J Kallioinen, P Pennanen

NEW TRENDS IN PHOSPHATE BENEFICIATION

ABSTRACT

During the last decade Outokumpu Oy has actively developed technology for phosphate ore beneficiation in Finland and abroad. The work has focused both on the development of equipment for treating phosphate ores and on the entire process of concentrating sedimentary deposits. The object has been to develop the most economic method of concentrating ores that are in either a carbonate or silicate matrix.

The development work has resulted in the successful application of large volume flotation machine technology. A new area of application is the use of coarse flotation technology (SKIM-AIR coarse flotation machine) to improve the recovery of apatite by the elimination of overgrinding.

A new on-stream analyzer has been developed that allows BPL concentrations to be measured on-line in several process streams. By integrating the analyzer with a control system, significant improvements can be achieved when controlling a flotation process. This technology has been successfully employed at several flotation plants.

The use of the flotation method in the beneficiation of sedimentary phosphate ores has been developed in cooperation with international reagent manufacturers. The work has produced a method that can be applied to the treatment of difficult ores. The conventional washing method has been improved so as to minimize energy and water consumption and the level of maintenance. A further result is the new compact layout solution. The combination of the washing method and flotation is an attractive alternative for producing high-quality concentrate, even from low-grade sedimentary phosphate ores.

1. OUTOKUMPU OK-FLOTATION TECHNOLOGY

1.1 OK-38 FLotation Machine

The use of large volume OK machines in phosphate beneficiation began in 1979 when the first OK-38 flotation cells, with a unit size of 38 m^3, were installed in an apatite flotation plant (Figure 3). A new and essential feature in this installation was the use of the big OK-38 cells also as cleaners. The advantages achieved were a simple layout and a minimal need of spare parts. So far the largest installation of OK-38 flotation machines is at the ANOF-3 concentrator in the Kola Peninsula with 144 cells totalling 5472 m^3 of cell volume.

1.2 OK-50 Flotation Machine

Development work on large volume flotation machines continues and the latest product is the OK-50 flotation machine with a cell volume of 50 m^3 (Figure 4). The target of the design was to develop a flotation machine which, despite its great volume, can replace a number of small machines even in a place where the installation height is limited. Much attention was paid to the transportability of the large unit as well. Special features of the OK-50 flotation machine are shown in figure 5.

1.3 General characteristics

The modular OK-flotation machine is constructed of a few rather small modules which are connected by bolted joints. Flotation banks are assembled by connecting together the required number of modules (feed box, tanks, intermediate and/or discharge boxes etc.)

Launders are located cross-cell at the top of the intermediate walls and they discharge to the same side of the bank of flotation machines. Elevated launder outlets open new possibilities for flotation plant design. For instance froth can be led to the cleaners by gravity. Pumping and piping is minimized and installation of froth pipes under cells is eliminated.

The advantages of OK-flotation machines are savings in the design and construction of the flotation plant, and savings in the investment and operating costs.

The advantages are fully utilized when the OK-50 cells are used. The OK-50 flotation machine is the solution for difficult renovation purposes. It provides considerable savings in the construction of new plants as well.

1.4 Outokumpu SKIM-AIR

SKIM-AIR coarse flotation machines are successfully operated in the beneficiation of sulphide ores (Figure 6). The machine is installed in the grinding circuit to float the cyclone sands (Figure 7). Valuable minerals tend to concentrate in the cyclone sand and, due to lack of slimes, they can be rapidly floated as coarse particles.

The basis of the coarse flotation method can be illustrated by an example. The tailings of an apatite flotation plant and the recovery of apatite in various size fractions are presented in figure 8. In this case the best recovery is between 30-100 microns, which is the optimum range of flotation with regard to grain size. In finer fractions the recovery drops rapidly. In the coarse fractions apatite particles up to about 200 micron can be floated with moderate recovery. This grain size can be regarded as a reasonable flotation limit in this case. The distribution of apatite in flotation tailings shows that the -30 and the +100-200 micron size fractions represent about 60% of the total losses of apatite.

To improve the results one should:

* reduce overgrinding of apatite in order to decrease losses into slimes

* improve the recovery of coarse apatite.

It can be seen from figure 9, that apatite has concentrated heavily into flotable grain sizes in the cyclone sands which are normally returned to the grinding. In the optimum range the P_2O_5 content is about twice the value of the ore. About 50% of the apatite of the cyclone sands reports in grain sizes under 200 microns, which are flotable.

The coarse flotation method:

*reduces overgrinding of apatite and slime losses arising thereby

*floats coarser apatite grains directly into a final concentrate in higher pulp density. Losses of coarse grains in the cleaner stage are thereby eliminated.

The use of coarse flotation machines in the grinding circuits is an existing and field-proven technology in the concentration of sulphide ores. Its full scale application in the beneficiation of phosphates has already started.

2. ANALYZING PHOSPATE STREAMS IN CONCENTRATION PROCESSES

Outokumpu has been developing and constructing for more than two decades on-line analyzers for the measurement of element concentrations in slurries. This type of instrument has become a standard in modern base metals concentration. Due to its active prdouct development and extensive field experience the company is nowdays the recognized market leader in this field.

Having established a solid reputation in on-line slurry analysis, Outokumpu started in the early 1980's to develop an analyzer for the continuous determination of mineral concentrations in process slurries. This project was started because it could be seen that the traditional on-line element analysis using X-rays has serious limitations, which makes it impossible to be utilized in many beneficiation processes outside the base metals area. If minerals could be measured directly, this would open new possibilities to improve process performance in many industrial minerals applications.

As a result of this project the first commercially available on-line X-ray diffraction analyzer, the COURIER 40 (Fig. 10), was developed. Much of Outokumpu's long experience in on-line slurry measurement could be utilized in the new analyzer - the field proven sampling system, the splash-proof housing of the instrument, as well as the electronics and data handling. The new part of the analyzer is the arrangement of the measuring geometry, with the X-ray tube and detectors mounted at a fixed angle in relation to the sample. This angle is set individually for each application to correspond with the X-ray diffraction angle(s) of the mineral(s) to be measured.

Like the on-line element analyzer, the mineral analyzer is able to monitor up to five different points in the benefication process sequentially. To meet practical demands in process control, the new instrument is additionally equipped to measure element concentrations in the sample. The sum of the different element and mineral analyses from a sample is limited to six. In phosphate applications the measured minerals vary according to the deposit, but typically francolite or apatite and quarzite (for insoluble determination) are measured with the diffraction channels. Additionally, for example, calcium and iron concentrations can be determined with the element channels.

Thus the analyzer system can give on-line information on the following process variables:

* BPL concentration in the streams
* CaO to BPL ratio
* AIR (Acid Insoluble Residue) content

Future analyzers can be equipped with a particle size measurement channel, which might throw further light on the effect of particle size on flotation recoveries.

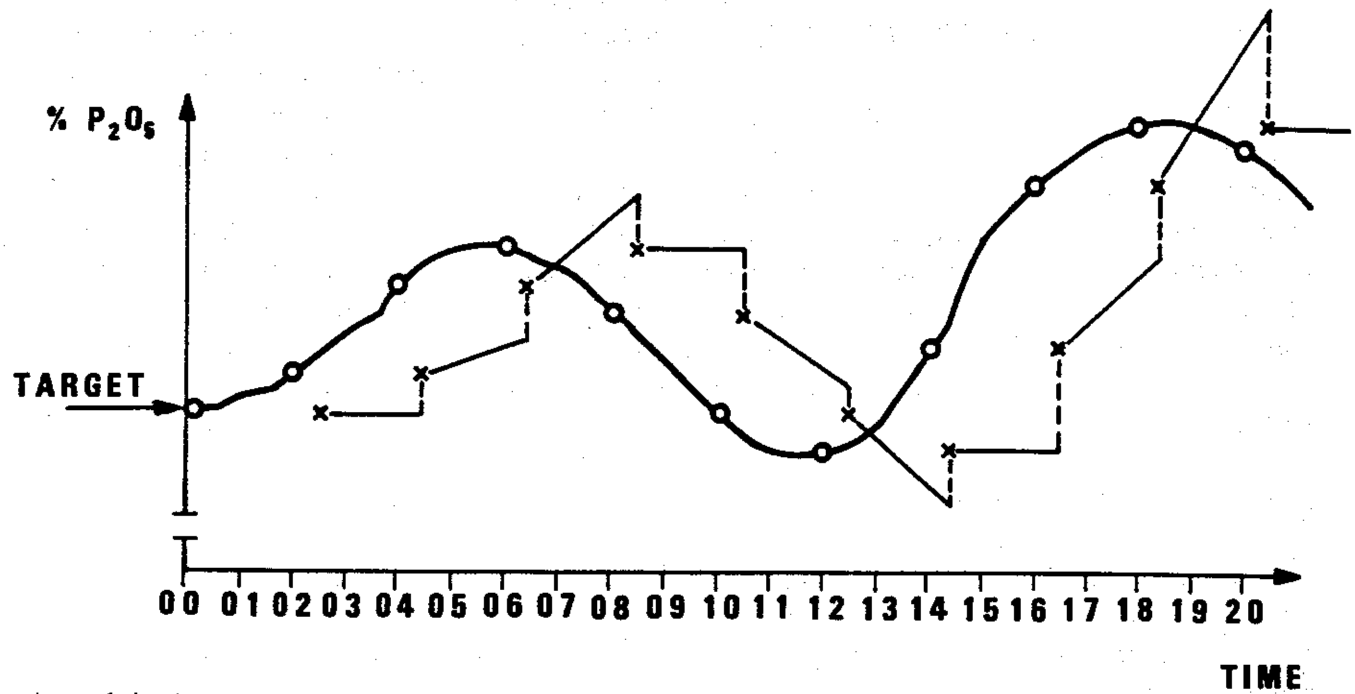
2.1 Experiences of the COURIER 40 Analyzer in Phosphate Flotation

Two COURIER 40 units were installed in concentrator plants early in1985 to test the reliability of the instrument in real field applications. One of the plants was a talc concentrator and the other was a phosphate concentrator. Both plants have recently decided to purchase the system.

Recently additional units were installed in Finland and in the ANOF phosphate concentrator in the USSR.

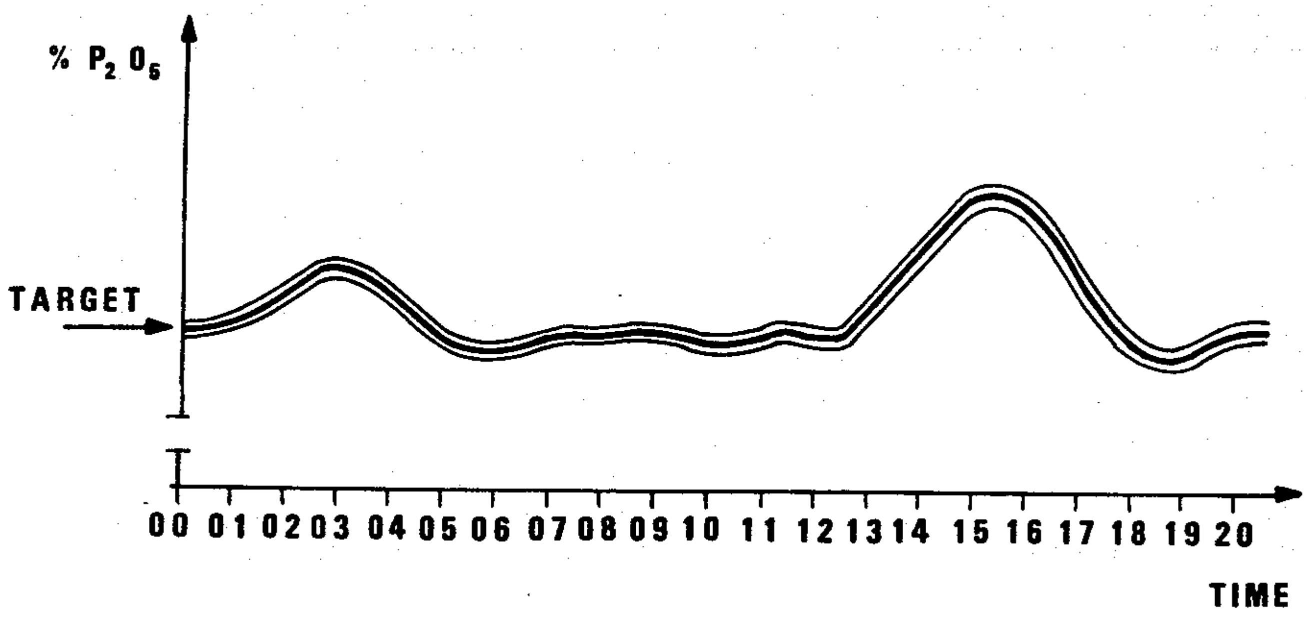
The experience gained at these installations has been positive. The potential for great improements in flotation efficiency has been proved.

The following pictures compare the traditional control of the phosphate flotation by laboratory analyses with control based on on-line assays. In this example two process dis-



A sample is taken to the laboratory every 2 hours and the result is presented to the operator 2.5 hours later. The analysis is free of error. The current process trend is determined by the process operator on the basis of the two previous analysis results.

FIG. 1. PROCESS CONTROL WITH LABORATORY ASSAYS



Analysis is made on-line and the result is available to the operator immediately. The analysis has a relative error of 1 to 10 %.

FIG. 2. PROCESS CONTROL WITH ON-LINE X-RAY ASSAYS

turbances, one at 00:00 hours and one at 12:00 hours cause the analysis to rise. With laboratory analyses taken at 2 hour intervals and results handed to operators 2.5 hours after sampling, the disturbance may be detected only 4.5 hours later. If we assume that the trend can be reversed after 1.5 hours due to process dynamics, the disturbance will start to correct after 6 hours.

With on-line X-ray analysis the individual measurement takes a maximum of 5 minutes and the result is available for the operator immediately. Thus the disturbance is detected immediately and the trend will be reversed after 1.5 hours.

As for example, a disturbance upwards in concentrate grade usually results in loss of recovery, it is easy to see the potential for significant economical savings with assay based control.

An additional benefit derived from on-line assaying includes reagent savings. When dosage of reagents is based on continuous feed grade analysis, only the correct amount and mixture of chemicals is fed into the process and no overdosing will occur. Usually this produces better flotation results.

Due to the faster availability of analytical information, additional benefits will arise through the increased process knowledge of the operators. It has been observed, that operators start to test their process when they get the new tool into the plant. As the process's response to the various control outputs can be seen immediately, the understanding of process behaviour will increase.

As the operating costs of an on-line X-ray analyzer are practically negligible, significant savings in analysis costs can be achieved.

2.2 Analytical Accuracy of the COURIER 40

As can be seen from figure 2, the required accuacy of an on-line analyzer used for process control should always be determined in relation to the size of the actual process variations. If variations in the process are great, even a less accurate but fast analysis with high frequency will improve process control. On the other hand, if process variations are usually very small, a greater accuracy will be required to show the changes in the process.

In the measurement of apatite concentrations in slurries the accuracies have been very satisfactory. The following table gives a summary of the accuracies achieved at a plant in Finland:

PROCESS FLOW	ANALYSIS RANGE %	ABSOLUTE ACCURACY%
Rougher concentrate	16-25	0.79
Final concentrate	33-40	0.68
Tailings	0.7 - 1.6	0.11

Table 1. Courier 40 accuracies in apatite measurement

3. CONCENTRATION OF SEDIMENTARY PHOSPHATES

Sedimentary phosphate ores are conventionally treated by washing and screening processes. At Outokumpu, the concentration of several sedimentary phosphate ores has been studied with the aim of finding more selective and economic process alternatives.

The development work has comprised mineralogical research as well as flotation and classification tests in laboratory and pilot scale in Finland and abroad.

3.1 Mineralogy

The minerals in sedimentary phosphate ores are very poorly crystallized compared to magmatic ores. Thus the production of good quality apatite concentrates is clearly more difficult from sedimentary ores than from magmatic phosphate ores.

Apatite occurs as francolite in which PO_4 is partially replaced by CO_3 in the sedimentary ores described in the following. In addition, the apatite has a comparatively high fluoride content but a low content of chlorine.

Examples of the varying occurrence of phosphate are shown in microphotographs 11, 12 and 13. Three grain types containing phosphate can be seen:

1. Pellets, which are round or elliptic, and have typically a relatively clear boundary surface, are usually of pure apatite. The size of pellets ranges between 50-600 microns and the content approx. 35-39% P_2O_5.

2. Fossil fragments, which are often pieces of bone, with varying size and shape, consist of either francolite or a mixture of francolite and silicate as microcrystalline quartz.

3. Aggregates, which are fairly large (maximum size less than 5 mm), roundish or irregular usually consist of a mixture of francolite and silicate in variable proportions.

The space between these granules is filled by a matrix which consists of either carbonate (mainly calcite), silicate (microcrystalline quartz) or a mixture of the two.

Pellets have the highest phosphate content of the different grain types. It would be ideal to recover into the concentrate only pellets and the fossil fragments that are rich in phosphate.

Figures 11, 12 and 13 also show the amounts of the main minerals in different grain sizes in crushed ore samples. The ore samples shown in figures 11 and 13 have a carbonate matrix. The main problem in the concentration is to separate carbonate and phosphate from each other. Although the amount of silicate is relatively low, it must be reduced to produce high-grade phosphate concentrate.

Figures 11 and 13 also show that the phosphate content is highest in the middle size fractions of 74-420 microns. Some upgrading of phosphate can be achieved by separating the coarse fraction and the fines by screening and washing. The method is commonly used for these ores. In most cases the production of high quality concentrate requires, however, the separation of carbonate from francolite by means of flotation.

The ore sample in figure 12 has a silicate matrix with a high silicate content in all size fractions. The problem is the liberation of phosphate from the matrix by selective grinding after which the silicates and carbonates must be separated from the francolite. This type of ore requires a finer grind than an ore with carbonate matrix.

3.2 Development of Beneficiation Methods

The purpose of the laboratory tests was to find a method for selective separation of both carbonates and silicates from phosphate in order to produce high-grade concentrate. Because the properties of the minerals are very much alike the separation is difficult and sensitive.

The most essential part of the concentration method used is the silicate-carbonate flotation in which apatite concentrate is recovered as flotation tailings.

The method includes, for certain ore types, separate handling of the fine and coarse fractions.

With the cooperation of international reagent producers suitable reagents for the flotation method were developed.

3.3 Development of Washing Technology for Sedimentary Phosphates

The conventional washing method used in the beneficiation of sedimentary phosphate ores has been further developed in order to improve the quality of the product and to minimize the energy and water consumption and maintenance costs of the plants. The basis for the development work has been the earlier mentioned comprehensive research work on the mineralogy, structure, chemical composition and grindability of sedimentary phosphates.

Figure 14 shows the P_2O_5 content of a sedimentary phosphate ore by size fractions and the minimum grade of the concentrate required. When the conventional washing method is used the fine-grained, low-content material is separated as tailings usually with hydrocyclones and the low-grade coarse material by screening.

Figure 15 shows correspondingly the contents of the most important impurities (MgO, Fe and Al_2O_3) of the same ore by size fractions.

According to the figures the coarse, +1 mm, material should be screened to tailings and the fraction of less than approx. 100 microns should also be classified as tailings in order to achieve the required P_2O_5 content. If the impurity contents are to be minimized, the separation limit of the fine-grained tailings should be raised even higher, up to 150-200 microns. In this case the recovery would decrease and further improvement of the concentrate quality would be impossible.

These disadvantages and limitation can be eliminated by the use of the Outokumpu phosphate process.

3.4 Outokumpu Phosphate Process

The stages of the Outokumpu phosphate process for sedimentary phosphates (figure 16):

1. Screening:
Separation of low-grade, coarse material directly to tailings, separation limit 2-5 mm

2. Desliming:
Separation of very low-grade and fine slimes directly to tailings

3. Coarse flotation:
Separation of coarse grain gangue

4. Classification followed by washing and flotation:
Fine material for flotation is separated from the main stream of coarse material passing directly through the washing process. Separation limit can be e.g. 150-300 microns.

To minimize the operation costs of the plant a "tower type" structure is introduced. The classification is done by cone classifiers. Figure 17 shows a simplified process flowsheet for the plant. The feed material and the water are fed to the mixing tank high up in the "tower". The main flow, which contains coarse material continues from one process stage to another by gravity all the way to filtered concentrate. Only the process waters and fine-grained pulp flows, containing small amounts of fine solids are pumped. Thus the pumping of the main flow, corresponding energy cost and maintenance of large pumps are completely eliminated. The part of the concentrate which has been produced by flotation is of high grade, 34-36 % P_2O_5, so it actually improves the quality of a combined final concentrate. The costs of concentration reagents are reasonable as only part of the feed flow is flotated conventionally.

The combination of the flotation method with a conventional washing process offers a very attractive alternative for the production of a salable, high-grade concentrate with low production costs and a high recovery.

CONCLUSION

Recently many phosphate ores have proved difficult to exploit utilizing solely conventional screening and washing methods. Only the use of advanced technology, i.e. flotation and process automation have made the projects feasible or have increased profitability.

BIOGRAPHIES OF AUTHORS

Jouko Kallioinen

Jouko O. Kallioinen received his Master of Science Degree in Mining and Ore Dressing at Helsinki Technical University in 1971. He joined Outokumpu Oy in 1973 and since 1987 he has been working as the manager of the ANOF-3 apatite flotation project of Outokumpu Engineering in the USSR. Between 1978-1981 he served as Mill Superintendent at Siilinjärvi Apatite Mine owned by Kemira Oy.

Petri Pennanen

Petri Pennanen graduated with an M.Sc. from the University of Technology in Helsinki where he specialized in control and automation technology and international economics. He joined Outokumpu Oy Electronics Division in 1986 and is currently responsible for analyzer applications in the area of industrial minerals production.

FIG 3.

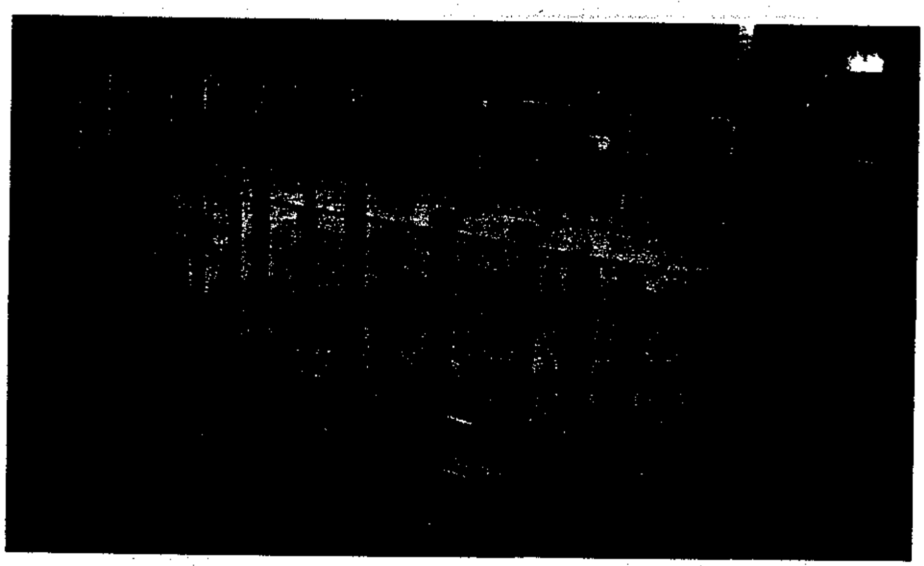


FIG. 4

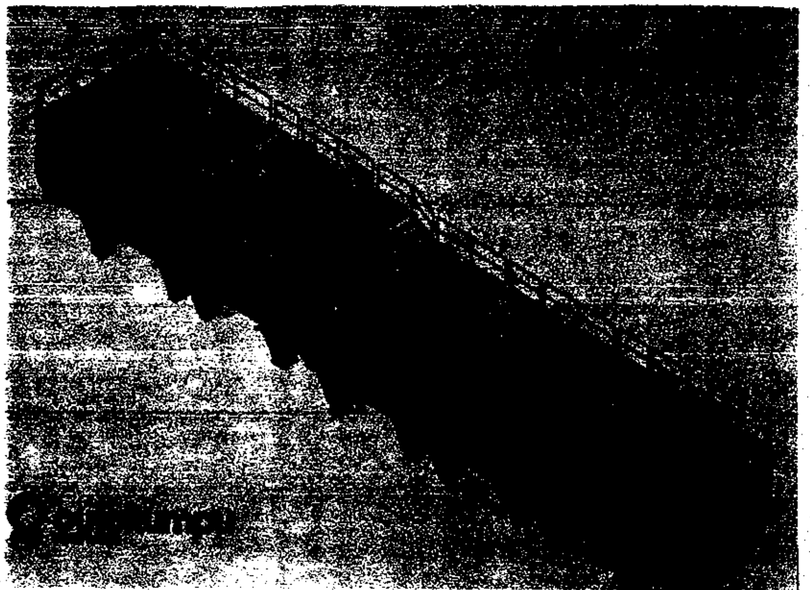


FIG. 5

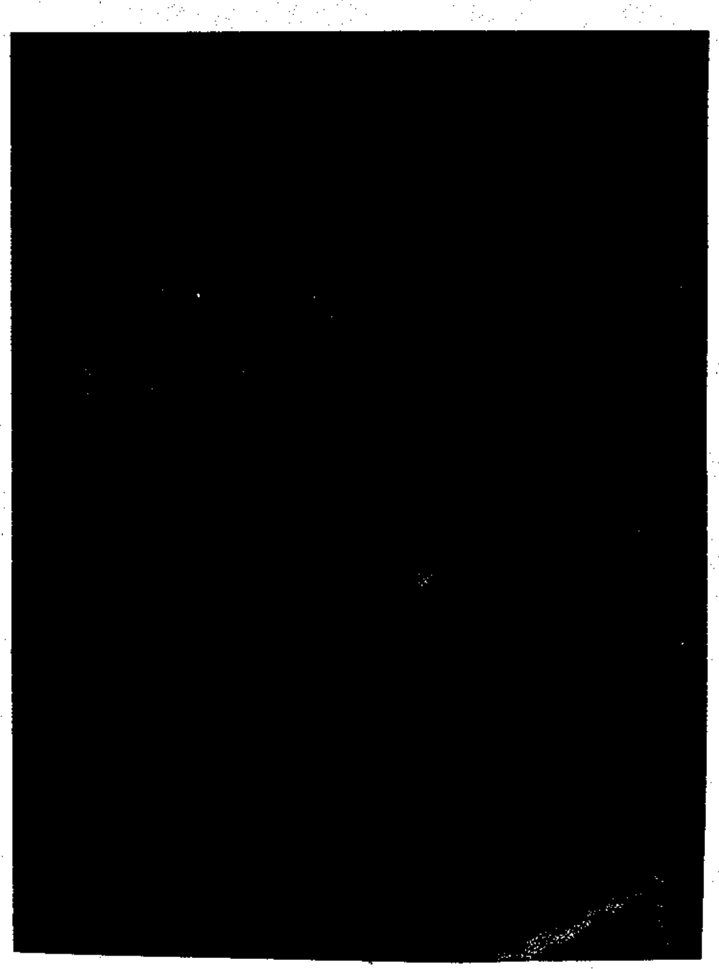


FIG. 6

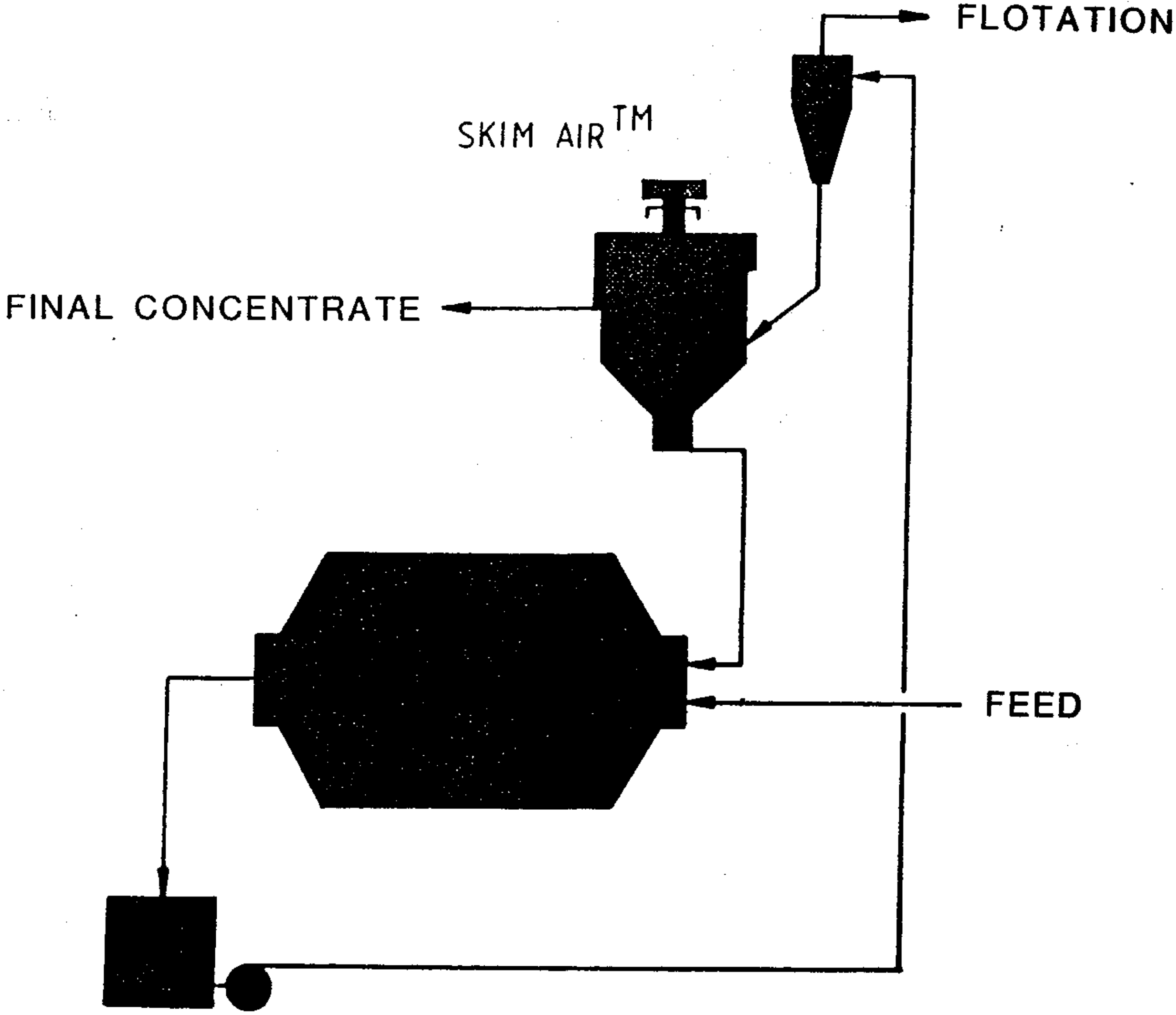


FIG. 7. COARSE FLOTATION MACHINE IN THE GRINDING CIRCUIT

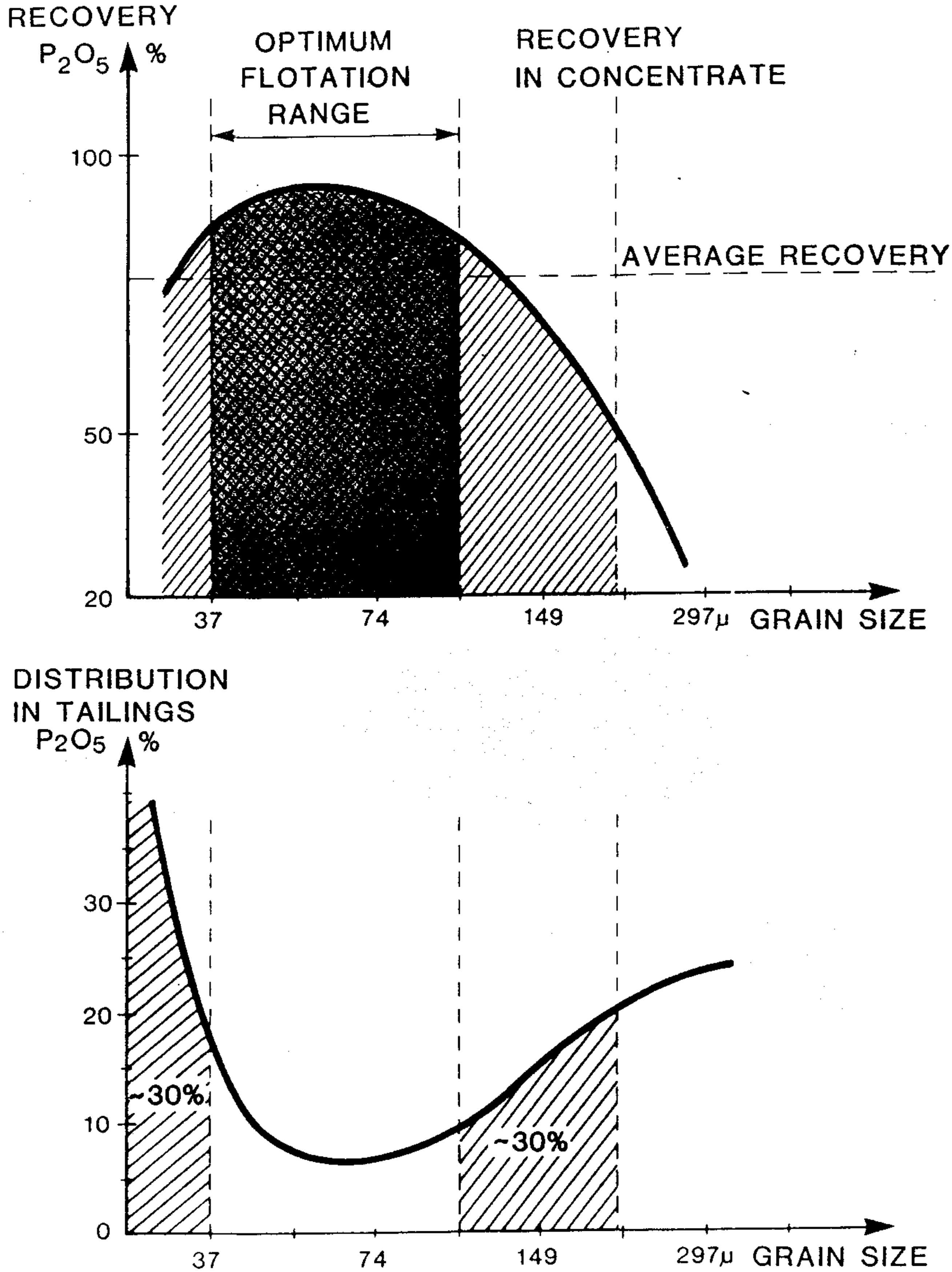


FIG. 8. APATITE FLOATABILITY (ABOVE) AND DISTRIBUTION IN TAILINGS (BELOW) DEPENDING ON GRAIN SIZE

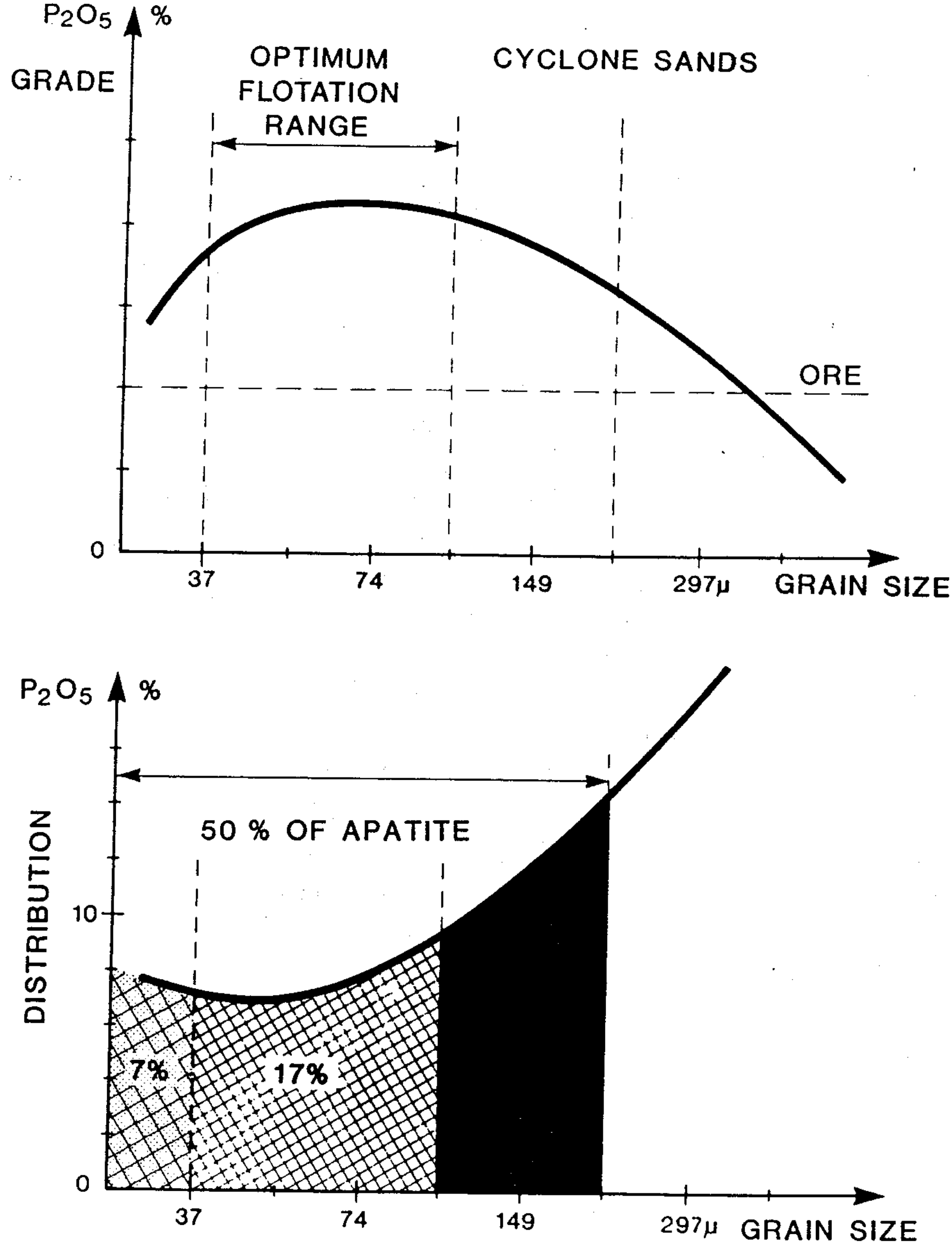


FIG. 9. CONCENTRATION AND DISTRIBUTION OF APATITE IN CYCLONE SANDS DEPENDING ON GRAIN SIZE

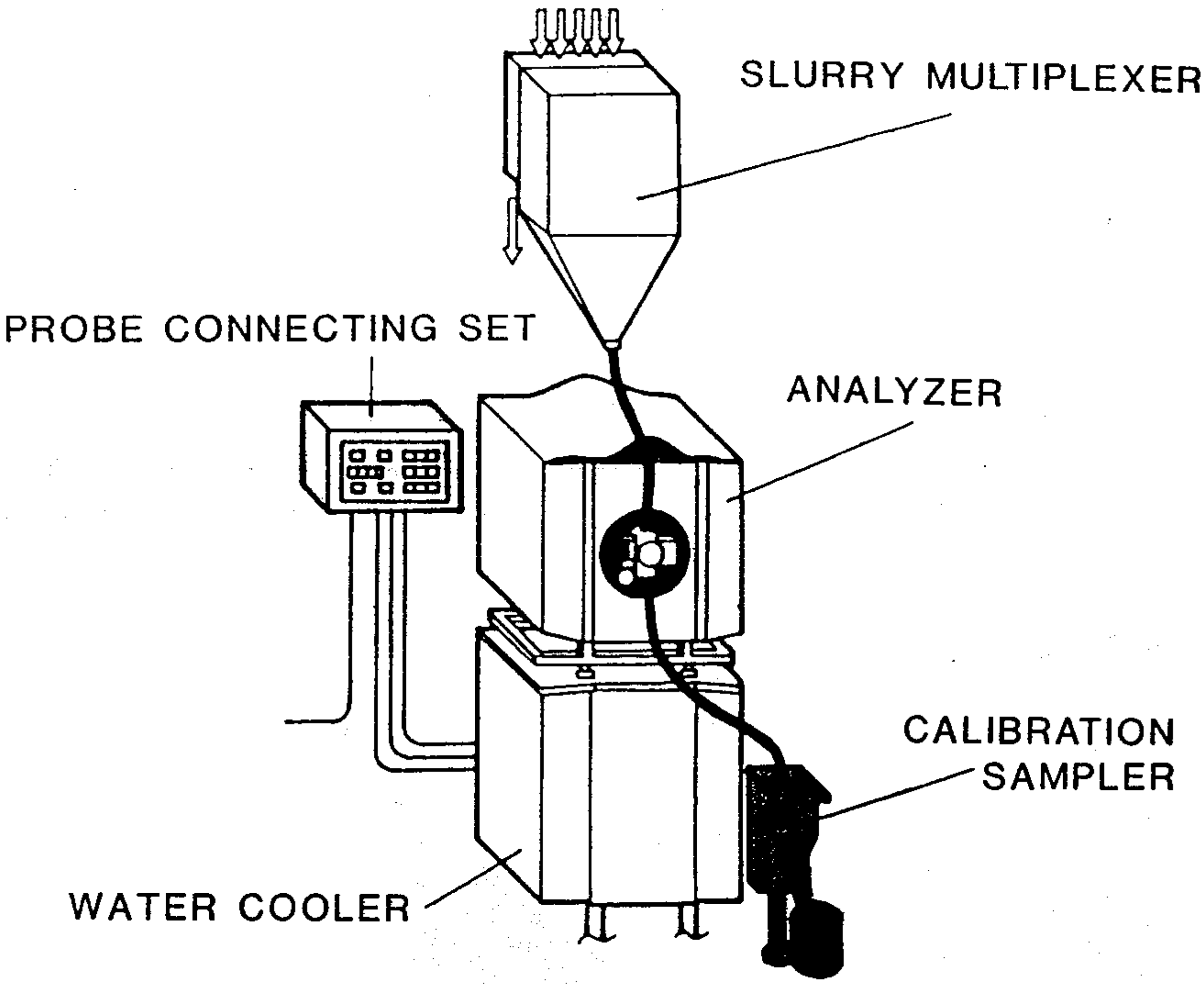


FIG. 10. COURIER 40 ANALYZER

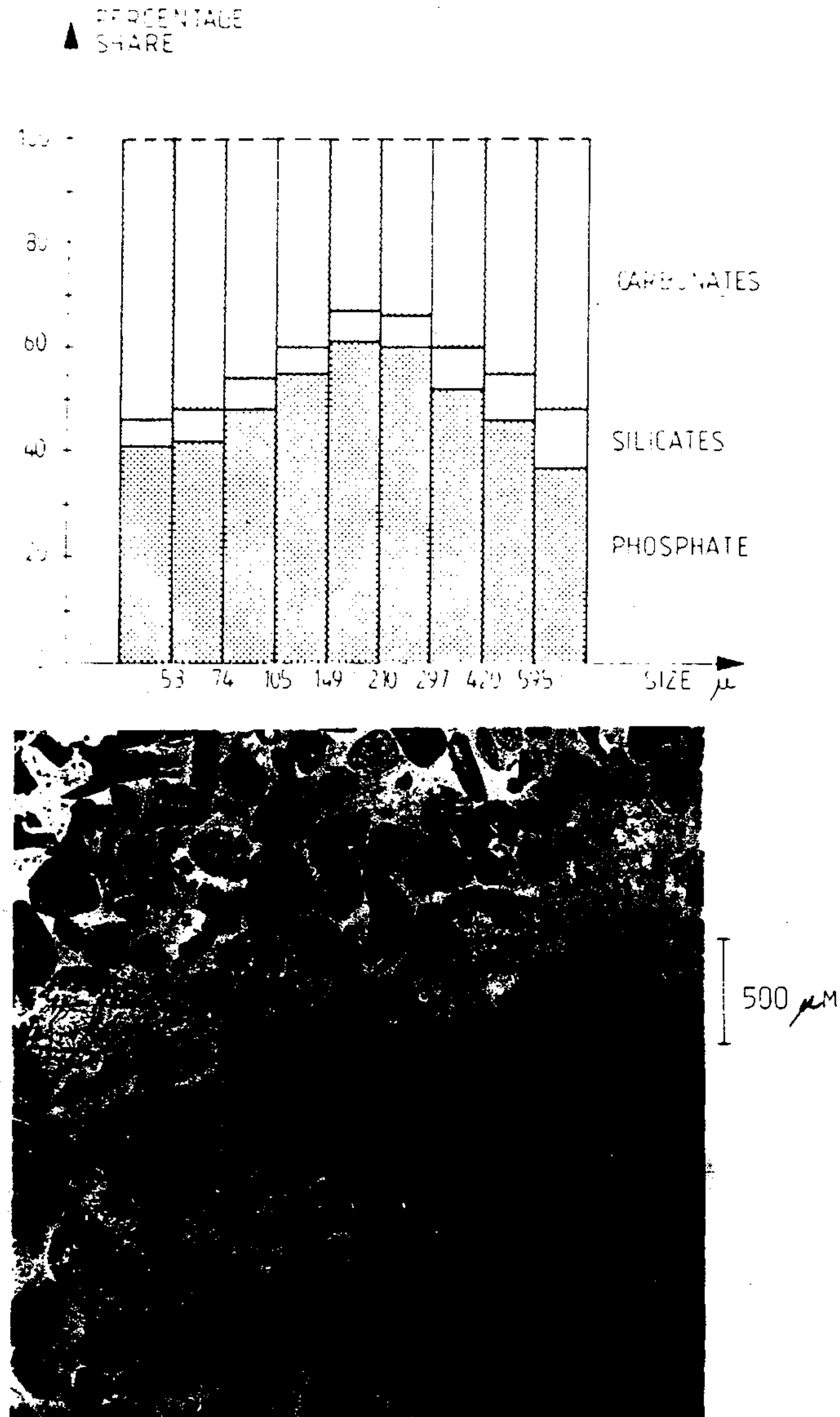


FIG. 11. PHOSPHATE IN CARBONATE

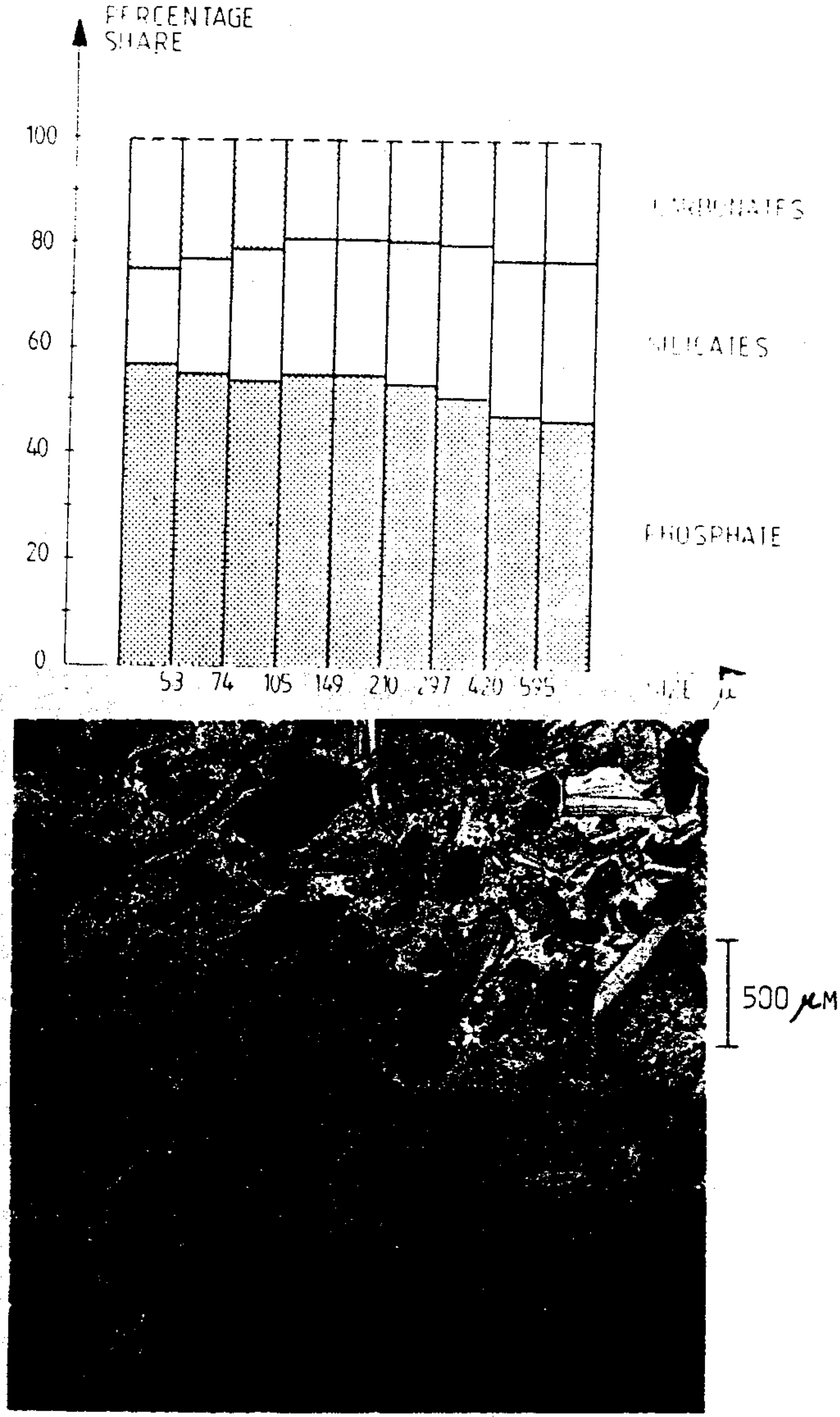


FIG. 12. PHOSPHATE IN SILICATE MATRIX

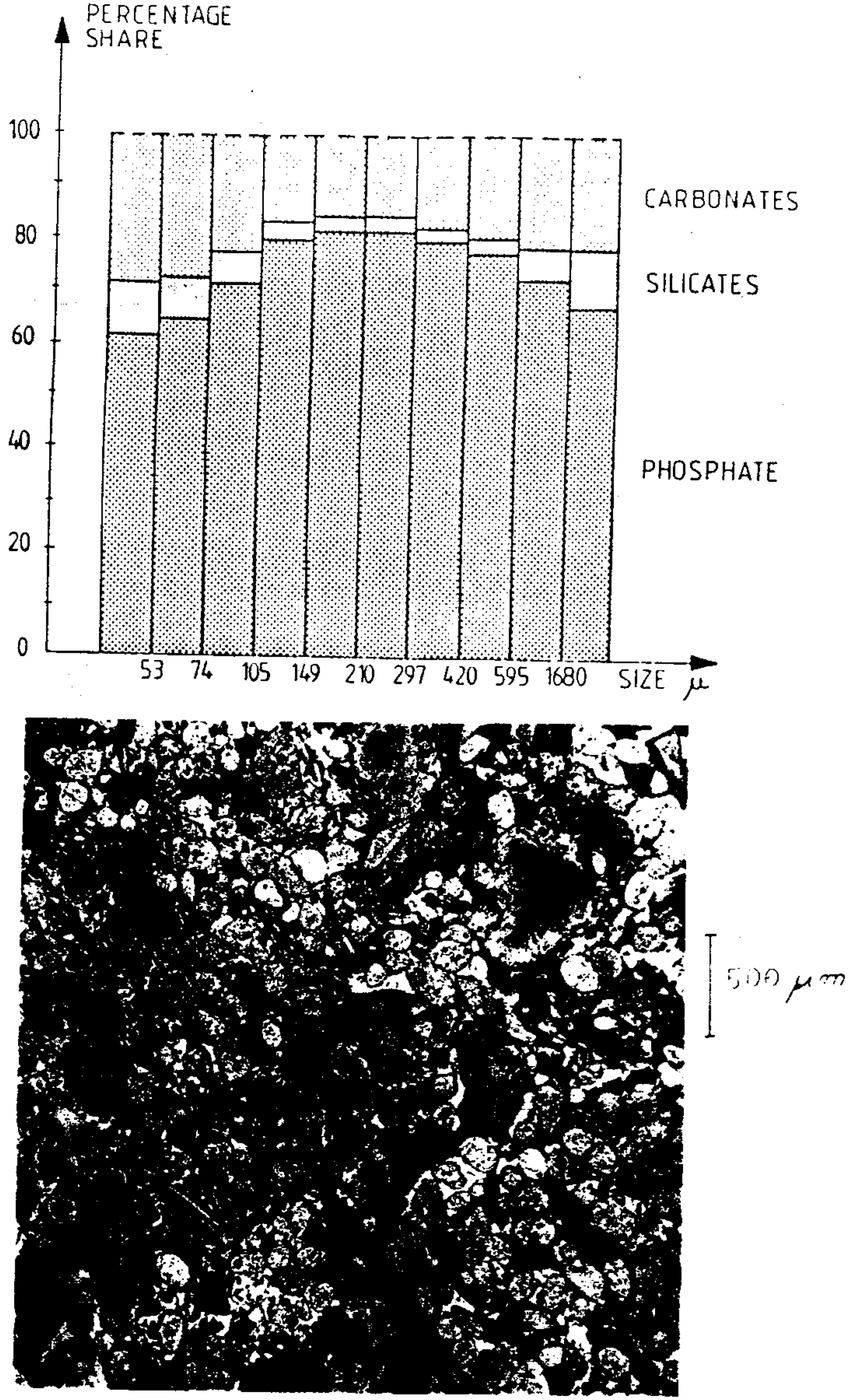


FIG. 13. PHOSPHATE IN CARBONATE MATRIX

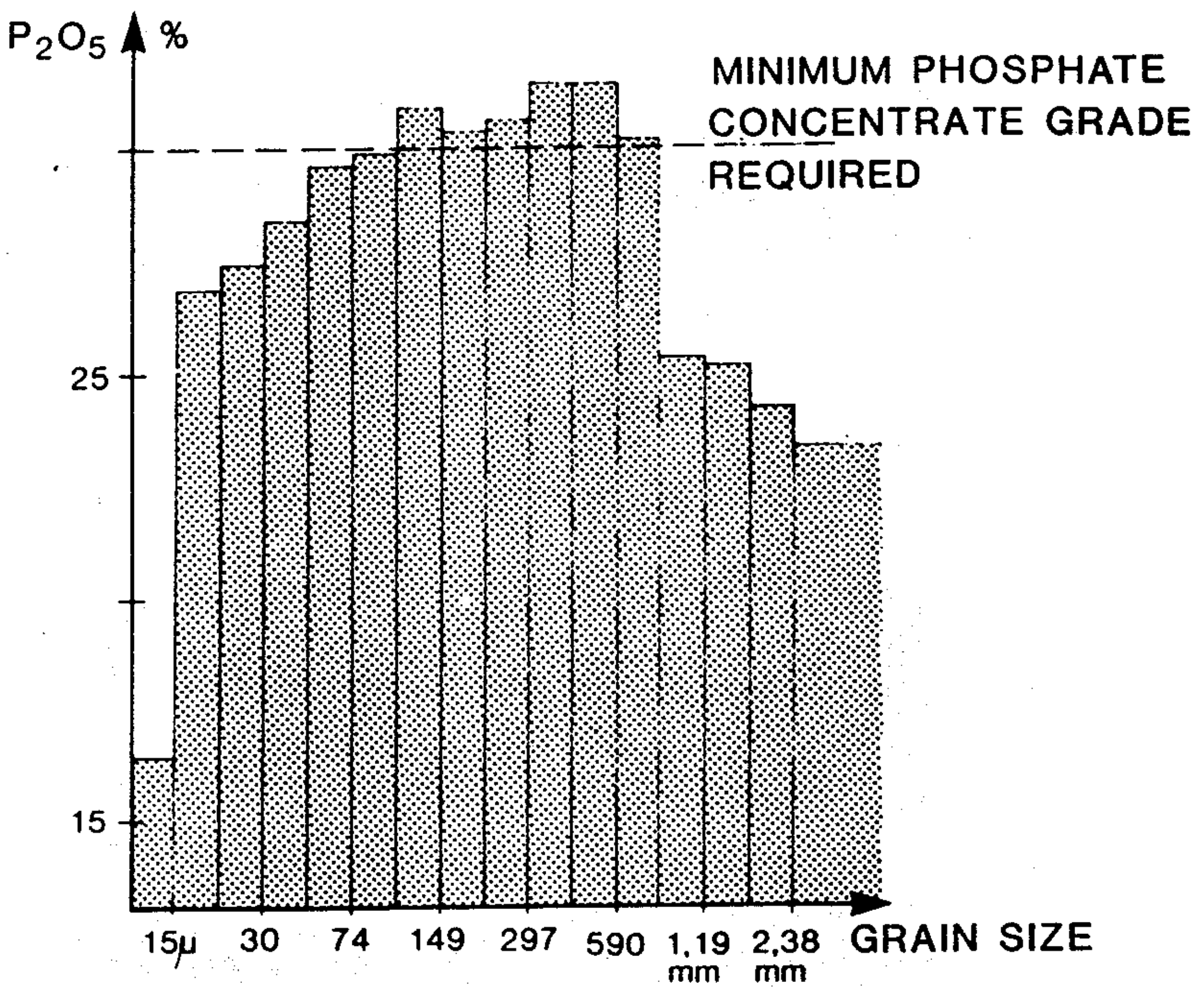


FIG. 14. P_2O_5 -GRADE IN SEDIMENTARY PHOSPHATE ORES

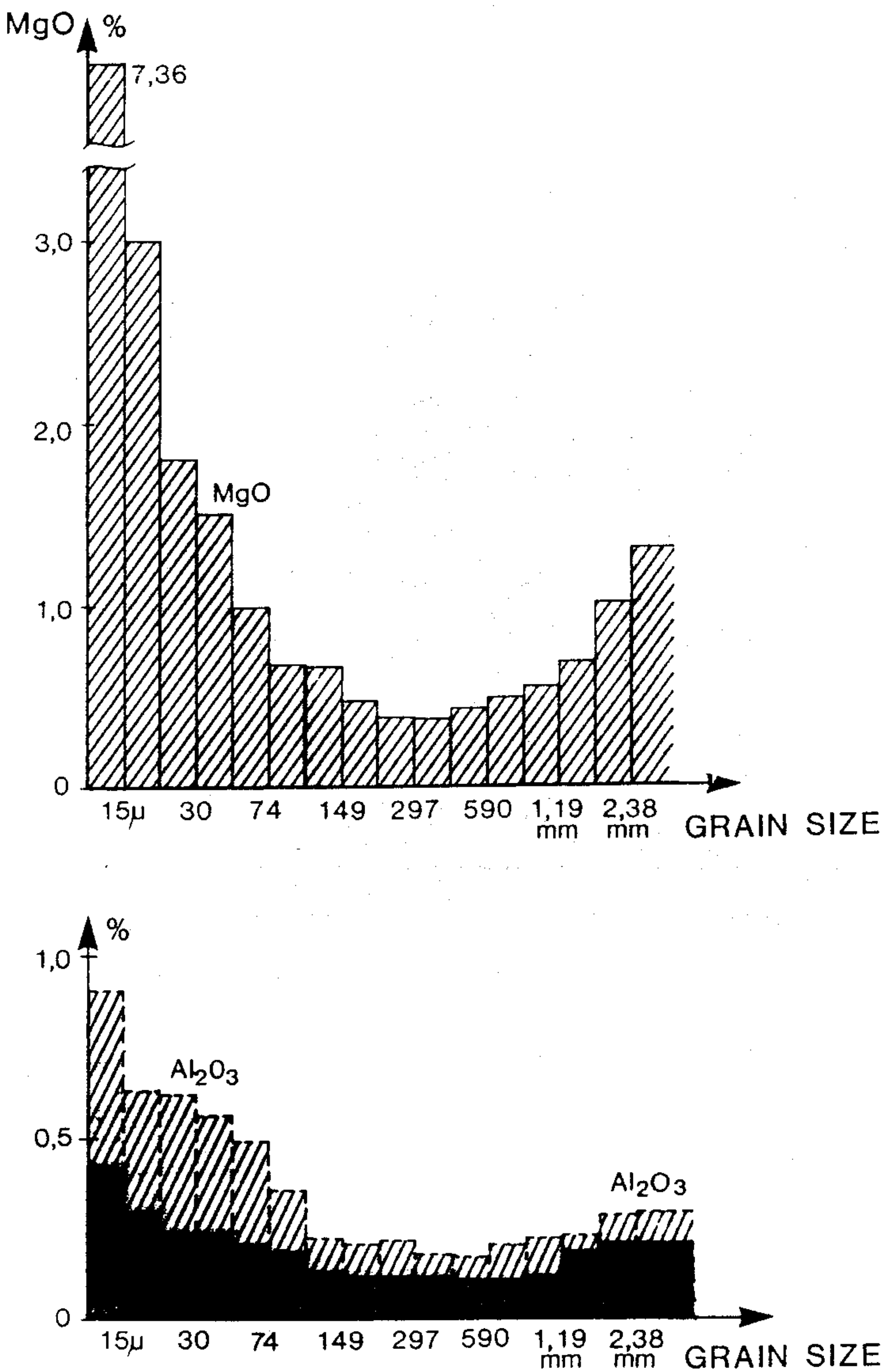


FIG. 15. IMPURITY CONTENTS OF SEDIMENTARY PHOSPHATE ORES AS FUNCTION OF GRAIN SIZE

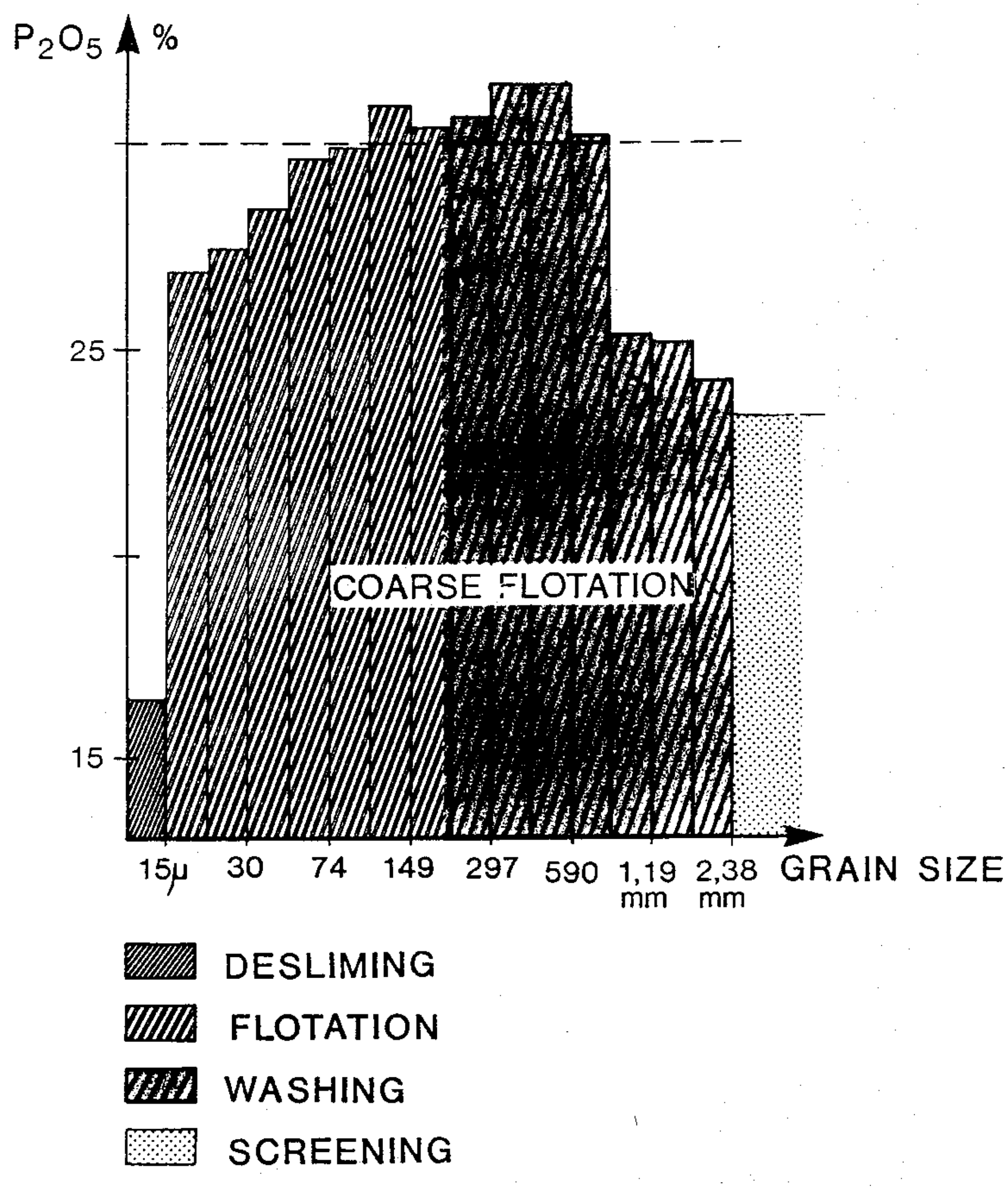


FIG. 16. PROCESSING OF A SEDIMENTARY PHOSPHATE ORE

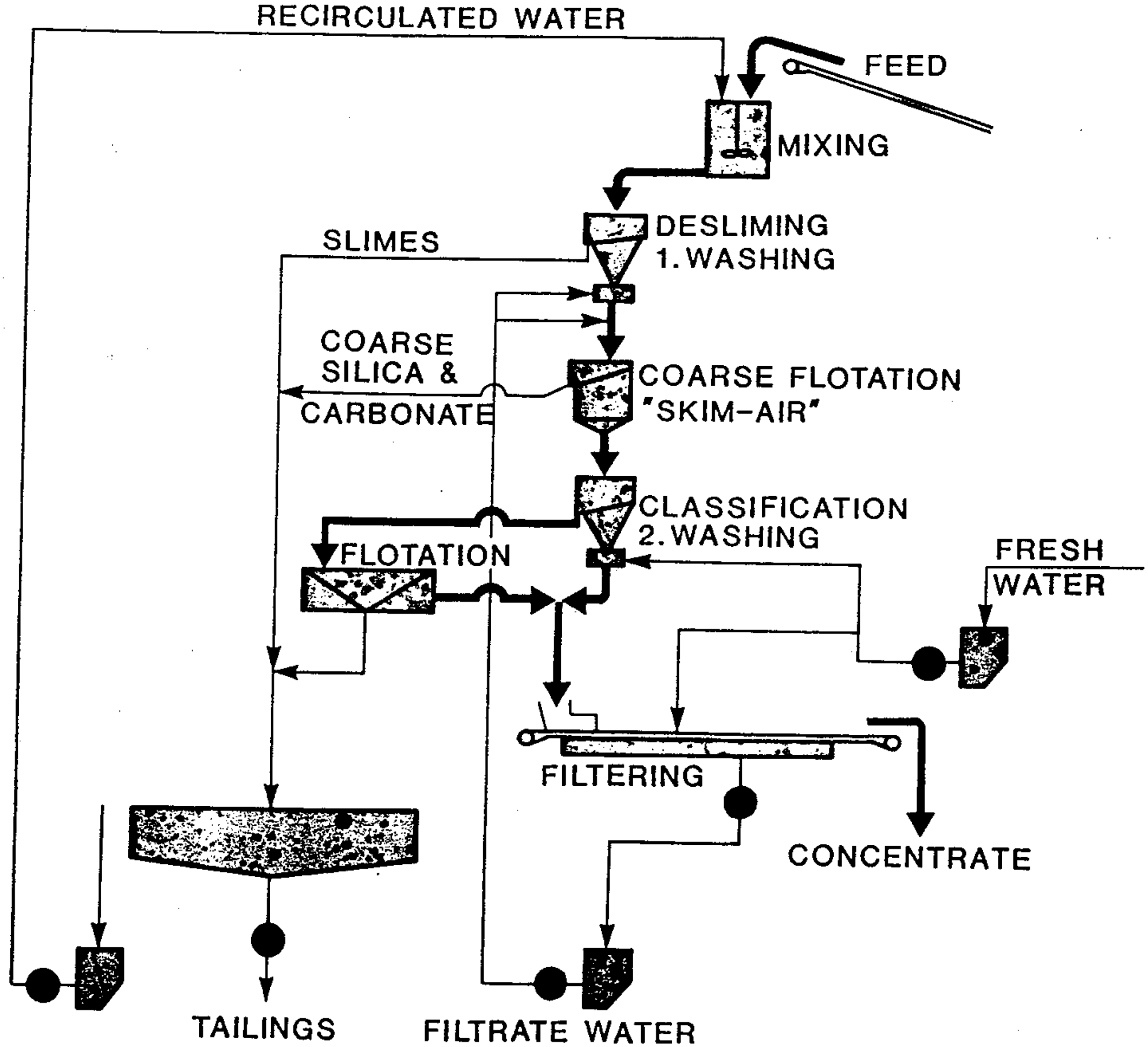


FIG. 17. CONCENTRATION OF SEDIMENTARY PHOSPHATE ORE, THE COMBINED WASHING-FLOTATION PROCESS