		0.24	
Uniaxial Compressive Strength (MPa)	47		47	

Drift stability was investigated by calculating and contouring stresses and safety factors. Safety factors were calculated using a Mohr-Coulomb failure criteria. Contours of maximum principal stresses around the drift are shown in Figure 6a. Maximum stresses are present in the upper left and lower right corner of the drift. This is where failure in the drifts is observed, indicating the failure is due to high stress (shear) rather than to tension. Low stresses occur in the upper right roof wall area the floor and the lower left side wall of the drift.

Contours of safety factor using a Mohr-Coulomb failure criteria are presented in Figure 6b. The areas of safety factors area consistent with observations in the mine. Reorientation of the haulage (calle) and drawdrifts (zanja), and heavier support in failure prone areas may be the most practical way to deal with the problem of drift failures.

6.9. Orientation of production and haulage drifts

Figure 7 presents a schematic diagram showing existing and proposed extraction and drawpoint drift orientations. Contours of safety factors using a Mohr-Coulomb failure criteria are presented in Figure 8 and 9 respectively, for actual and modified haulage drift (calle) and checkpoint (zanja). From these Figures, it can be appreciated the smaller zones of potential shear failure at the proposed system. Furthermore it can be assumed that an azimuth of 150° corresponds the best location for a drift. Based upon this, both drifts (calle and zanja), have been directed 30° degrees either side of the implied preferred direction.

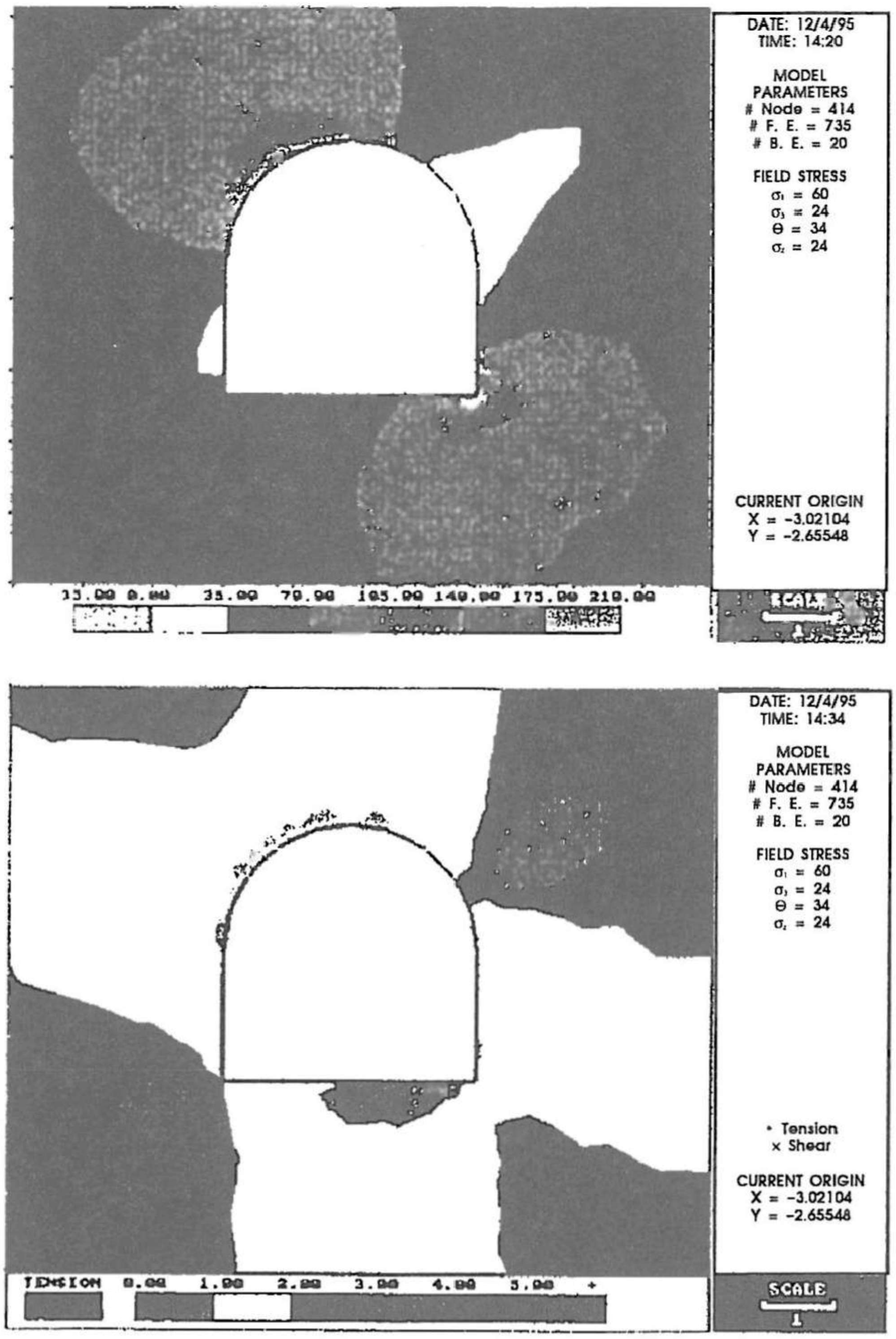


Fig. 6. Drift cross-section showing stress contours and safety factor for actual situation
Rys. 6. Przekrój przez chodnik przedstawiający kontury naprężeń oraz współczynnik bezpieczeństwa dla obecnej sytuacji

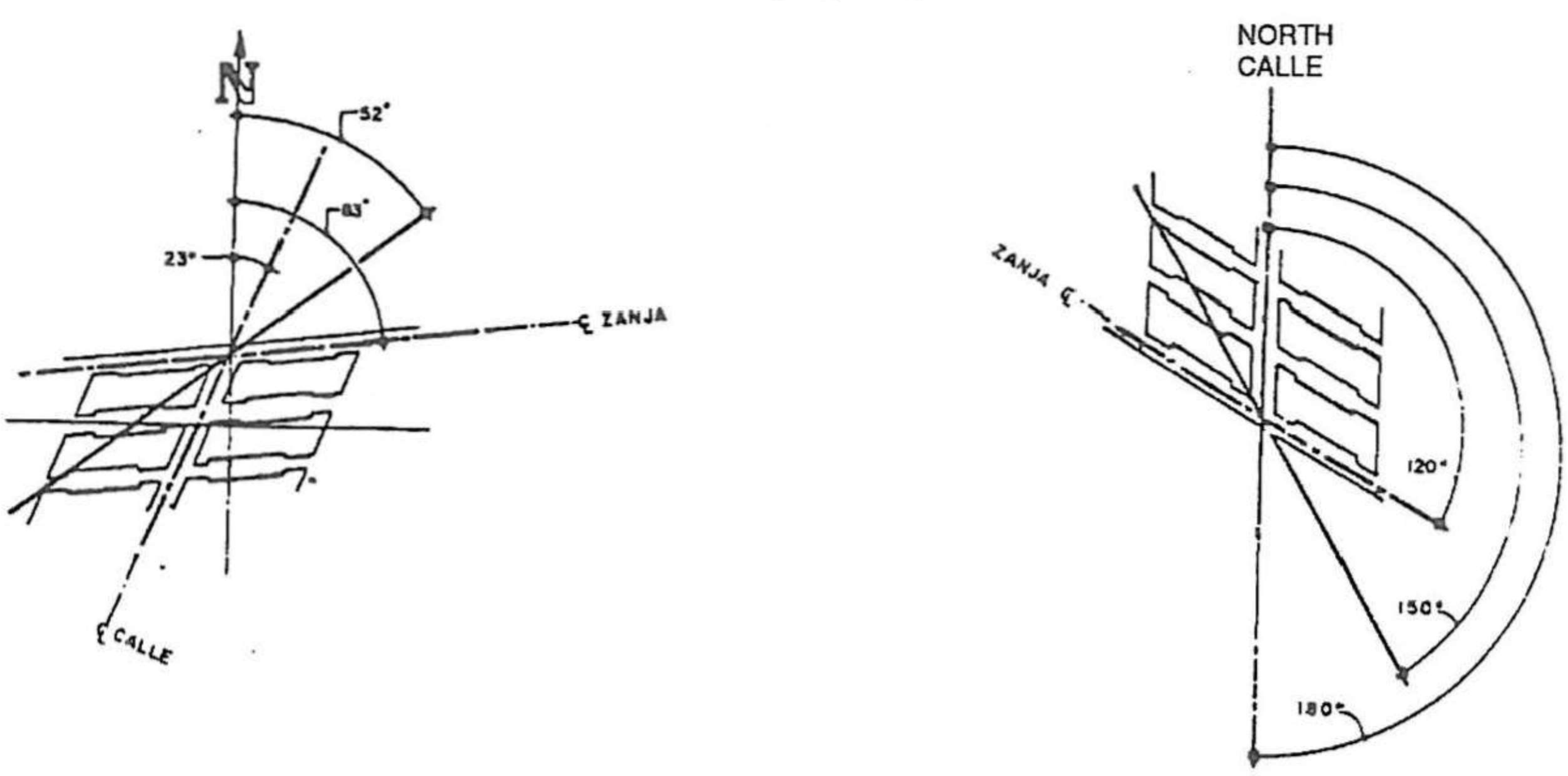
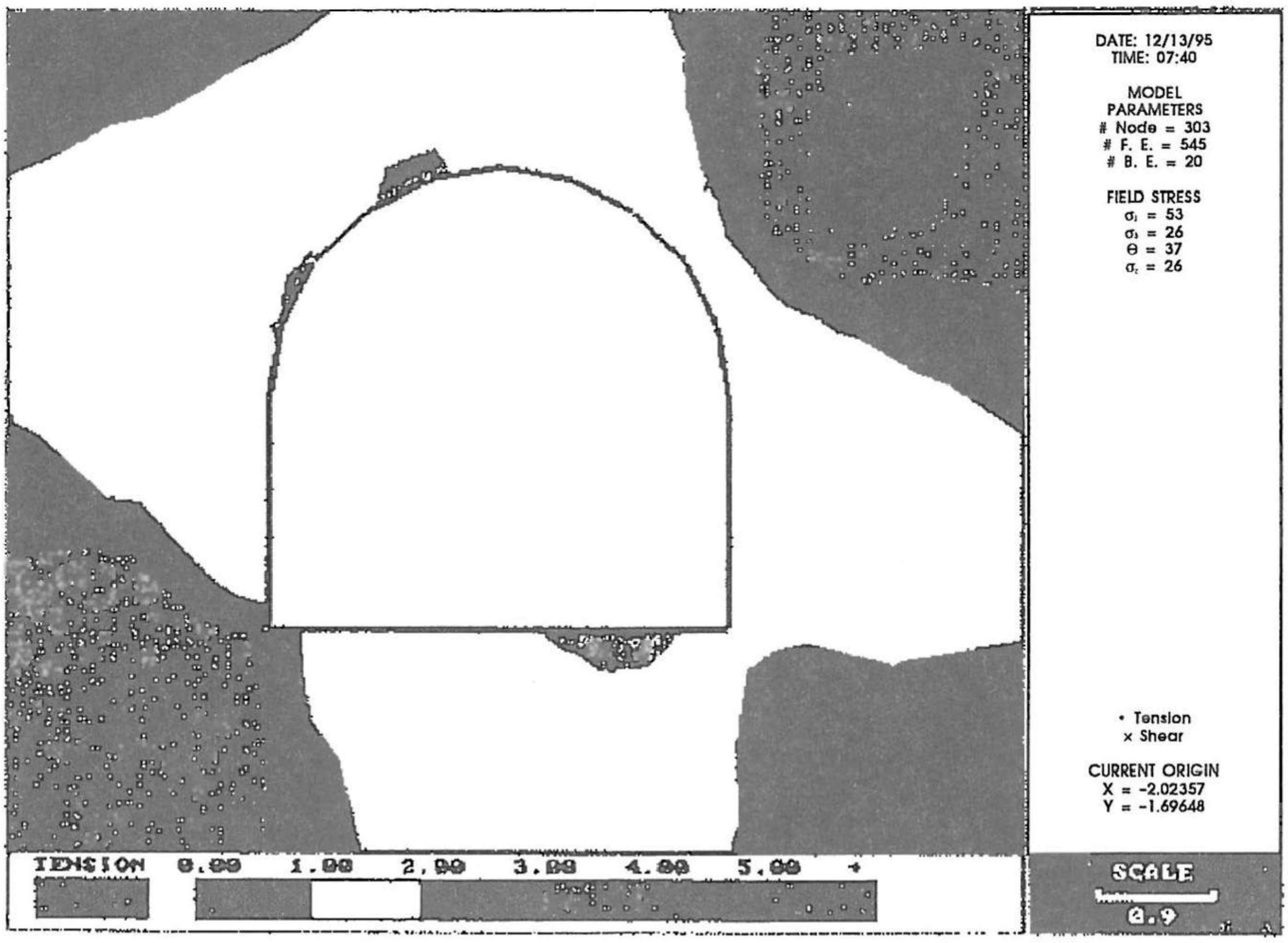


Fig. 7. Diagrams showing existing and proposed extraction and drawpoint drift orientations
Rys. 7. Diagramy przedstawiające istniejące i proponowane kierunki choodnika eksploatacyjnego i odstawczego



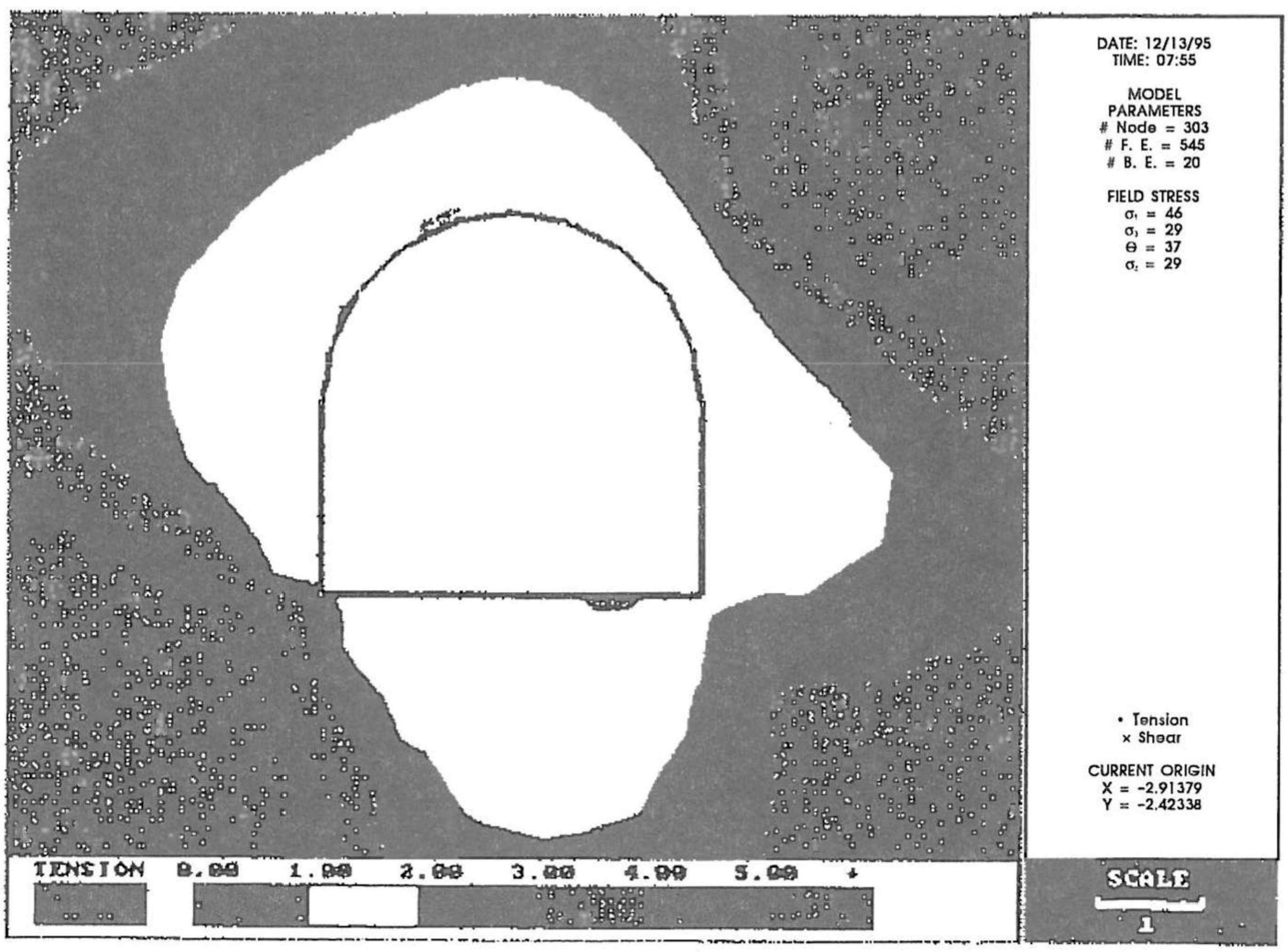


Fig. 8. Drift cross-section showing contours of safety factor for extraction drifts (calle) for actual and modified situation

Rys. 8. Przekrój przez chodnik przedstawiający kontury współczynnika bezpieczeństwa dla chodników wydobywczych w obecnej i zmodyfikowanej sytuacji

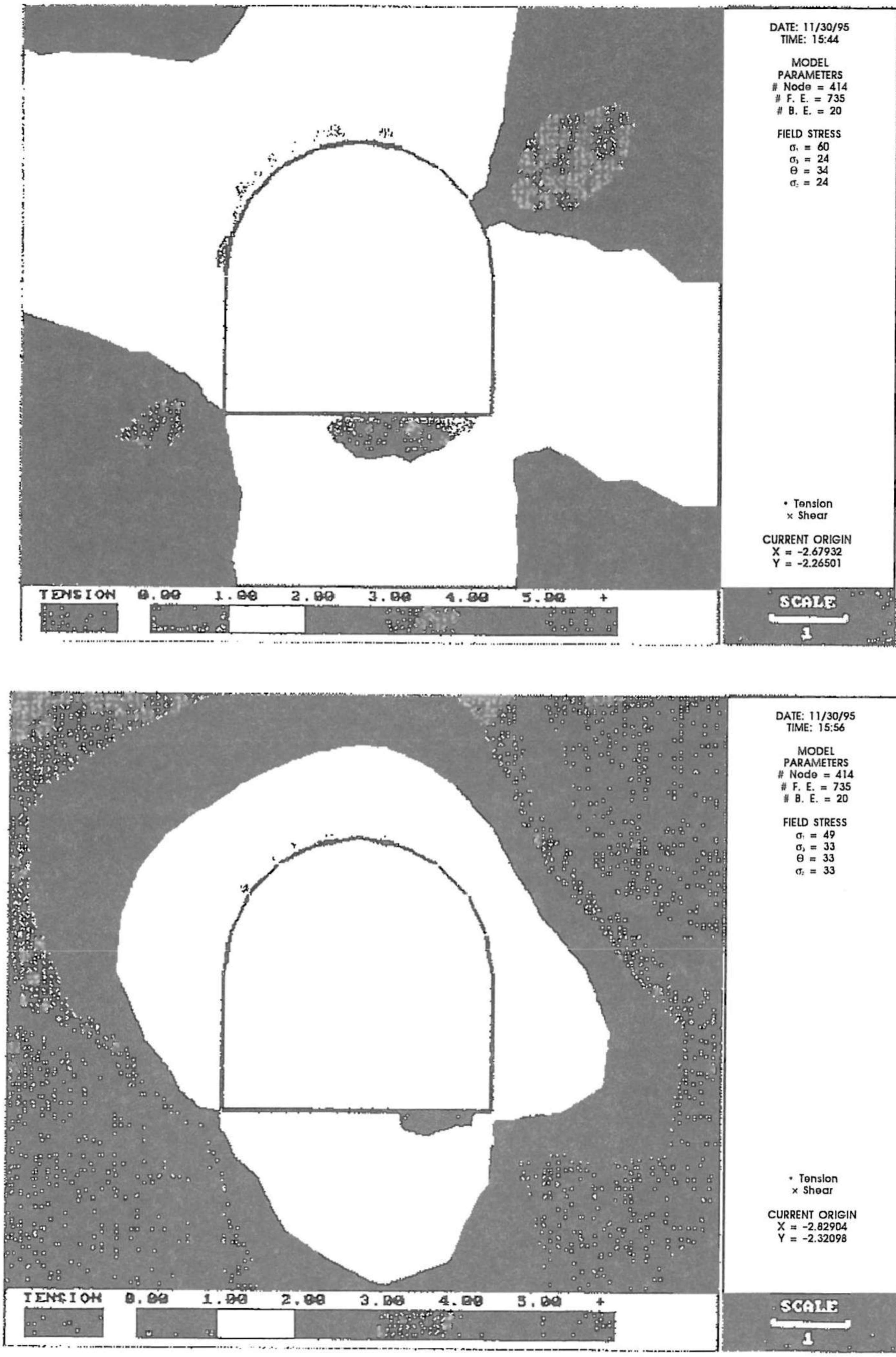


Fig. 9. Drift cross-section showing contours of safety factor for drawpoint drifts (zanja) for actual and modified situation

Rys. 9. Przekrój przez chodnik przedstawiający kontury współczynnika bezpieczeństwa dla punktów wybierania w obecnej i zmodyfikowanej sytuacji

7. Mine design

— **Pillar thickness between under cut and production level.**

Currently, there exists a 14.5 meter pillar between the roof of the extraction drift (calle) and the floor of the undercut drift. Under operational considerations and empirical design, pillar thickness is often related to other design factors such as the drawpoint spacing, and cross-sectional area of the drift driven within the pillar. At many block caving mines (El Teniente also), the pillar thickness is roughly equivalent to the drawpoint spacing.

A relationship also exists between the pillar thickness and the cross — sectional area of the drift driven within the pillar. Again, information from other block caving mines, the design of pillar thickness in primary ore also agrees with practices at other mines. Furthermore to date, no major pillars failure in competent rock (intact rock) in the production area have occurred.

7.1. Caveline orientation and retreat

Mining by block caving causes a reorientation and redistribution of stresses about the mined area. Usually a caveline oriented perpendicular to major structures, acts to reduce the amount of ground weight. Furthermore efforts must be made to keep the caveline perpendicular to extraction and haulage drifts: Under this situation, an angular caveline roughly 45° is used.

As the LHD extraction area at El Teniente is homogenous, then an E-W caveline orientation will keep the compromise with the drifts orientation proposed. Besides it is necessary that the area and shape of the mining area be of sufficient length and width to initiate and sustain a caving condition. Furthermore the elongation of the caving area must be a function of the in situ stresses.

For the LHD block cavig at El Teniente they are using an orientation E-NE, and a E-W caveline elongation which is consistent with geotechnical considerations. Figure 10.

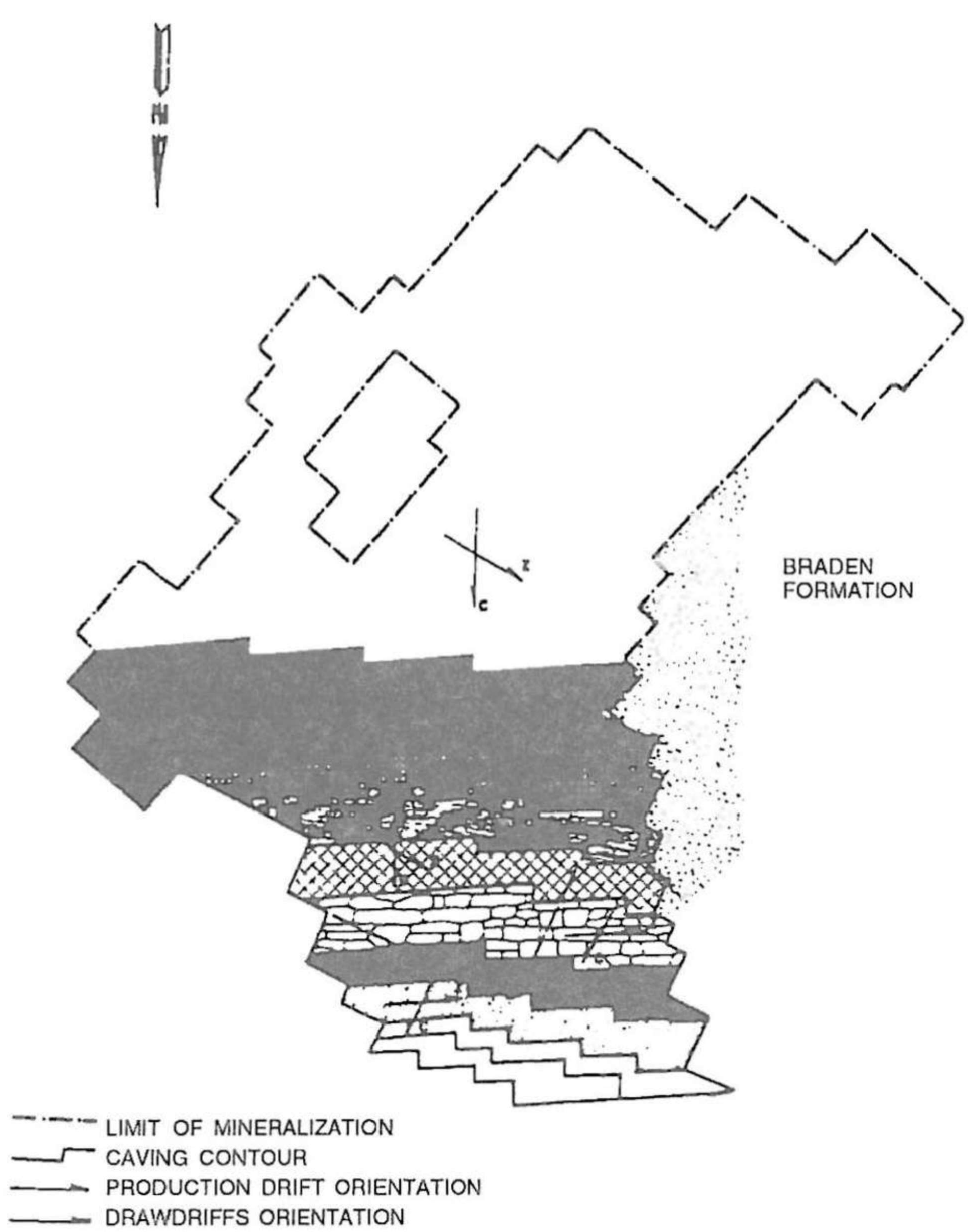


Fig. 10. Caveline orientation and retreat for a panel caving with LHD

Rys. 10. Kierunek linii zawału i wybierania panelowego z zawałem przy zastosowaniu LHD

7.2. Caving evaluation

The method used at El Teniente mine, was proposed by Laubsher, which consists in estimating the following parameters:

a. Area to caving, A.
b. Perimeter of the caving area, P.
c. Average MRMR of the rock mass of the caving area.
d. Determination of the hydraulic radio, RH (RH = A/P)
e. Graphical evaluation of the area of caving by means of RH and MRMR.

7.3. Subsidence

Block Caving results in discontinuous subsidence which influences large areas at the surface. The extent of this influence, as defined by the angle of break (Angle with horizontal formed by a straight line down from the undercut level to the extremity of surface disturbance) varies among others by the following factors:

— Strength properties of the orebody and overburden.
— Presence of mayor structural features.
— Depth of mining as defined by the undercut level.

Making an analogy with the supercritical model of subsidence as developed in coal mines; people from El Teniente have developed the following model of subsidence Figure 11.

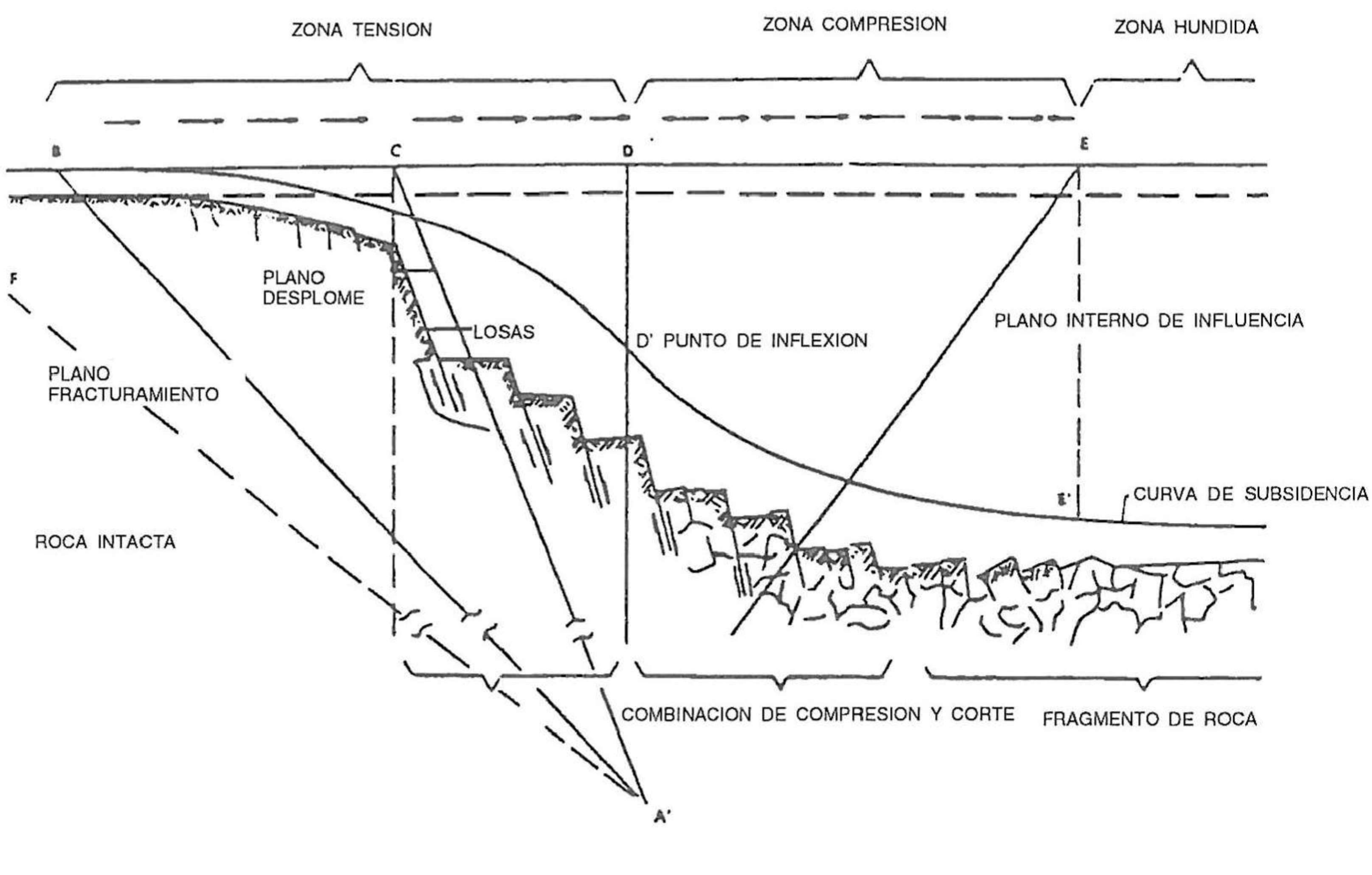


Fig. 11. El Teniente subsidence model
Rys. 11. Model osiadania w kopalni El Teniente

Where:

A'B — Limit plane of failure

CA' — Collapse plane

A'E — Internal plane of influence

A'F — Intact rock mans (No changes in the rock mass strength are produced outside the limit zone).

C — Cliffs zone where sliding occur throughout point C.

D' — Inflection point where the tension zone changes to compression.

EE' — Subsidence zone filled with broken material.

A' — Caving Level location.

Actually the determination of the parameters before mentioned, are made by means of visual observations and monitoring for checking of superficial movements.

8. Mathematical model for estimating subsidence in block caving

This mathematical model has been developed at El Teniente mine for calculating the angles of collapse and failure of subsidence. This model is based on the concept of limiting equilibrium previously used by Hoek (1974), Brown et al. (1979) and Kvapil et al. (1989). The analysis of subsidence with relation to depth is presented in Figure 12. Analyzing this Figure it can be established the following equations.

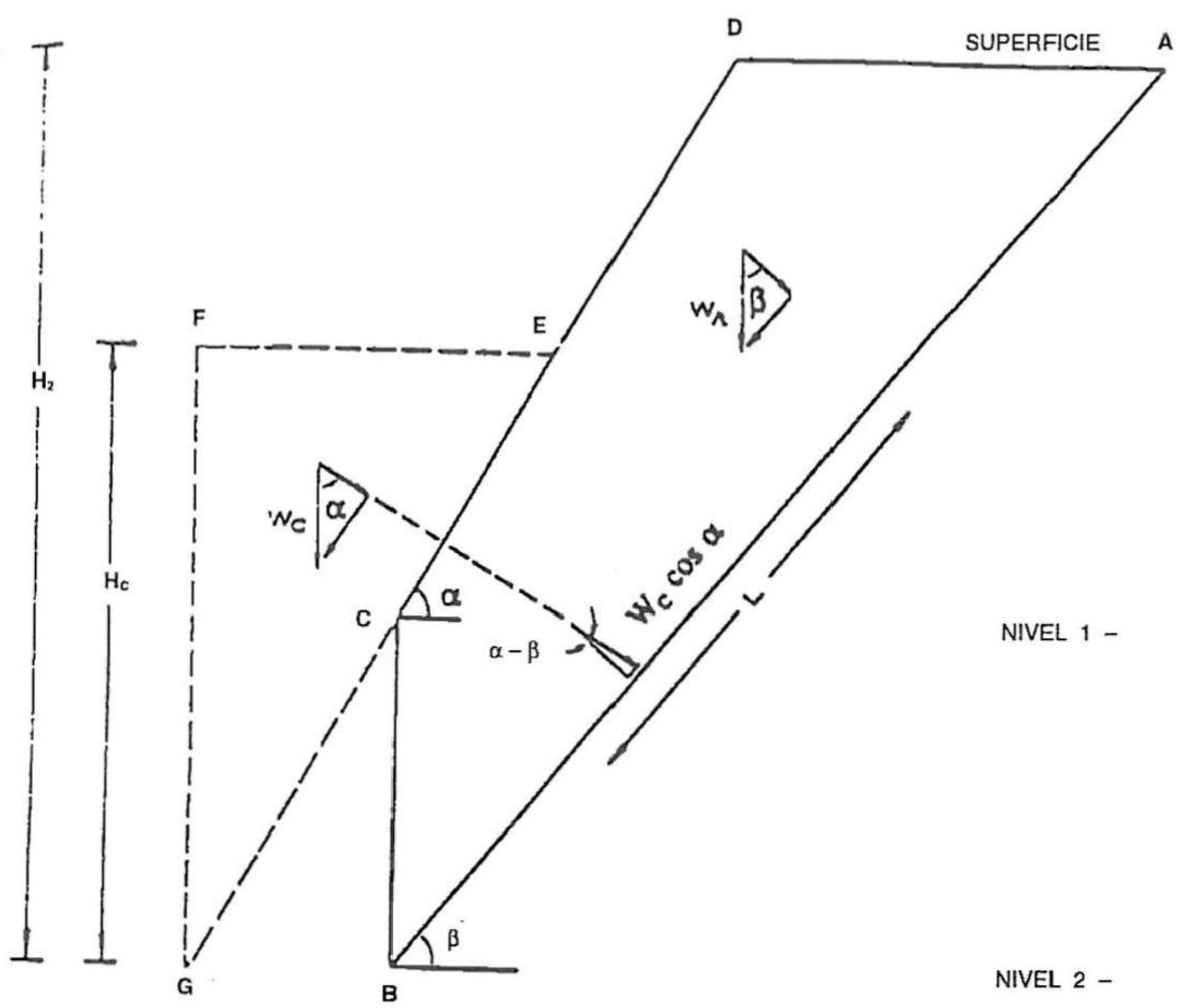


Fig. 12. Mathemathical model of subsidence with relation to depth mining

Rys. 12. Model matematyczny osiadania w zależności od głębokości eksploatacji

Disruptive forces:

$$Wr \sin\beta - Wc \cos\alpha \sin(\alpha - \beta)$$

Resistive forces:

$$CL + [Wr \cos\beta + Wc \cos\alpha \cos(\alpha - \beta)] \, tag\varphi$$

Where:

C — Rock mass cohesion
φ — Friction angle
Wr — Weight of intact rock
Wc — Weight of caving material
α — Collapse angle
β — Failure angle

The shear strength is assumed to be the strength that is defined by the equation

$$\tau = C + \sigma n \, tag\varphi$$

In a condition of limiting equilibrium when the disturbing forces is exactly equal to the resisting force, the inclination of the failure plane is determined by the following expression:

$$Wr \sin\beta - Wc \cos\alpha \sin(\alpha - \beta) = CL + [Wr \cos\beta + Wc \cos\alpha \cos(\alpha - \beta)] \, tag\varphi$$

α, β are determined by iteration.

Assumptions to the model

1. Principal structures are not considered.
2. Both planes (collapse and failure) are modelled by means of a straight line.
3. The failure surface is assumed planar.

Application of this model by people from El Teniente has developed the following curves of operational design for estimation of α and β. Figures 13 to 14.

8.1. Rock support

The objective of the support is:

— To protect people and equipments.
— To secure opening stability.

Ground practices of rock support at El Teniente mine must fulfill the followings characteristics:

— Set of elements support must be installed immediately after the round blasting.
— It must deliver greater safety as much as people and equipments.
— Avoiding deterioration of the rock mass.

Typical support used in development openings are rock bolts and accessories, mesh and Shotcrete Figure 15.

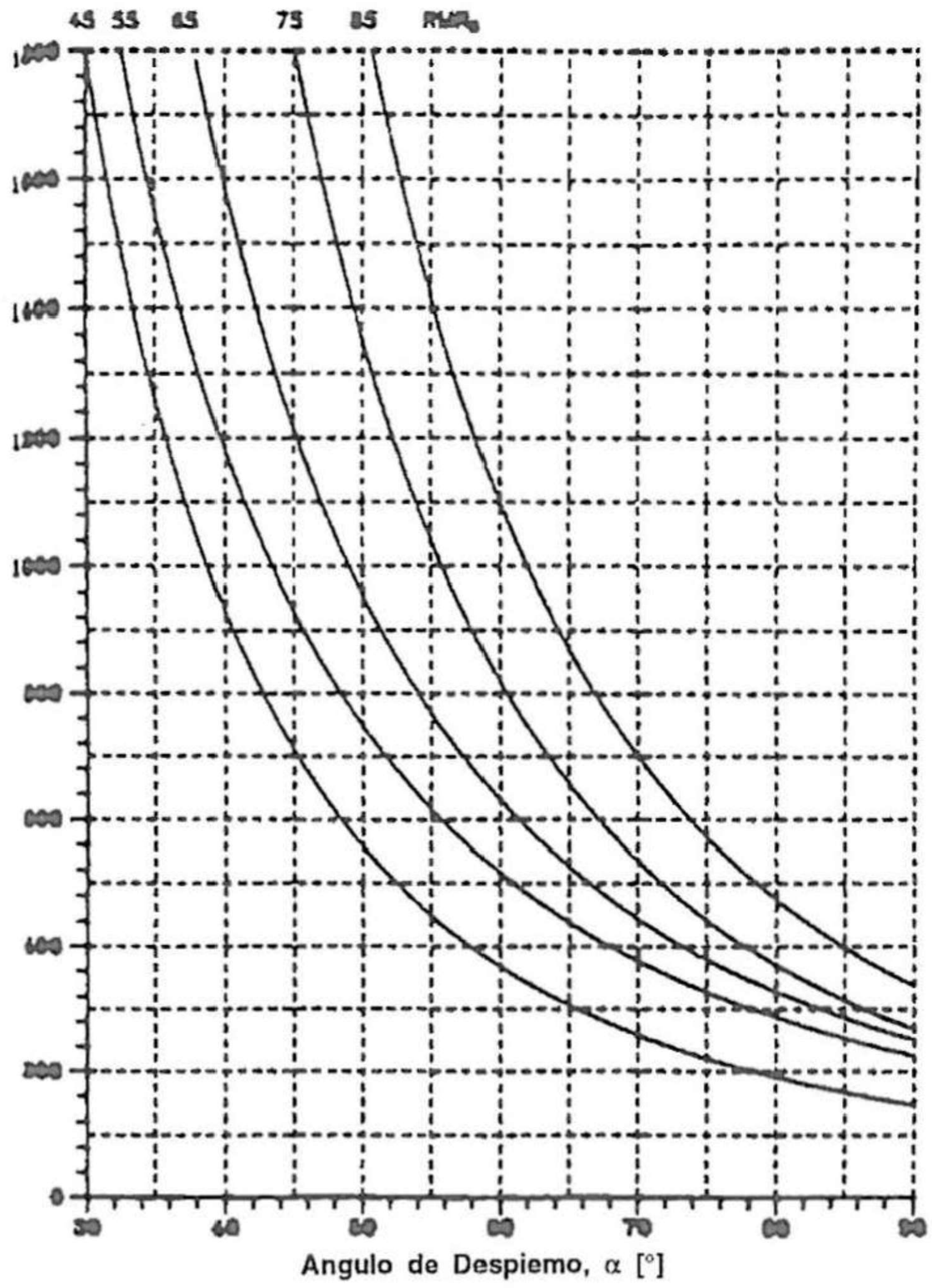


Fig. 13. Operational design curves for estimation the collapse angle
Rys. 13. Krzywe dla obliczenia kąta nachylenia płaszczyzn poślizgu α

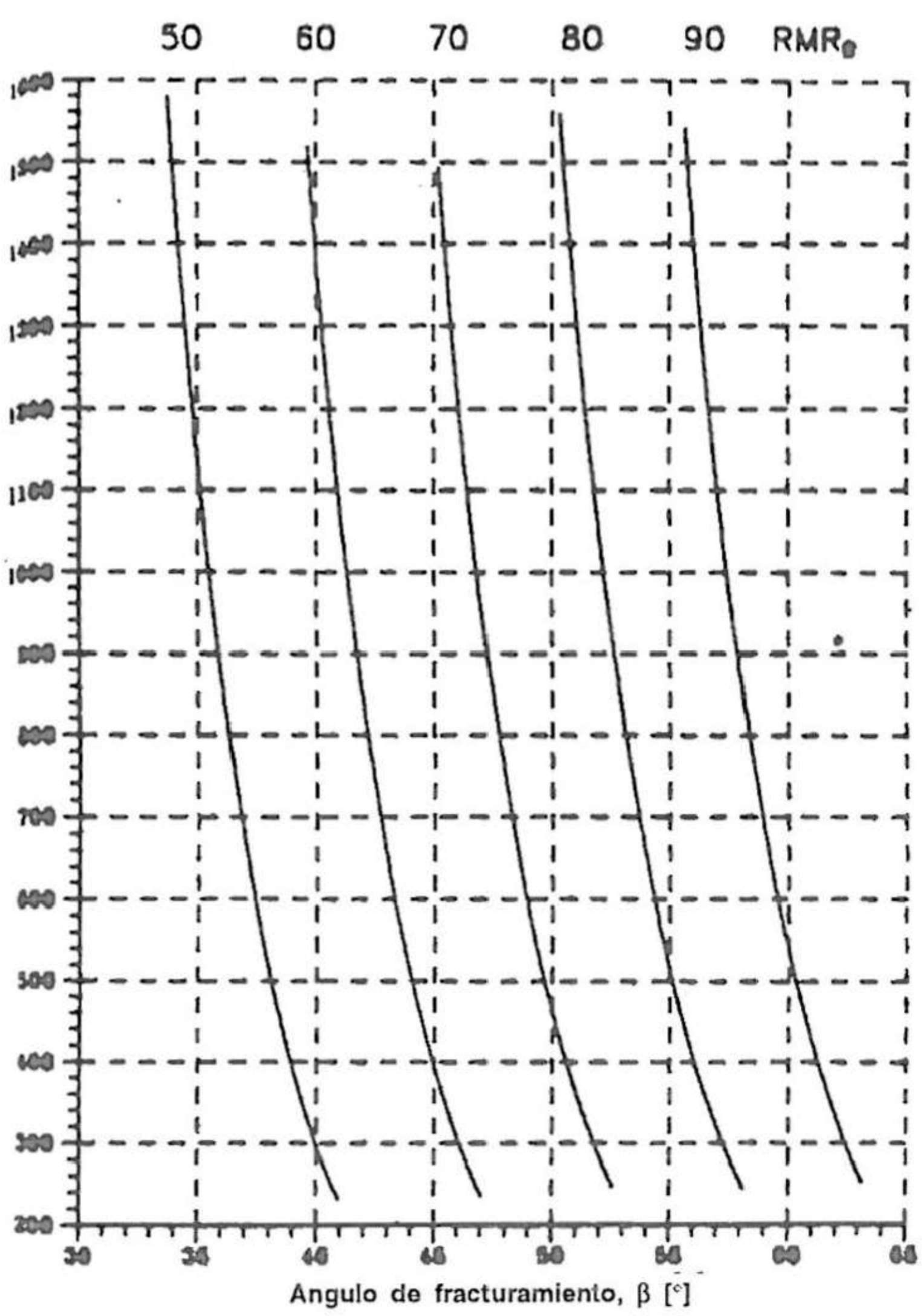
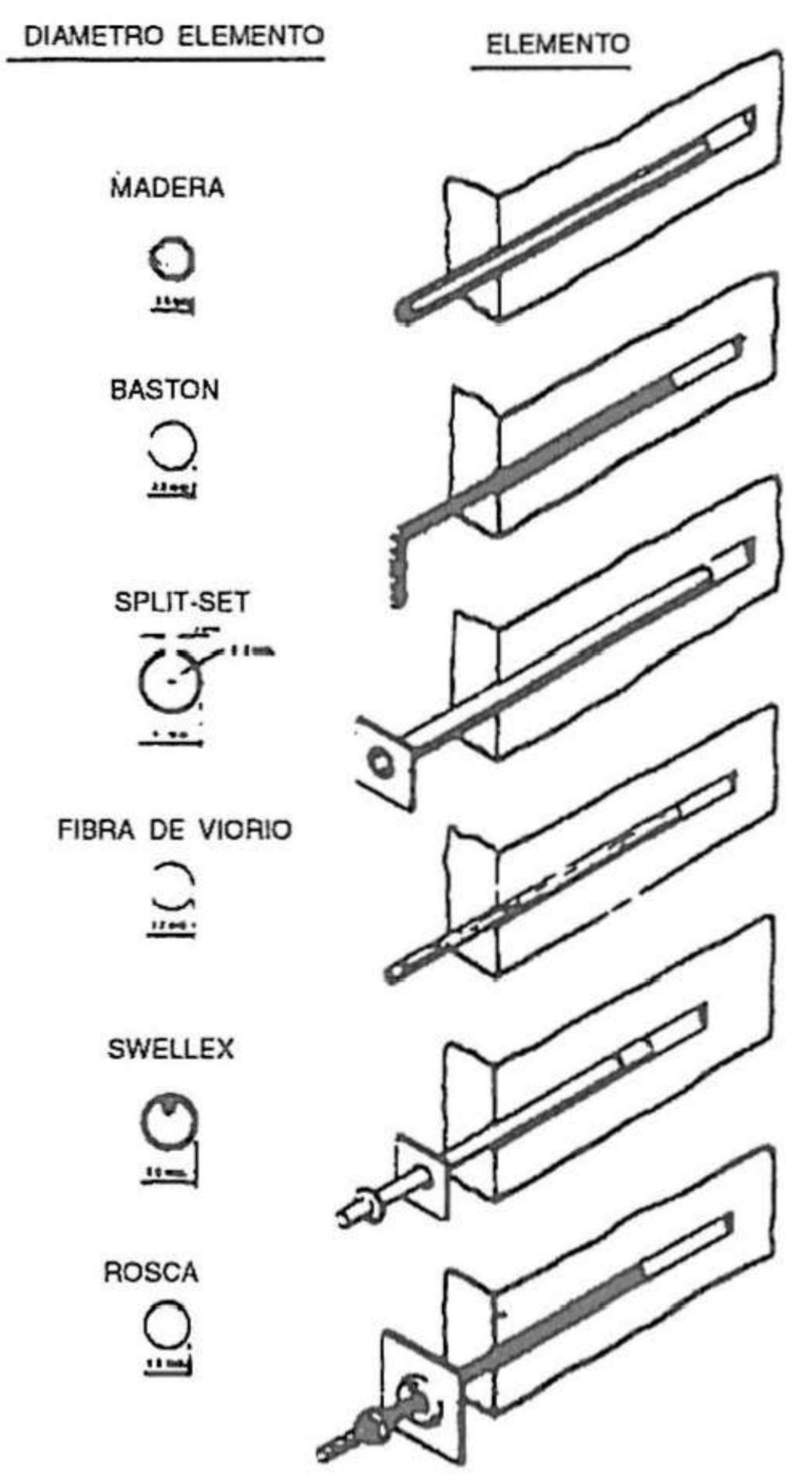
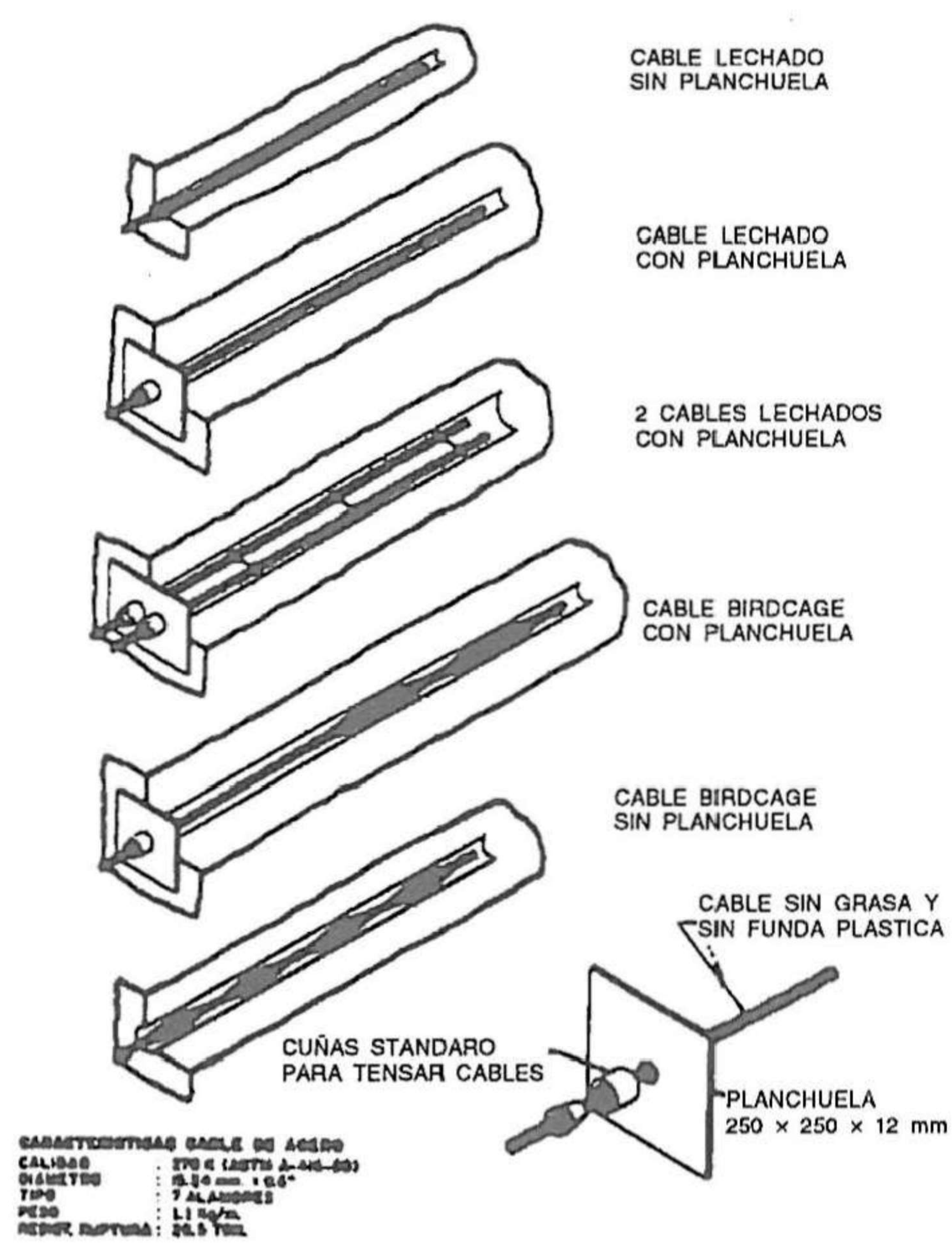


Fig. 14. Operational design curves for estimation the failure angle of subsidence
Rys. 14. Krzywe dla obliczenia kąta β

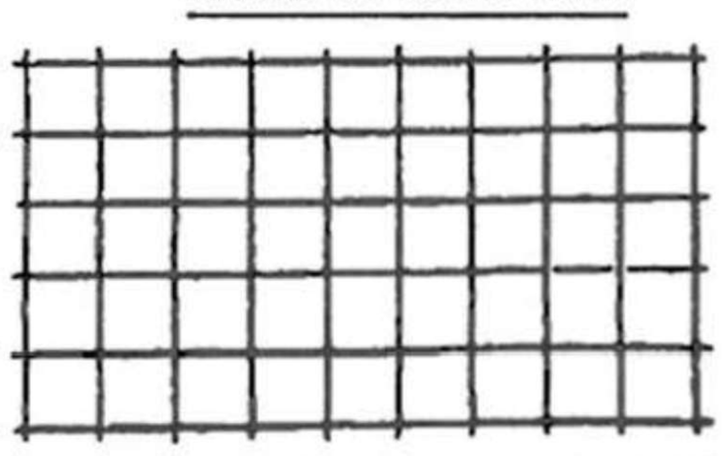


TIPOS DE PERNOS



TIPOS CABLES DE ACERO

MALLAS DE ACERO ACMA

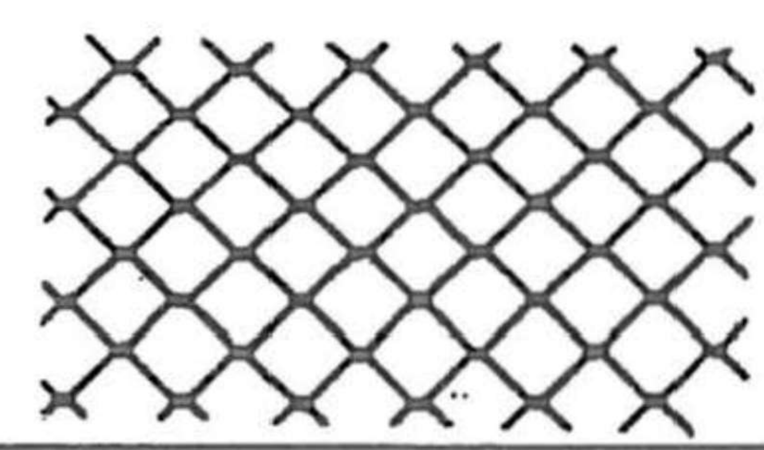


TIPO	MALLA mm	ALAMBRE φ mm	PESO Kg/m²
C-139	100	4.2	2.18 (1)
C-196	100	5.0	3.08 (1)
C-257	150	7.0	4.11 (1)
C-443	150	9.2	7.30 (1)
MA 3020	150	6.0	3.10 (2)

Presentación : paños

(1) Resitencia Acero : 50—56 Kg/mm²
(2) Resistencia Acero : 30—40 Kg/mm²

MALLAS DE ACERO TIPO BIZCOCHIO



TIPO	MALLA mm	ALAMBRE Nº	PESO Kg/m²
50 08	50	8	4.8
50 10	50	10	3.10
100 10	100	10	1.60
100 06	100	6	3.5

Presentación : rollos
Resistencia alambre : 38—44 Kg/mm²

Fig. 15. Types of rock boltings, cables and accesories used at El Teniente Mine
Rys. 15. Rodzaj kotwi, lin i innych elementów obudowy stosowanych w kopalni El Teniente

Types of ground support practices for extraction drifts and extraction drifts intersection are sketched in Figure 16.

Other types and support configurations used in other mining openings and structures are presented in Figure 17.

9. Conclusions

In this report it was analyzed the most important design parameters, that influence in a sector of exploitation of a Block Caving operation as El Teniente mine. The most important indications to be found since an operational and planning points of view area as follows:

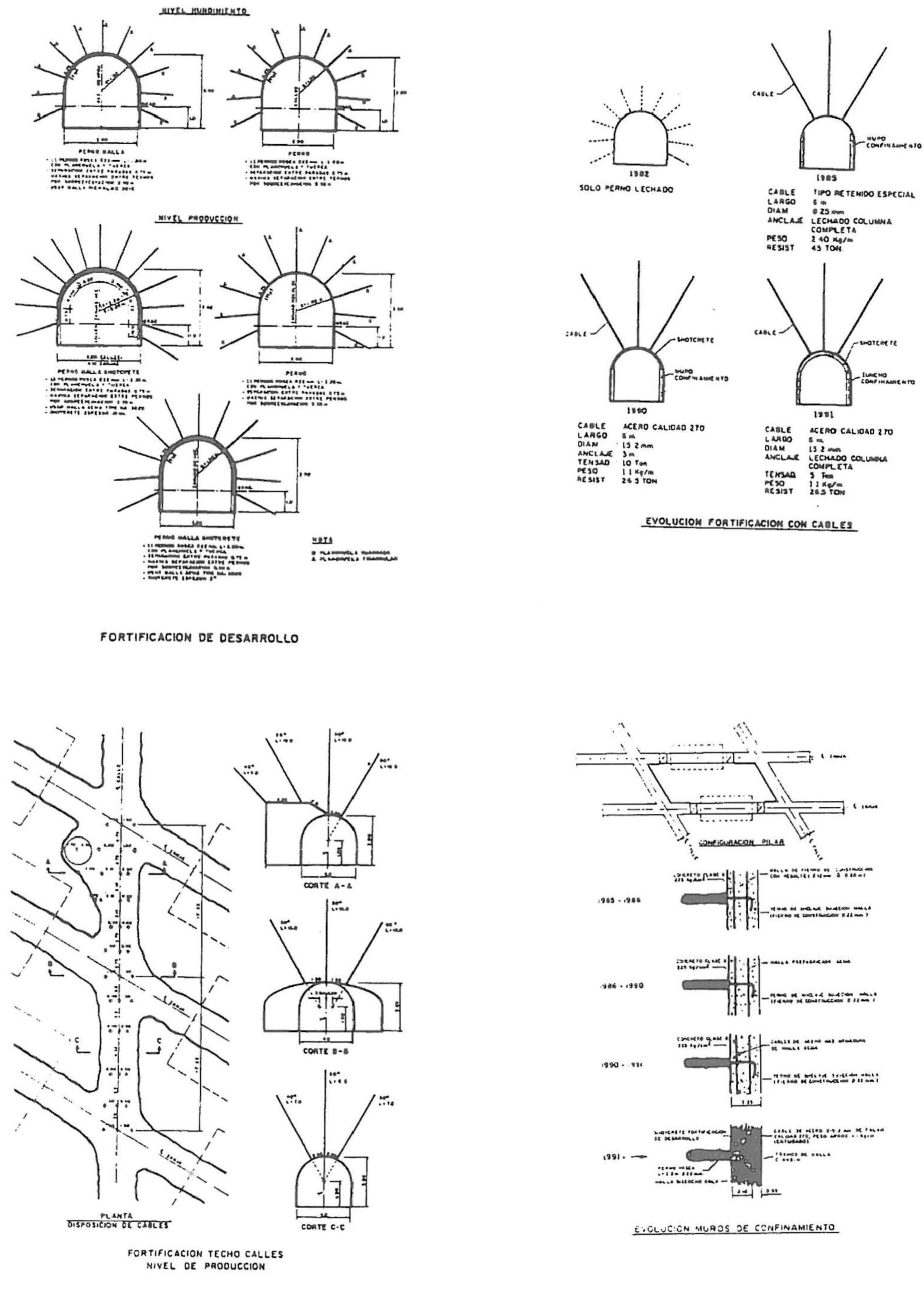


Fig. 16. Typical supports used in extraction and drawpoint intersections
Rys. 16. Typowe obudowy stosowane na skrzyżowaniach chodników eksploatacyjnych i odstawczych

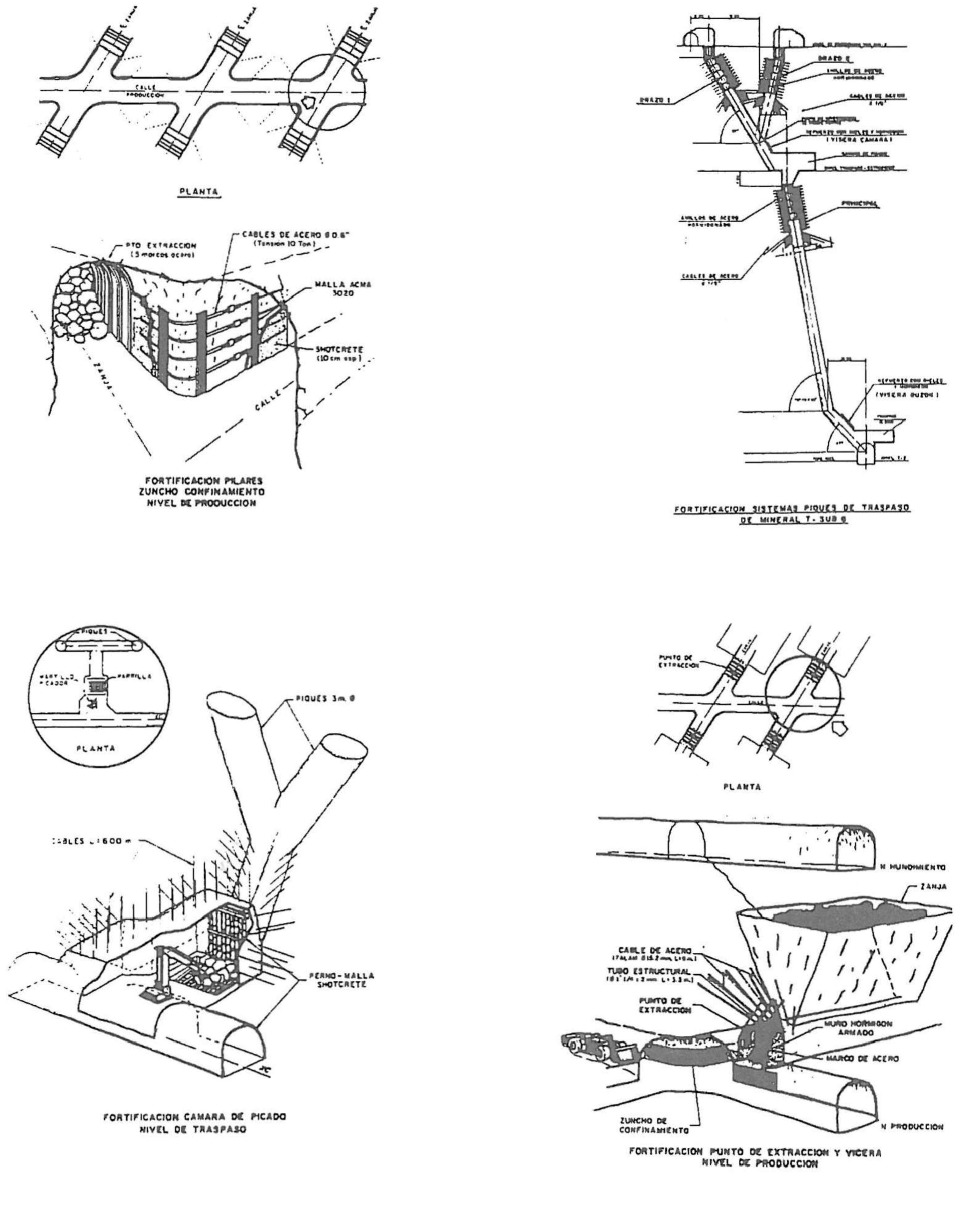


Fig. 17. Typical support configurations for mining structures
Rys. 17. Typowe schematy kotwienia dla wyrobisk górniczych

In spite of the slight variation in the stress direction in different working zone at El Teniente mine, the characteristics of the overbreak do not appear to change significantly. Model studies indicate that the stresses are sufficiently high to result in localized shear failures in underground workings. A preferred direction for optimum stability is related to direction (150—330); in consideration of this preferred direction an orientation of 120° is suggested for zanjas and haulage ways in the exploitation zone. Besides, an undercut and extraction drift orientation of 180° is suggested. A caveline oriented roughly E—W and directed from north to south appears to be the best compromise when the existing mine area, the stress distribution and the suggested drift orientation are considered.

With respect to rock support, people from El Teniente will have to develop more research, related to yielding type supports for the rock burst conditions found in the mine.

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Aspekty geomechaniczne górnictwa rud w Chile

Streszczenie

Omówiono szeroki zakres problemów geomechanicznych związanych z podziemną eksploatacją złóż rud. Rozważając strukturę górotworu ze szczególnym uwzględnieniem układów szczelin i spękań oraz wpływu warunków wodnych przeanalizowano warunki stateczności wyrobisk podziemnych. Uwzględniono zarówno wyniki rozwiązań modeli numerycznych, jak również pomiarów odkształceń i naprężeń uzyskanych in situ.

Szczególną uwagę poświęcono największej na świecie podziemnej kopalni miedzi w Chile — El Teniente, gdzie prowadzi się liczne badania geomechaniczne.