SPECIAL REPORT

Virgin versus mature reserves: a dilemma for new investment

by I.F. Machado, S.P. Bordonalli and F.E.N. Hegenberg

During the mining cycle the general rule is to observe declining grades of ores and minerals being exploited along the life of most mines. This is more evident for metal mines than for industrial minerals. One important consequence is the increasing operating cost, aggravated by the not negligible environmental compliance costs appearing in the last decades. Two examples are depicted here: copper and kaolin (high grade type) reserves. It is argued that mining of virgin reserves is presently a competitive advantage in favor of developing countries.

Professor Iran F. Machado holds a Ph.D. degree in Geology and is with the Mineral Resources Policy and Management Department (State University of Campinas), Instituto de Geociencias – UNICAMP – 13083-970 Campinas, SP – Brazil. Sergio P. Bordonalli and Flavio E. N. Hegenberg hold B.Sc. degree in Geology and are M.Sc. students.

It is noteworthy to observe that the striking differences between virgin and mature reserves of ores and minerals have not deserved a special attention by many authors in specialized journals and magazines dealing with mineral exploration or mineral economics. To the authors of this paper, *virgin reserves* are those defined in the end of detailed exploration stage or under development to start up a mine. *Mature reserves* are typically those being exploited in the second half of a mine life. Under this definition, there is an intermediate zone corresponding to the reserves being exploited in the first half of a mine life; this third category, that could probably be named *young reserves*, is not fully considered in this paper. Obviously, a mine life may be extended when new exploration efforts are made, but the purpose of this article is to call the attention to the extremes of such a classification.

Virgin and mature reserves are plainly explained by the mining cycle, characterized by five phases (exploration, development, production, maturity, and depletion), according to most authors. This cycle exists only because reserves are identified, measured, exploited and finally depleted (or sometimes the mine is prematurely closed or abandoned due to economic, legal, environmental, political or social problems). In this century there has been a gradual shift of mining operations from the industrialized to the developing countries. While the former were actively developing their industrial base, the latter were more dedicated to exploit their agricultural commodities, or gold and silver, during the colonial times. Thus, in general terms, virgin reserves were consumed more quickly in Europe, North America and Japan, whereas they are still untouched and sometimes undiscovered in the Third World.

Table 1

Comparison between the exploitation of virgin and mature reserves

	Virgin reserves mostly found in developing countries	**Mature reserves** mostly found in developed countries
Ore grade	Higher	Lower
Depth of deposit	Shallower	Deeper
Overburden ratio	Better	Worse
Infrastructure	Poor	Good
General cost structure	Costly start-up Less technology intensive	Original investment already depreciated More technology intensive
Waste disposal	Plenty of alternatives	Few alternatives
Labor	Less skilled	More skilled
Health and safety	Lax regulations and enforcement	Strict regulations and enforcement
Political and legal framework (including environmental factors)	Full of incentives	Increasing disincentives

Opencast copper mine of Andina division, Codelco Chile.

The comments made above apply equally to both metallic and nonmetallic deposits. In the class of metallic commodities this evolution from virgin to mature reserves is accompanied by a slow but steady decrease in ore grade, besides other physical factors that may deteriorate as well and have some impact on the mine economics. Every professional involved in feasibility studies of mining projects knows that a number of factors affect the costs of mine development, e.g.,

- size and grade of the deposit,
- depth from the surface,
- shape of the orebodies,
- content of by-products and/or co-products,
- location of the deposit,
- economy of scale,
- capital requirements,
- mining technologies,
- infrastructure: transport, water, power, and communications,
- labor costs,
- mining taxes,
- environmental protection costs.

Table 1 shows a comparison between the exploitation of virgin reserves, nowadays predominantly located in developing countries, versus mature reserves typically located in industrialized countries or in old mining districts of developing countries (tin in Bolivia, iron ore in Southeast Brazil, silver in Mexico, and so on).

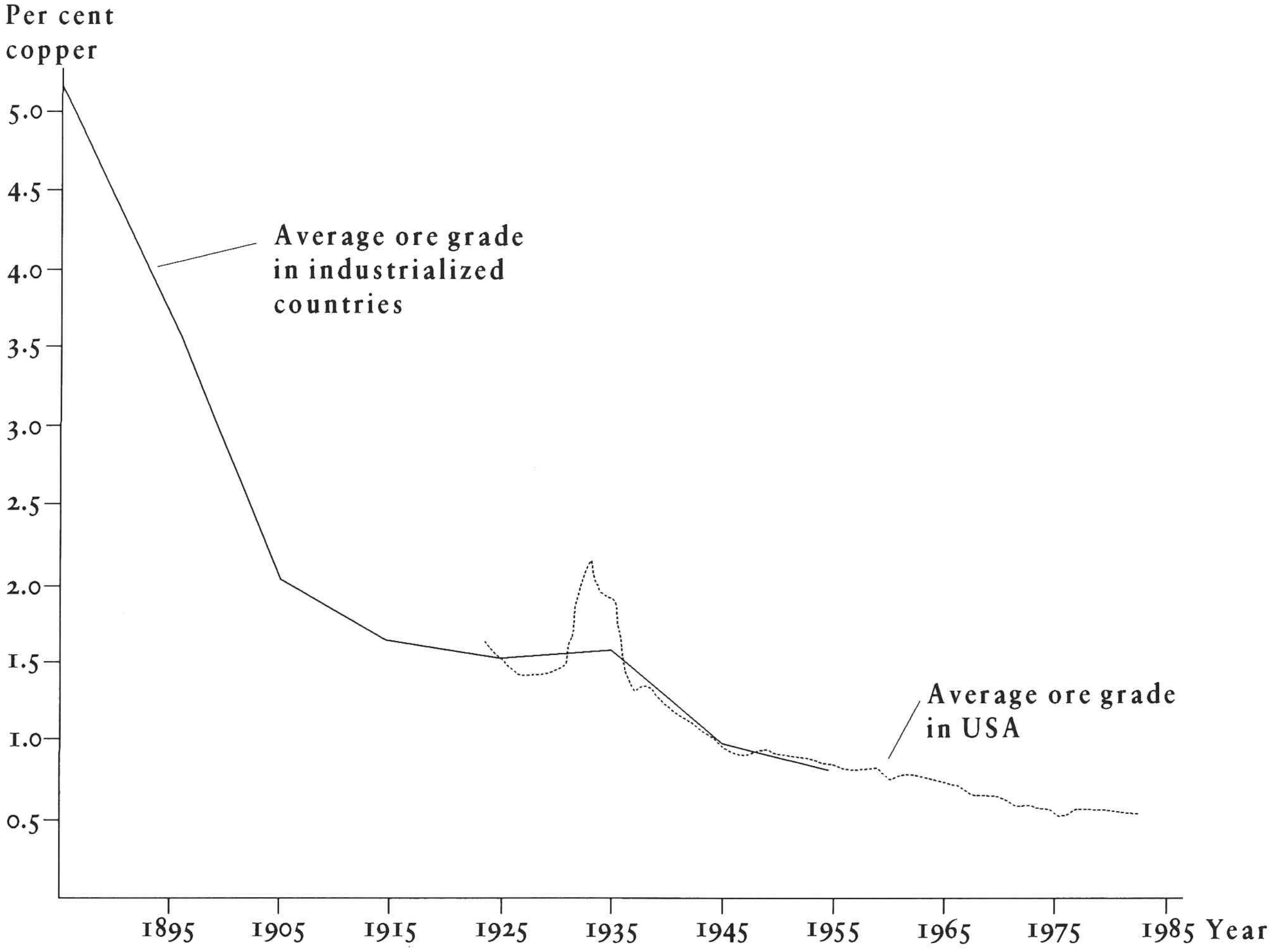
In this paper the authors will try to emphasize the close relationship existing between the aging of reserves and the mining cycle. Two examples were selected: *copper* for the metallic commodities, and high grade *kaolin* for the nonmetallics or industrial minerals. In many papers this fundamental relationship does not appear in a clear way or it shows up in incomplete tables that are only half true. This is more often the case of industrial minerals, where an equivalent to "metal content" may be missing.

To avoid misunderstanding or unwanted criticism, it is relevant to remind that technology has been one powerful instrument used by industrialized countries to compensate for the physical deterioration of their reserves.

Copper reserves

Even recognizing that many factors have implications for the feasibility of a copper project, as stressed above, we are going firstly to concentrate our arguments on ore grade.

Figure 1
Evolution of copper ore grades
in European and American mines 1882–1982



Sources: Industrialized countries: Jankovic 1967, USA: Wagenhals 1984.

It is known that a few centuries ago only high grade copper deposits could be mined. For instance, the percentage yield of copper ore mined in Cornwall, from 1771 to 1786, and in the Royal Saxonian mines in 1844 averaged 12 per cent[1]. Jankovic[2] analysed 300 copper deposits from 1880 to 1960 and proved the existence of the steady decline of ore grades along time. Studies made by the U.S. Bureau of Mines confirm this trend for the American copper mines in the period 1924-1982[3].

Figure 1 is a composition of data collected by Jankovic in the industrialized countries and those data shown by Wagenhals[3], giving a span of one century of declining ore grades. The only anomaly in this long period (the peak in the early 1930s) is due to the Great Depression, when higher yield than usual had to be obtained.

The demand for copper is the result of a very rapid growth since 1900, and especially in the post-World War II period. Copper production rose from 10 000 Mt a year from 1800 to 1810, to 750 000 a century later, to a range of 7-8 Mt in 1978[4], and finally to 10.7Mt in 1990[5].

The copper deposits are generally classified into three metallogenetic classes (porphyry type, strata-bound and massive sulfide deposits), but the porphyry copper play the most important role in present world production. Porphyry deposits occur predominantly in Chile, Peru, Mexico, the United States, Western Canada, Papua

Drilling at El Teniente division of Codelco Chile.

New Guinea and Philippines. They generally contain the largest ore reserves, but have the lowest grade of copper content, whereas the strata-bound deposits are usually smaller in reserves and present a higher grade[6]. The 255 most important copper deposits in the world, are surveyed in Metallica 2000 database[7]. There are:

- 136 active mines,
- 2 closed mines,
- 12 deposits under development,
- 95 deposits after exploration,
- 10 deposits with unknown status.

Using the proper classification, this means:

- 107 virgin reserves (active and closed) and
- 138 young and mature reserves (under development and after exploration).

The mean grade (weighted average) of the 255 deposits is 0.80 per cent Cu, while the mean grade of the active mines is slightly higher, 0.83 per cent. The Americas are the largest producers, with 51.2 per cent of total world production[5]. It is interesting to observe that North American active mines (USA + Canada) have a mean grade of 0.50 per cent Cu and the Latin American active mines show a mean grade of 1.00 per cent; thus, there is a ratio of 2:1 in favor of Latin America.

Now, let us consider the case of virgin reserves. North American deposits present a mean grade of 0.52 per cent Cu and Latin American deposits, 0.83 per cent. The rest of the world mean grade is 0.49 per cent Cu.

This means that by and large Latin America is presently and in the foreseeable future the region with the best copper grades in the world. No wonder that so much foreign capital is being poured into Chilean projects.

When we select those deposits having a tonnage higher than 500 million metric tons of copper ore - giant deposits - the Metallica 2000 list contains 34 of those deposits, being 16 (47 per cent) of them located in Latin America, 10 in North America, 4 in Asia, 3 in Australasia and 1 in Africa (Table 2).

These deposits correspond to "giant accumulations" and "large accumulations" according to the criteria defined by Laznicka, and Hodgson[8] (giant accumulations = 5.5 Mt Cu and up, and large accumulations = 550 kt Cu and up).

The parameter ore grade is very important too when one considers productivity in mining.

In a study about this subject, Pye[9] called attention to the fact that in manufacturing industries it is assumed that the quality of materials inputs does not change over time.

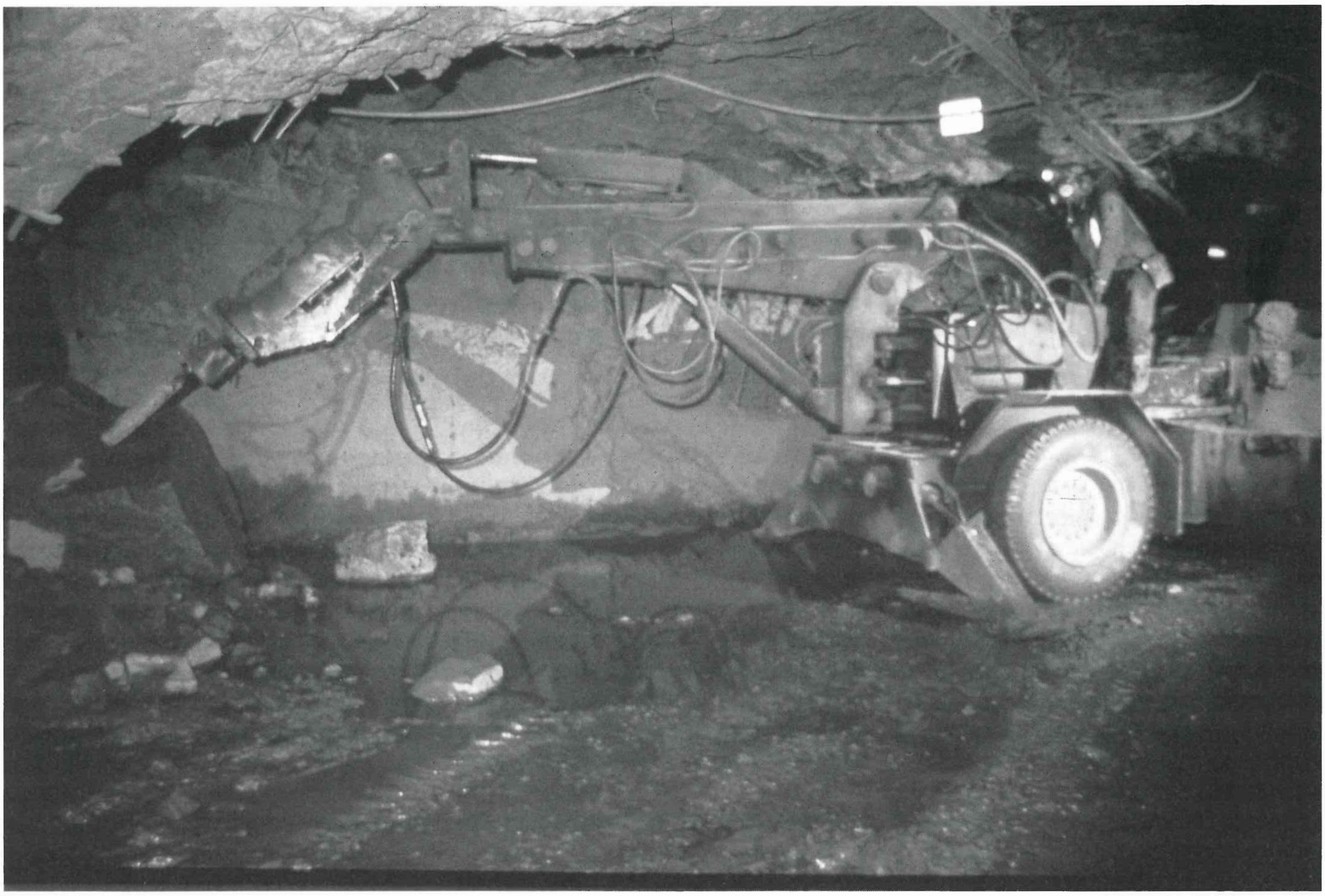


Table 2
Giant copper deposits

	Mine or deposit	Status	Reserve Gt	Grade per cent Cu	Metal content Gt	Country
1	El Teniente	O	2080	1.12	23.30	Chile
2	Collahuasi	X	1849	0.92	17.01	Chile
3	La Escondida	O	1800	1.60	28.80	Chile
4	Cananea	O	1670	0.62	10.35	Mexico
5	La Caridad	O	1499	0.39	5.85	Mexico
6	Los Bronces	O	1380	0.81	11.18	Chile
7	Morenci	O	1310	0.51	6.68	U.S.A.
8	Sar Cheshmeh	O	1200	1.20	14.40	Iran
9	Bagdad	O	1116	0.37	4.13	U.S.A.
10	Bingham Canyon	O	1059	0.62	6.57	U.S.A.
11	Ray	O	1016	0.63	6.40	U.S.A.
12	Cebu	O	893	0.41	3.67	Philippines
13	Sierrita/ Twin Buttes	O	889	0.29	2.58	U.S.A.
14	Namosi	X	815	0.43	3.51	Fiji
15	Petaquilla	X	794	0.60	4.76	Panama
16	Grasberg/Ertsberg	O	733	1.47	10.78	Indonesia
17	Florence	X	725	0.38	2.76	U.S.A.
18	Mansa (Centre)	X	700	1.30	9.10	Chile
19	Salobo	X	700	0.70	4.90	Brazil
20	Radomiro Tomic	X	691	0.73	5.04	Chile
21	Sipalay	O	650	0.49	3.19	Philippines
22	Chuquicamata	O	650	0.85	5.53	Chile
23	Highland Valley Copper	O	633	0.41	2.62	Canada
24	Toromocho	NA	600	0.68	4.08	Peru
25	Haib	X	600	0.32	1.92	Namibia
26	Olympic Dam	O	574	2.10	12.06	Australia
27	Pinto Valley	O	567	0.19	1.08	U.S.A.
28	Casino	X	557	0.25	1.41	Canada
29	Bajo de la Alumbrera	X	550	0.52	2.85	Argentina
30	Michiquillay	X	544	0.69	3.75	Peru
31	Cerro Verde	O	536	0.74	3.96	Peru
32	Mission Complex	O	512	0.67	3.43	U.S.A.
33	Ok Tedi	O	510	0.69	3.52	Papua New Guinea
34	Toquepala	O	509	0.86	4.38	Peru

Source: Metallica 2000 Mining Database.
Legend: O - Operational, X - Exploration, NA - Not available.

However, this is not the case in mining, where mine operators can alter the grade of the ore mined on a year-to-year basis, but their control is very limited over the entire life of the mine. This fact explains why Mikesell[10], in a simulation of a hypothetical copper project, put in its cash flow analysis declining ore grades from an initial 0.65 per cent Cu to 0.60 per cent in the third year of production, and eventually to 0.55 per cent in the fifth year, continuing at that rate until the 10th year (end of the cash flow period).

If we go through the environmental factors, there is a gloomy future for the copper industry in the North American horizons, compounded on the declining ore grades.

In a study promoted by the National Materials Advisory Board of the United States, and coordinated by the Committee on Competitiveness of the Minerals and Metals Industry[11], in 1990, they concluded that among other factors that have contributed to the decline of U.S. mineral industry two are: lower grade ores and excessive environmental regulations. The report says that these factors and fourteen more work to the disadvantage of the domestic minerals and metals industry relative to foreign producers and processors. Another study[12] states very bluntly:

"Because of its long and aggressive record of mining, the grades of orebodies being mined in the U.S. have steadily declined over the years, and currently are considerably lower than the grades of similar ores being mined in other countries. For example, compared to an average grade of about 0.6-0.8 per cent Cu in the North America porphyry copper deposits, newly developed porphyry copper deposits in Chile and Argentina often carry an average grade of more than 1.5 per cent Cu. Our price competitiveness is further hampered by the fact that the U.S. mines are getting deeper, adding to the cost of production.

The cost of meeting the vast array of environmental regulations has become a major obstacle to the growth of mineral industry in the U.S., especially during a period of weak metal prices. For example, the U.S. copper industry has been severely strained by the cost of meeting sulfur dioxide emission standards -some 695 MUSD between 1974 and 1987, and an estimated additional amount of 953.5 MUSD(1974 dollars) through 1987. In contrast, copper producers in most foreign countries do not have to incur such additional cost."

In Canada the situation is not different. Under pressure by a record of 3,000 abandoned mines, the Province of Ontario approved in 1989 Bill 71[13] (an Act to amend the Mining Act), where the great innovation was the "financial assurance", meaning that this disbursement will be part of a closure plan presented by mining companies, and shall be received by the provincial government in the form of cash, letter of credit, bond or another form of security. The closure plan and attached financial assurance must be accepted by the Director of Mine Rehabilitation. These new requirements imply a frozen up-front payment of several million dollars to be inserted in a project cash flow. Obviously, this changes completely the former concept of mining project feasibility. Other provinces in Canada adopted the same guidelines for protecting the environment, trying to hinder the recurrence of abandoned mines in their domains in the future.

One of the best examples is Windy Craggy copper project, in British Columbia. Its Mine Development Certificate (MDC) was issued only after review of environmental and socio-economic studies achieved by the applicant. The issue was further complicated by the involvement of the Canadian Federal Government and the comprehensive Federal environmental assessment. Incidentally, the Mining Association of British Columbia recorded more than 40 Federal statutes that could give rise to an environmental assessment. The uncertainty about the future of the project was growing and its cost was escalating. According to an observer, "the Windy Craggy debate had become more of a land-use issue than an environmental concern" [14].

Finally we will add some comments about the cost of labor. It is known that U.S. wages are higher than those of most copper producers. As observed by Misra[12], the hourly wages (including fringe benefits) for copper mine workers in the Philippines is less than 1 USD, in contrast with more than 8 USD for the basic hourly wage in the U.S. In addition, the American mines incur higher costs due to health and safety standards established by OSHA (Occupation Safety and Health Administration). OSHA's arsenic standard set in 1978 cost a copper producer almost 80 MUSD in capital costs at three of its smelters and more than 11 MUSD in added operating costs. As we know, similar safety standards do not exist in many foreign countries, or they are not enforced with the same severity.

Kaolin reserves

In the industrial minerals it is also possible to prove the physical deterioration of reserves along time, even though this record is more subtle than for metallic deposits. In some examples of the former class, there is no equivalent to ore grade, and this introduces more difficulties to evaluate the aging of reserves.

In exploration for kaolin deposits, the most important properties to be studied are here summarized[15]:

a. physical properties (brightness, particle size distribution, yield or grit content, abrasion, low shear viscosity, high shear viscosity, and other less important properties);

b. mineralogical properties (identification of kaolinite, halloysite, montmorillonite, etc.);

c. chemical properties: these refer to the chemical composition of major oxides like Al_2O_3 and SiO_2, and the impurities represented by minor oxides, like FeO, Fe_2O_3, TiO_2, MgO, CaO, Na_2O and K_2O;

d. other factors shown in the Introduction. Kaolin is today produced in about 70 different countries worldwide, for different uses in paper, rubber, paint, adhesives, ceramics, animal feeds, brick & tile, pharmaceuticals, glass, refractories, pesticides, printing inks, sealants and other industries. However, when we consider the distribution of high grade kaolin deposits in the world, that is, kaolin adequate for paper coating applications, the present knowledge shows only four countries: United Kingdom, the United States, Brazil and Australia. There were many unsuccessful exploration programmes achieved by the leading producers in France, Spain, Portugal, Guyana, Colombia, Mexico and other countries, while searching for high grade kaolin deposits.

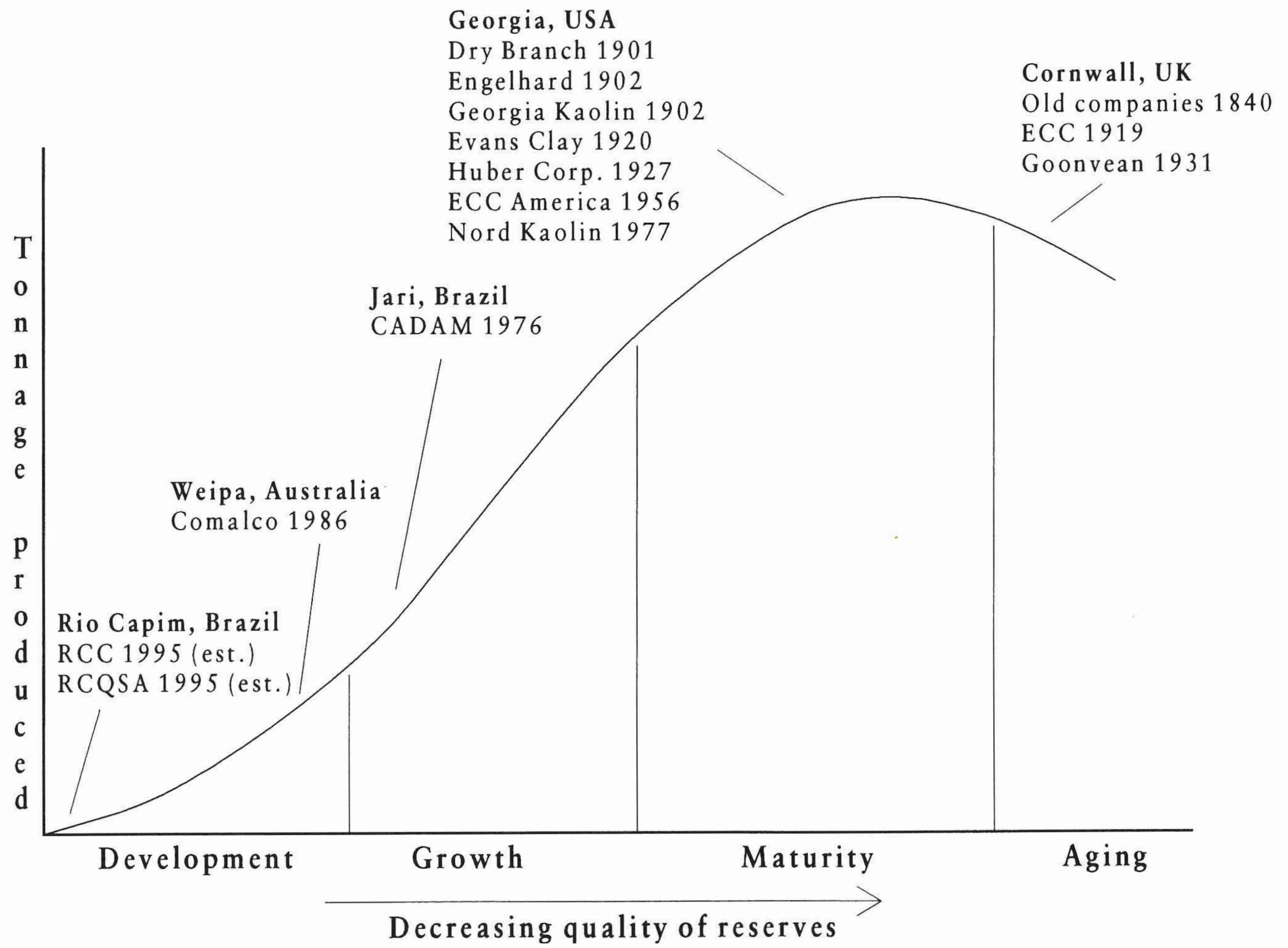
In 1992 Bristow[16] wrote an interesting paper about the future perspectives of kaolin production. Talking about reserves of high grade kaolin, his estimates are the following:

Remaining reserves (mt):
- Cornwall and Devon 75,
- Georgia and S. Carolina 210,
- Amazon region (Brazil) > 1 000,
- Queensland (Australia) 13.

When focusing on quality of reserves, he states although not convincingly: "Future growth in world kaolin consumption is likely to be largely met from those already established areas of production *whose deposits are of the requisite size and quality to meet future market requirements*" (italics ours). About the intention of newcomers (especially Brazil and Australia), he concludes that "there will be continuing difficulty in justifying major capital investment in greenfield kaolin plants in new areas, whose products are aimed at international markets."

We disagree completely on this assumption, as stressed in this paper, because that author simply ignores the reality of mining cycles.

Figure 2
Evolution of high grade kaolin districts and the mining cycle



Source: Adapted from Ward 1990.

Using the classification of reserves adopted in this paper, the situation is the following:

• *Virgin & young reserves*:
Brazil: Jari river (Amazon),
Capim river (Amazon),
Australia: Weipa (Queensland).

• *Mature reserves:*
United Kingdom: Cornwall and Devon,
United States: Georgia and South Carolina.

This classification is represented schematically in Figure 2, according to the evolution of kaolin districts (mining cycle) and their major producing companies in these four countries, including some companies that do not exist anymore.

Three kinds of evidence lead to the superiority of the Brazilian and Australian virgin reserves, when compared to those mature reserves found in the U.S. and U.K.:

a. The evolution of coating grades produced by English China Clays in the United Kingdom: Table 3 shows the evolution of those grades produced and sold by ECC in the international market since 1971. Beginning with a very comfortable situation in 1971, when it produced four coating grades (Supreme, Dinkie Special, Dinkie A, and SPS), ECC is now limited to SPS grade. This reduction, according to some British sources, was dictated by difficulties presented by poor quality reserves. Due to several factors, including the strategic planning options of ECC, the environmental constraints imposed by Cornwall local authorities, etc. it is doubtful whether ECC will continue to produce coating grade beyond the year 2000 in the United Kingdom. Of course, its operations in the US were strenghtened by the acquisition of Georgia Kaolin in 1991, after resolving legal problems raised by the U.S. Department of Justice (Antitrust Division);

b. Dosage of leaching chemicals used in kaolin processing: prime quality virgin reserves like those from Capim river in Brazil have natural high brightness and as a consequence less colored pigments; thus, less leaching chemicals are required in its processing. In pilot tests achieved with samples from Capim river deposits (Brazil), the dosage was only 2.5 to 5 kg of zinc dithionite (bleaching agent); in contrast, in Central Georgia reserves, the typical dosage used by producers was in the range of 3 to 4 kg per ton of clay. This difference is significant for two reasons:

• It implies a lower processing cost as the consumption of leaching chemicals is an important item in the cost structure of kaolin processing.

• A lower dosage means a lower cost in the treatment of effluents disposed by the processing plant every year;

c. Magnetic separation: in the mid-seventies Georgia kaolin producers, including all of the majors, started to commission the purchase of magnetic separators in large numbers, either to produce types with higher brightness, or to make use of reserves of crude with lower brightness requirements than the usual standard. In the middle of the 80s, 23 magnetic separators (84-inch high gradient canister-type) were operated by kaolin producers in the U.S., U.K., West Germany (in this case, filler production) and Australia[17]. In contrast with this technological upgrading, the Brazilian processing plant of CADAM started operations in 1976 to produce Amazon 88 without the use of any magnetic separator in its processing flowsheet. This product has been a success in European and Japanese markets since then. This situation persisted until 1993, when CADAM installed its first magnetic separator in its processing plant.

This superiority of virgin reserves is not explicitly recognized by some authors, which is quite a surprise for anybody dealing with the history of mining districts.

Virgin versus Mature Reserves

Globalization in the mining industry started much earlier than in manufacturing industry. The search for gold and silver during the sixteenth century and later in the Americas, promoted by European crowns, financiers and adventurers, is part of our history. At that time the virgin reserves were all at the surface, visible and accessible.

In more recent times, even in a country famous for its privileged endowment like the United States, growth in demand for minerals in the nineteenth century started to stimulate interest in global exploration[11]. One of the first targets was gold, considering that U.S. deposits could not fulfill the needs of the economies of the industrialized countries. Thus, U.S. and British corporations opened new gold mines in South Africa, Australia and Latin America. Somewhat later this was extended to base

Table 3

Coating grades produced by EEC in UK (last decades)

1971	1975	1993	2000
Supreme			
Dinkie special	Dinkie A	SPS	?
Dinkie A	SPS		
SPS			

Sources: Industrial minerals, several issues, and other sources. The authors did not obtain data about grades produced prior to 1971.

metals in Canada, Australia and Mexico. In the beginning of World War I, a number of large copper projects were already operating in Chile and central Africa and, at the same time, rich lead, zinc and silver ores were being exported from Peru. During World War II, the Brazilian government was persuaded to create a state company - CVRD - to meet the requirements of iron ore of both the U.S. and UK warfare industry, exposed to vulnerable supplies during the war.

In the 50s and 60s there was a halt in the growth of multinational corporations in the mining industry of developing countries due to the wave of nationalism that swept the world. Many copper, lead, zinc, nickel, tin, diamond mines were expropriated in Latin America and Africa by then. As a consequence, in that period virgin reserves in developing countries were underrated, obviously because of the political risk to start a project in a not reliable country. Nowadays the situation is the reverse, as most developing countries are eager to attract foreign capital to invest in new mining projects or to participate in privatization programmes.

In the preceding pages we emphasized the striking differences in quality between virgin and mature reserves. It would be false and misleading to state that the competitive advantage of virgin reserves located preferably in developing countries would be unsurmountable by some industrialized countries operating their own mines. All of us know that these producers compensated for declining grades through economies of scale and technological advancements in the last decades. However, as we stressed before, the business climate for the mining industry in North America is nowadays full of disincentives, mainly caused by a severe environmental legislation and by a competition with more technology-intensive sectors regarding potential investors. In addition, there are authors who remarked that "even if market prices do rise, decreasing ore grades will tend to put a squeeze on profits."[9] These facts put together, as remarked by Gooding[18], are leading a host of transnational corporations to think that they are better off exploring and buying assets outside the industrialized countries.

References

1 Whitney, J.D. *The metallic wealth of the United States compared with that of other countries,* Philadelphia 1854.

2 Jankovic, S. *Wirtschaftsgeologie der Erze*, Wien 1967.

3 Wagenhals, G. *The World Copper Market*, Berlin 1984.

4 Page, W. Some non-fuel mineral resources. In: Freeman, C. & Jahoda, M. (eds.) *World Futures: the great debate,* Oxford 1978, p.169-206.

5 Metallsgesellschaft AG *Metallstatistik 1980-1990*, 78th. ed. Frankfurt 1991.

6 Whitney, J.W. The physical characteristics of the copper industry, in Mikesell, R.F. (ed.) *The World Copper Industry*, Baltimore 1979, p.45-59.

7 *Metallica 2000 Mining Database.* Mining Journal Ltd. & Montagu Mining Finance - version 1.3, London, 1992. Update Apr.1994.

8 Hodgson, C.J. Introduction to giant ore deposits, in *Proceedings of the Giant Ore Deposits Workshop*, 11-13 May 1992, Kingston, Ontario, Queen's University, 1992, p. 1-12.

9 Pye, C.H. *Profitability in the Canadian Mineral Industry*, CRS, 1981, p. 178.

10 Mikesell, R.F. *The World Copper Industry*, Baltimore, Johns Hopkins, 1979, p. 393.

11 National Research Council (U.S.), Committee on Competitiveness of the U.S. Minerals and Metals Industry. *Competitiveness of the U.S. Minerals and Metals Industry.* Washington, 1990, p. 140.

12 Misra, K.C. *Mineral and energy resources.* Univ. of Tennessee, Dept. of Geological Sciences, Studies in Geology 14, 1986.

13 Bill 71 - An Act to amend the Mining Act - Legislative Assembly of Ontario - Dec. 6th., 1989, p. 61.

14 The Economist Canadian Mining: right holes, wrong provinces, *The Economist*, 327(7817):78-9, June 26th., 1993.

15 Murray, H.H. *World kaolins - diverse quality needs permit different resource types*, 8th Industrial Minerals International Congress, Boston, 1988, p. 127-131.

16 Bristow, C.M. *Development of kaolin production and future perspectives*, Camborne School of Mines, Cornwall, p. 19, 1992.

17 Clark, G. Industrial mineral processing: 4-magnetic separation, *Industrial Minerals*, n.212, May 1985, p. 21-33

18 Gooding, K. Introduction. *Financial Times Mining International Year Book 1994*, London 1993.

19 Ward, M.H. Strategic planning, in Kennedy, B.A. (ed.) *Surface Mining*, 2nd. ed, Littleton, p. 1026-37, 1990. ■