

# The size distribution and morphology of gold particles in Witwatersrand reefs and their crushed products

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## SYNOPSIS

Undistorted gold particles were obtained from samples of a variety of Witwatersrand reefs by dissolution of the quartz in hydrofluoric acid. The size distribution of the gold particles and their shapes and association with thucholite and pyrite are discussed. Gold particles with a natural flat, plate-like appearance occur in varying proportion in all reefs.

The effect of a number of different comminution processes on the gold particles was investigated, and the shape of gold particles in mill pulp from a number of mines was examined.

## SINOPSISIS

Onverwonge gouddeeltjies is verkry uit monsters van 'n verskeidenheid Witwatersrand rotslae deur die kwarts in hidrofluooruur op te los. Die grootteverdeling van die gouddeeltjies en hul vorms en assosiasie met thucholite en piriet is bespreek. Gouddeeltjies met 'n natuurlike plat, bordagtige voorkoms kom in verskillende verhoudings in alle rotslae voor.

Die effek van 'n aantal verskillende vergruisingsprosesse op die gouddeeltjies is ondersoek. Die vorm van gouddeeltjies in slyk van 'n aantal myne is ook ondersoek.

## INTRODUCTION

During the course of investigations aimed at improving reef-sampling procedures, specimens of about 200 g each from many Witwatersrand reefs were dissolved in hydrofluoric acid<sup>1</sup>. The residue contained gold and minerals such as thucholite, pyrite, chromite, zircon, chalcopyrite, sphalerite, rutile, and garnet. The gold and all these minerals were not attacked by the hydrofluoric acid, so that they were recovered undistorted, in their original form. Microscopic examination of the residues revealed many interesting features concerning the size and shape of the particles and the association of gold with the other minerals. In addition, some experiments were also conducted to determine the effects of different methods of comminution on the gold particles themselves.

Some of the results are presented here with the belief that they may be of interest to those concerned with gold recovery processes.

## SIZE DISTRIBUTION OF GOLD PARTICLES

Much of the gold in the residues from the samples treated with hydrofluoric acid occurred as free

particles (originally occluded in quartz), but some gold was attached to thucholite and some to coarse pyrite. The thucholite was separated from the residue, bromoform at a specific gravity of 2,85 being used as the separating medium. The heavy fraction was then sieved into different size fractions. The sieves used had apertures of 1 mm (18 mesh), 0,3 mm (50 mesh), 0,15 mm (100 mesh), 0,075 mm (200 mesh), and 0,05 mm (270 mesh).

In all the samples treated here, all the gold in the plus 1 mm size fraction was in the form of small particles attached to large pyrite particles. In the 0,3 mm to 1 mm and 0,15 mm to 0,3 mm size fractions, there was only a small proportion of gold attached to pyrite,

while all the gold in the size fractions less than 0,15 mm was in the free form.

The proportion of gold in each size fraction was determined by means of a non-destructive gamma-ray fluorescence technique under development by the Chamber of Mines Research Organization<sup>2</sup>. Although the equipment was not designed for the determination of the gold in small, rich samples, it yielded reasonably consistent results. It was estimated that the error in each proportion was about 4-10 per cent, with a somewhat higher error in the small proportions.

Table I shows the size distribution of the gold in samples taken from the Vaal Reef. About 45 per cent of the gold was in the free form less than 0,15 mm in size. The

TABLE I  
THE GOLD SIZE DISTRIBUTION IN SAMPLES FROM THE VAAL REEF AT KLERKSDORP

FRACTION	VAAL REEF								
	Stilfontein							Western Reefs	
	1	2	3	4	5	6	7	1	2
< 0,075 mm	24	22	43	21	41	18	9	5	40
0,075 - 0,15 mm	19	27	22	15	22	14	8	44	23
0,15 - 0,3 mm	21	21	19	13	22	19	10	19	20
0,3 - 1,0 mm	16	21	16	12	15	19	23	7	8
Attached to coarse pyrite	—	—	—	24	—	25	—	—	—
Attached to thucholite	20	9	—	15	—	5	50	25	9

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gold that was attached to pyrite was also less than 0,15 mm in size and amounted to about 6 per cent of the total. About 34 per cent of the gold was fairly coarse, while about 15 per cent was attached to the thucholite.

Table II shows the size distribution of gold in samples from the Basal and B Reefs in the Orange Free State. The size distribution of the gold in the Basal Reef was similar to that in the Vaal Reef, except that more gold was attached to pyrite. About 38 per cent of the gold was less than 0,15 mm in size, 34 per cent was fairly coarse, 12 per cent was attached to pyrite, and 16 per cent was attached to thucholite. However, much of the gold in the 0,3 to 1,0 mm fraction was also attached to pyrite; in some instances, the gold formed a matrix between pieces of recrystallized pyrite and, in others, the gold formed a coating on porous buckshot pyrite. In the samples from St Helena, the gold in the 0,3 to 1 mm fraction occurred as large single grains. In the B Reef, about

25 per cent of the gold was attached to thucholite.

Table III shows the size distribution of gold in a variety of reefs. In the Carbon Leader Reef, 43 per cent of the gold was attached to thucholite, while virtually no gold was attached to pyrite. The Kimberley Reef from the Evander area is notable for its very high proportion of fine gold.

MORPHOLOGY OF GOLD PARTICLES

The gold particles can be classified into three categories depending on their association with the thucholite, the pyrite, or the quartz and silicates in the reef. The free gold in the residue of the samples treated with hydrofluoric acid was attached to the quartz and the silicates. Thus, it is seen from Tables I, II, and III that most gold is associated with quartz and the silicates.

Particles of gold were selected from each category and were examined by means of a stereo-microscope and a scanning electron-microscope.

Gold associated with Quartz and Silicates

In this category, the gold particles had the following typical shapes: flat plate-like particles, crystalline particles, and spongy or porous particles. Particles of one or other of all these shapes were found in the same reef, but usually one shape predominated.

The flat, plate-like particles with smooth surfaces were generally widespread throughout the various reefs.

In samples of Kimberley Reef from Bracken and Leslie Gold Mines, fine plate-like particles (Fig. 1) less than 0,05 mm in size were predominant and accounted for about 40 per cent of all the gold. Larger, flat particles in other reefs (Fig. 2) have a rougher surface and some of them are up to 2 mm across in size.

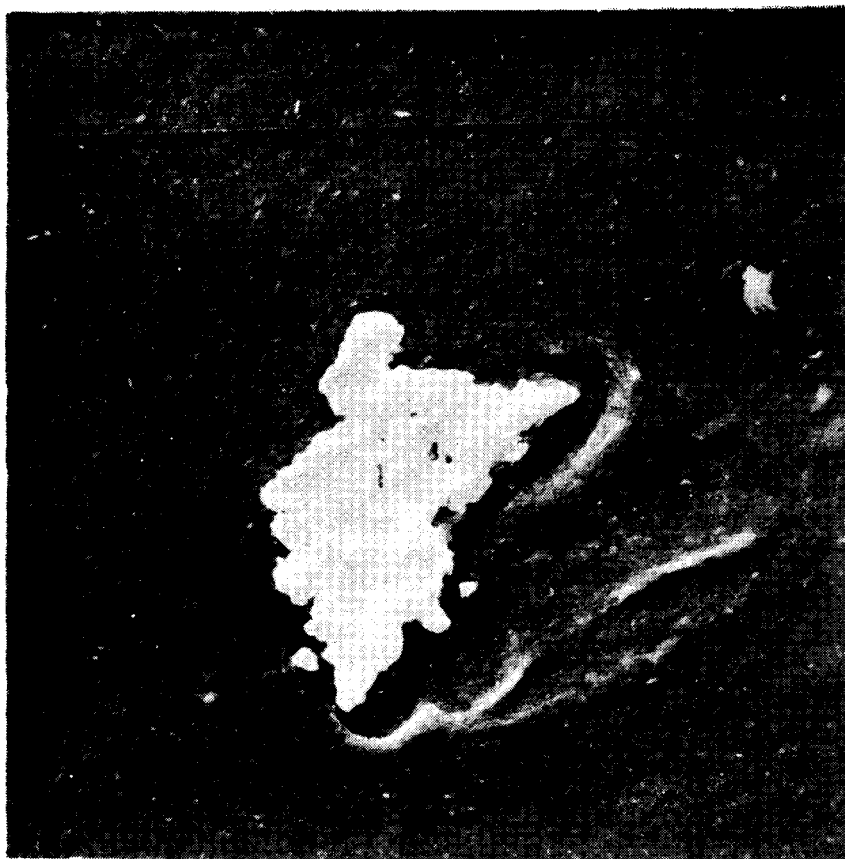
Nearly all particles of gold in Witwatersrand reefs show some sign of metamorphism or recrystallization. Well-crystallized particles can be found in most reef samples (Fig. 3). In the samples from the Basal Reef at St Helena, evidence

TABLE II.  
THE GOLD SIZE DISTRIBUTION IN SAMPLES FROM THE BASAL REEF AND THE B REEF IN THE ORANGE FREE STATE

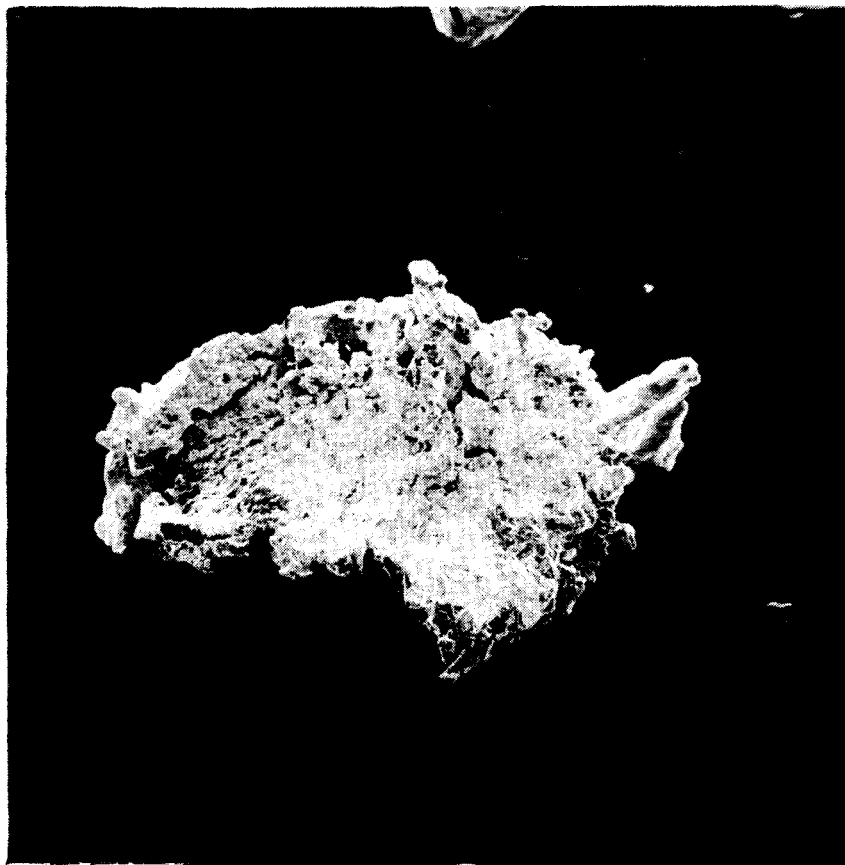
FRACTION	BASAL REEF										B REEF			
	Lorraine					Free State Geduld		St Helena		Western Holdings		Lorraine		
1	2	3	4	5	1	2	1	2	1	2	1	2	3	
< 0,075 mm	10	27	32	5	10	28	51	33	19	4	15	45	42	3
0,075 — 0,15 mm	9	18	19	11	16	27	18	17	14	13	6	27	22	1
0,15 — 0,3 mm	9	12	7	24	9	17	12	17	13	18	16	8	10	12
0,3 — 1,0 mm	50	25	4	10	4	13	8	19	13	59	35	3	14	5
Attached to coarse pyrite	19	2	2	50	15	4	—	8	16	—	28	—	—	9
Attached to thucholite	4	16	36	—	46	11	11	6	25	6	—	17	12	70

TABLE III.  
THE GOLD SIZE DISTRIBUTION IN SAMPLES FROM THE CARBON LEADER AND THE VENTERSDORP CONTACT REEFS NEAR CARLETONVILLE, THE MONARCH AND SOUTH REEFS NEAR KRUGERSDORP, AND THE KIMBERLEY REEF AT EVANDER

FRACTION	CARBON LEADER REEF			V.C.R.	MONARCH REEF	SOUTH REEF	KIMBERLEY REEF
	Western Deep Levels	Doornfontein		Western Deep Levels	West Rand Consolidated	West Rand Consolidated	Bracken
< 0,075 mm	13	21	18	20	31	19	51
0,075 — 0,15 mm	20	18	13	7	4	17	11
0,15 — 0,3 mm	9	11	23	30	20	31	23
0,3 — 1,0 mm	6	4	17	19	40	3	7
Attached to coarse pyrite	—	—	—	24	—	—	8
Attached to thucholite	52	46	29	—	5	30	—



**Fig. 1—Irregular-shaped, flat gold particle from Leslie Gold Mine  
Scanning electron-microscope. Magnification 260X**



**Fig. 2—Flat, slightly distorted gold particle from a sample of Vaal Reef, Stilfontein Gold Mine  
Scanning electron-microscope. Magnification 90X**

of recrystallization was particularly marked. Coarse gold occurred as single imperfect octahedrons and as filigree-like particles consisting of numerous small crystals (Fig. 4). The fine gold consisted of rounded particles with crystalline faces (Fig. 5).

Many gold particles have a rough surface, but some are so rough and irregular as to appear spongy or porous (Fig. 6). A large number of such particles were found in samples from the Vaal Reef. It was thought that the composition of these particles would be different from that of other particles, but it was found that their silver and copper contents were similar to those of the other particles.

#### *Gold Associated with Thucholite*

Thucholite, or carbon, which was found to be a fossilized plant, is a prominent constituent of the Carbon Leader Reef and, to a lesser extent, of the Basal Reef and Vaal Reef. Coarse gold is found embedded between the carbon grains making up a carbon seam. These particles are frequently nugget-shaped (Fig. 7). Their size varies greatly from about 0.05 mm to more than 2 mm, and the large particles appear to be aggregates of the smaller ones.

Extremely fine gold particles have been observed right within the structure of the individual carbon grains and seem to be due to a biological mechanism of concentration. The gold consists of single round inclusions and thin fibres about 1  $\mu$ m in diameter (Fig. 8). It is probable that this fine gold within the carbon grains accounts for much of the gold losses attributed to thucholite in reduction plants.

#### *Gold Associated with Pyrite*

The gold associated with the pyrite shows much evidence of the mobilization and redeposition of gold due to geological processes. The gold appears to have grown on, or coated, pyrite grains. In some instances this process was so extensive that the gold appears as a matrix between grains of pyrite. It is most marked in the Ventersdorp Contact Reef, the Elsburg Reef, the Basal Reef, and the Vaal Reef. Samples of the Ventersdorp Contact

Reef at Western Deep Levels showed gold redeposited on the surface of secondary pyrite crystals (Fig. 9). In many reefs, the primary pyrite pebbles have been coated with gold (Fig. 10).

### MORPHOLOGY OF GOLD PARTICLES AFTER COMMINUTION

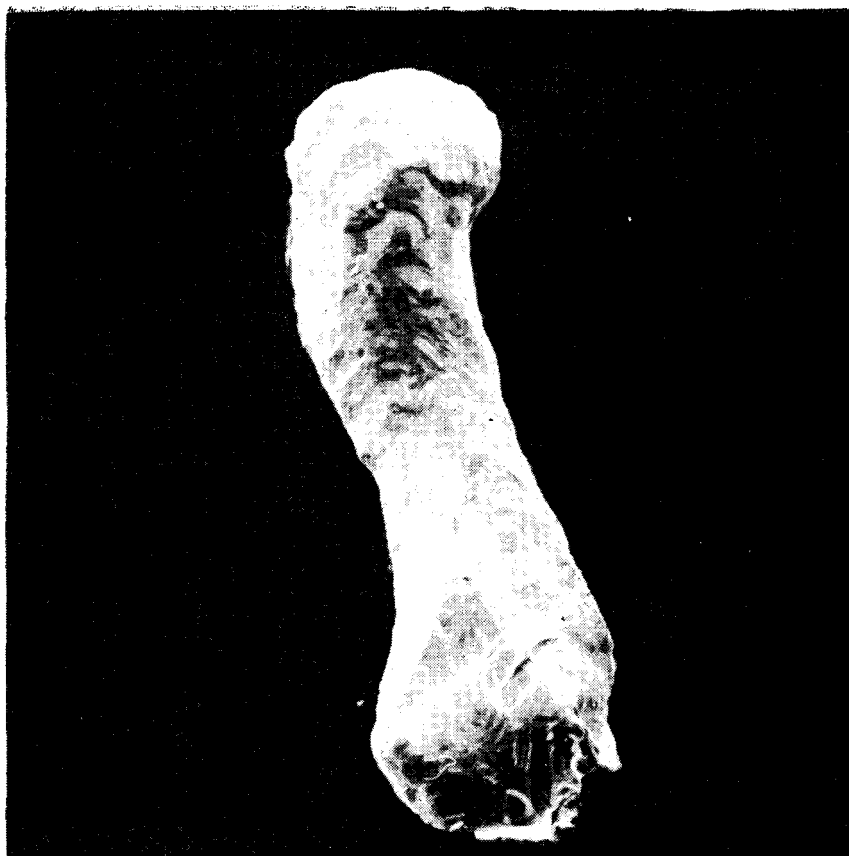
An experiment was conducted to determine the effects of different methods of comminution on the gold particles in the ore. A sample of Vaal Reef was crushed and split into equal portions, which were comminuted by different methods until at least 90 per cent passed through a sieve having apertures of 0,15 mm. The pulp was treated with hydrofluoric acid, and the residue was sieved into different size fractions. The relative gold content of each fraction was determined by means of the gamma-ray fluorescence technique.

Table IV shows the size distribution of the comminuted product and of the gold particles themselves in the comminuted product. It can be seen that the size distribution of the entire comminuted product is similar for the different methods. However, the gold particles from the ball mill and disc pulverizer are coarser than those from the other processes, and are significantly larger than the average comminuted product. At first sight it would seem that the gold particles had been reduced in size, but, since the particles were radically changed in shape, it is not at all certain that the gold particles were broken up to any significant extent.

Gold particles larger than 0,075 mm were selected from the pulp and examined by means of a scanning electron-microscope.

There was no obvious difference between particles that had been milled wet and those that had been milled dry in the ball mill. Most of the gold particles had been flattened (Fig. 11), and small pieces of pyrite were embedded in the surface. Judged by the rough surface, pieces of quartz had also been embedded in the surface but had been removed by the hydrofluoric acid (Fig. 12).

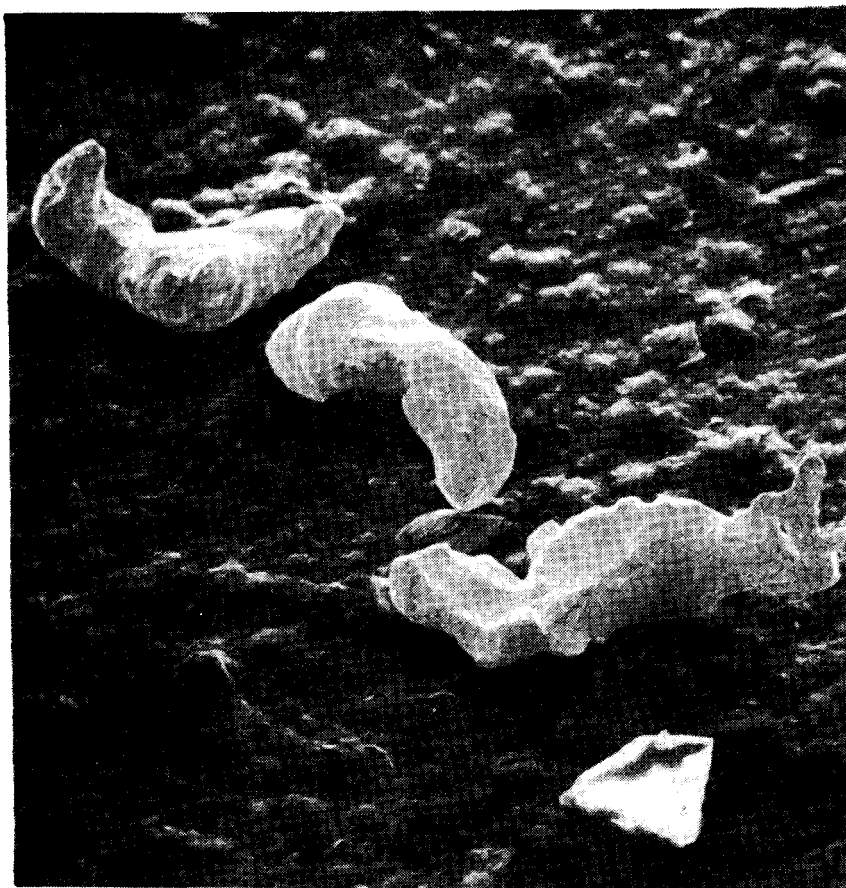
The gold particles in the ground material from the hammer mill



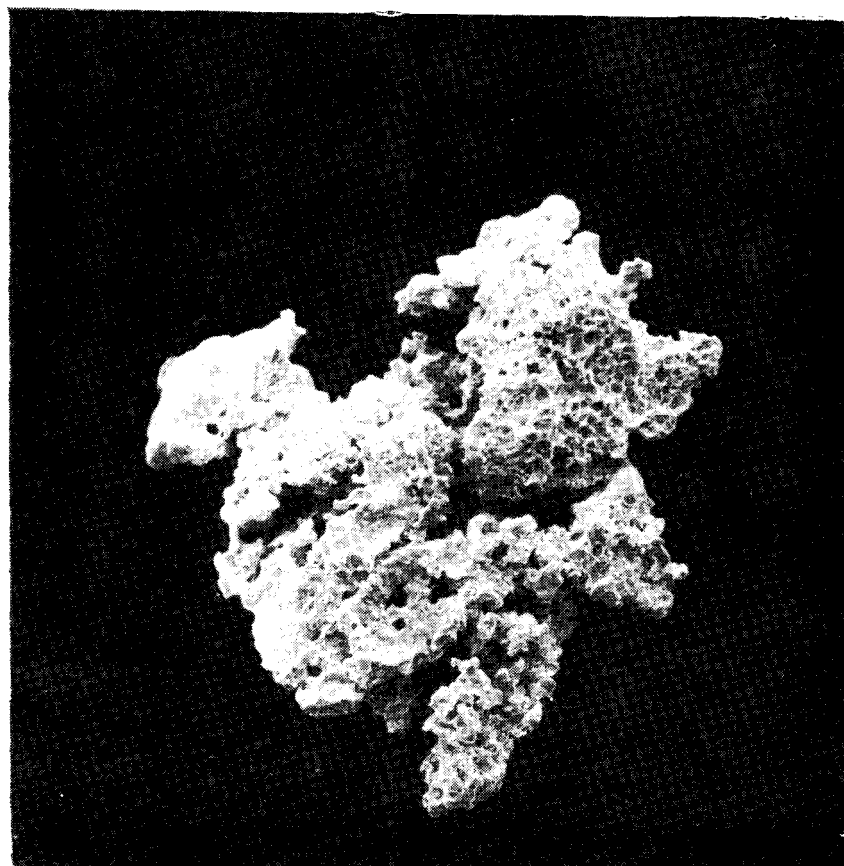
**Fig. 3—Gold particle extracted from a sample of Vaal Reef, showing a distinct crystalline structure**  
Scanning electron-microscope. Magnification 280X



**Fig. 4—Scanning electron photomicrograph of a gold particle from St Helena Gold Mine, showing a filigree-like aggregate of small crystals**  
Magnification 95X



**Fig. 5—Gold particles of the minus 0,05 mm fraction of a sample of gold ore from St Helena Gold Mine  
Scanning electron-microscope. Magnification 475X**



**Fig. 6—Porous, spongy gold particle extracted from a sample of Vaal Reef, Stilfontein Gold Mine  
Magnification 620X**

(micropulverizer) were rounded in shape, with flat faces. No flat particles were observed. The surfaces of all the particles showed inclusions of fragmented pyrite and quartz (Fig. 13).

The particles from the vibrating mill were rounded and slightly cylindrical, and there appeared to be relatively less embedding of minerals in their surfaces.

There was no apparent difference between the gold particles after comminution of reef in the disc pulverizers, regardless of whether the plates were new or worn. Most of the particles were spherical or cylindrical in shape (Figs. 14 and 15) and appeared to have been rolled in the gap between the discs. They contained large quantities of fragments of other minerals. The particles from the pestle and mortar were both flattened and irregularly rounded. These particles were relatively free of embedded minerals in their surface.

Samples of mill pulp taken from the classifier overflow were collected from various mines. Gold particles were extracted and examined as before. The gold particles had been distorted in the same way as from the ball mill, as described above. All the particles larger than 0,075 mm had been flattened, and most of the smaller particles were greatly distorted. Numerous smaller particles of pyrite and quartz were embedded in the surfaces of the flattened gold particles (Fig. 16).

## CONCLUSION

The undistorted gold particles recovered from samples of reef by dissolution in hydrofluoric acid can be classified into three categories depending on their association with the quartz and silicates, the thucholite or the pyrite. The particles associated with quartz were characteristically flat or crystalline or porous. The gold associated with thucholite occurred as minute particles inside the structure of the carbon grains, and as coarse, sometimes nugget-shaped, particles embedded between grains making up the carbon seams. The gold associated with pyrite occurred as firmly attached small particles or thin coatings on pyrite particles.

TABLE IV.

COMPARISON OF THE SIZE DISTRIBUTION OF GOLD PARTICLES WITH PARTICLES OF ORE FROM THE VAAL REEF AFTER COMMINATION BY DIFFERENT METHODS

METHOD OF COMMINATION	SIZE DISTRIBUTION AFTER COMMINATION, %					
	Gold Particles only			Entire sample of ore		
	+ 0,15 mm	0,075—0,15 mm	— 0,075 mm	+ 0,15 mm	0,075—0,15 mm	— 0,075 mm
Ball mill, dry	10	34	56	2	19	79
Ball mill, wet	8	34	58	1	13	86
Hammer mill (micropulverizer)	1	28	71	Trace	24	76
Vibrating mill (Siebtechnik)	8	28	64	8	20	72
Disc pulverizer—new plates	2	43	55	Trace	24	76
Disc pulverizer—worn plates	1	47	52	Trace	22	78
Pestle and mortar	2	28	70	Trace	22	78



Fig. 7—Scanning electron photomicrograph of a rounded, nugget-like gold particle from a sample of Vaal Reef, Stilfontein Gold Mine  
Magnification 315X

In the Kimberley Reef at Evander, virtually all the gold was associated with quartz and the particles were flat and very fine.

In the Carbon Leader Reef, a very large fraction of the gold was attached to thucholite. The rest of the gold was associated with quartz and the silicates, and the particles

had a wide variety of shapes and sizes.

In the Basal Reef, most gold was associated with quartz and the silicates, and the particles had a wide range of sizes. There were many large and small crystalline particles and flat particles. A considerable amount of gold was at-

tached to thucholite and to pyrite.

In the Vaal Reef, most gold was associated with quartz and the silicates. The particles occurred in a wide range of sizes and shapes. A significant amount of the gold was attached to thucholite, and a small amount to pyrite.

All methods of comminution severely distort the gold particles. Ball mills and disc pulverizers do not appear to break the gold particles down to any significant extent. Ball mills produce flattened gold particles, while disc pulverizers produce spherical or cylindrical particles. Both methods cause large quantities of fine quartz and pyrite to become embedded in the surfaces of the gold particles.

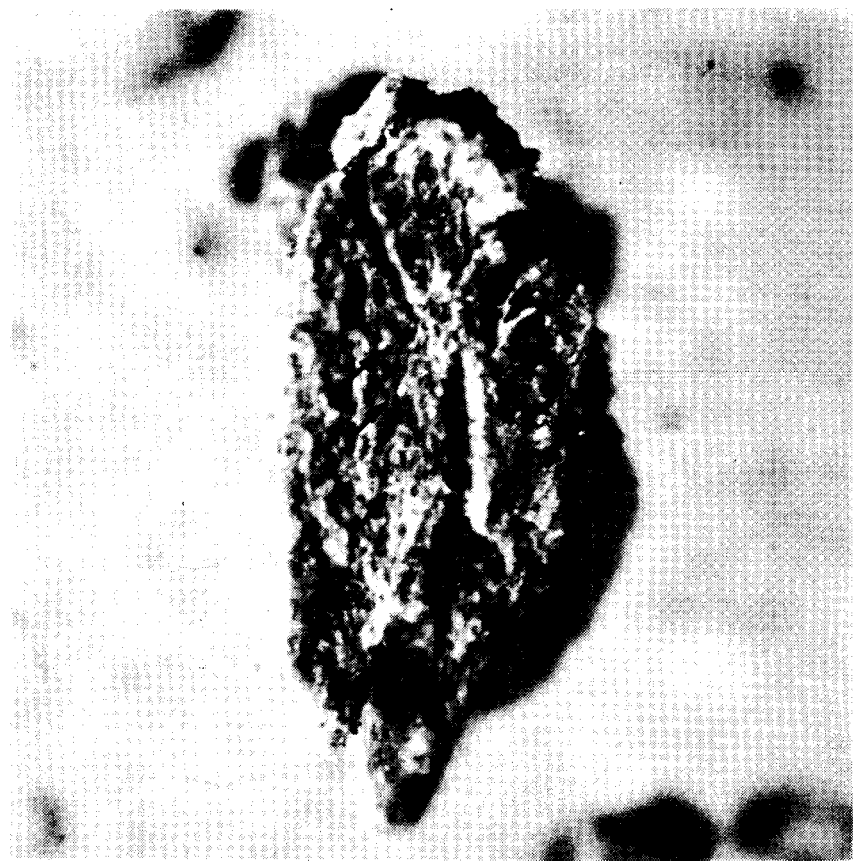
#### ACKNOWLEDGEMENT

This paper describes some of the work being done in the Mining Research Laboratory of the Chamber of Mines of South Africa.

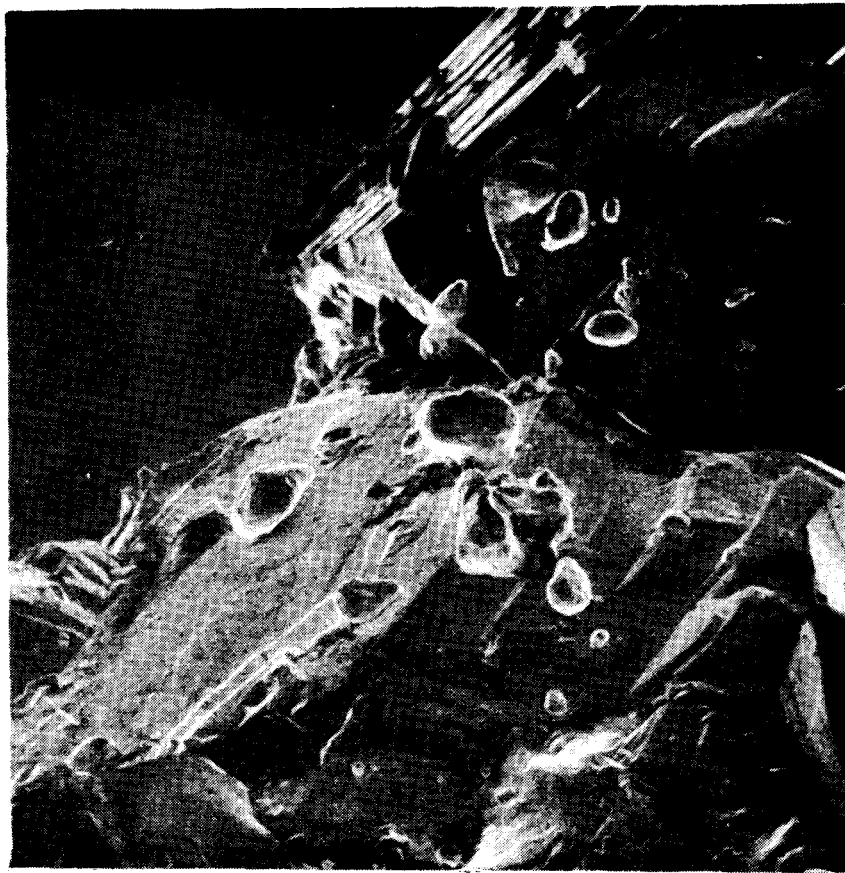
The assistance of a great many gold mines in providing reef samples and mill pulp is gratefully acknowledged.

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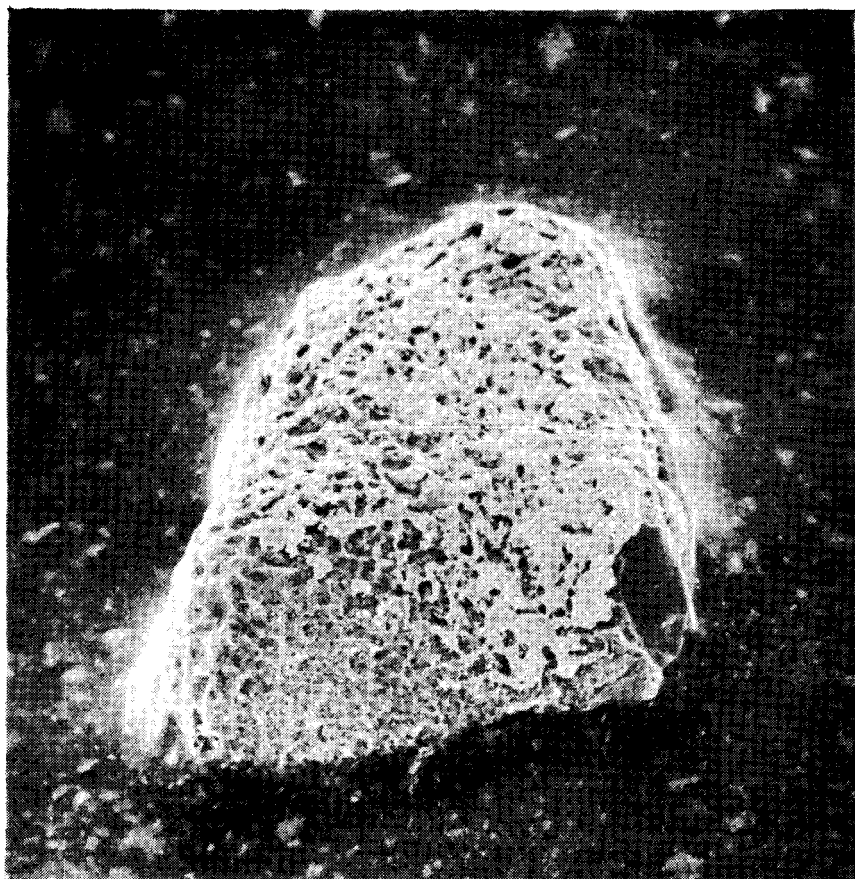


**Fig. 8—Photomicrograph of an oxidized columnar carbon particle showing a fibrous framework of inorganic material and small inclusions of gold (arrows)  
Magnification 90X**

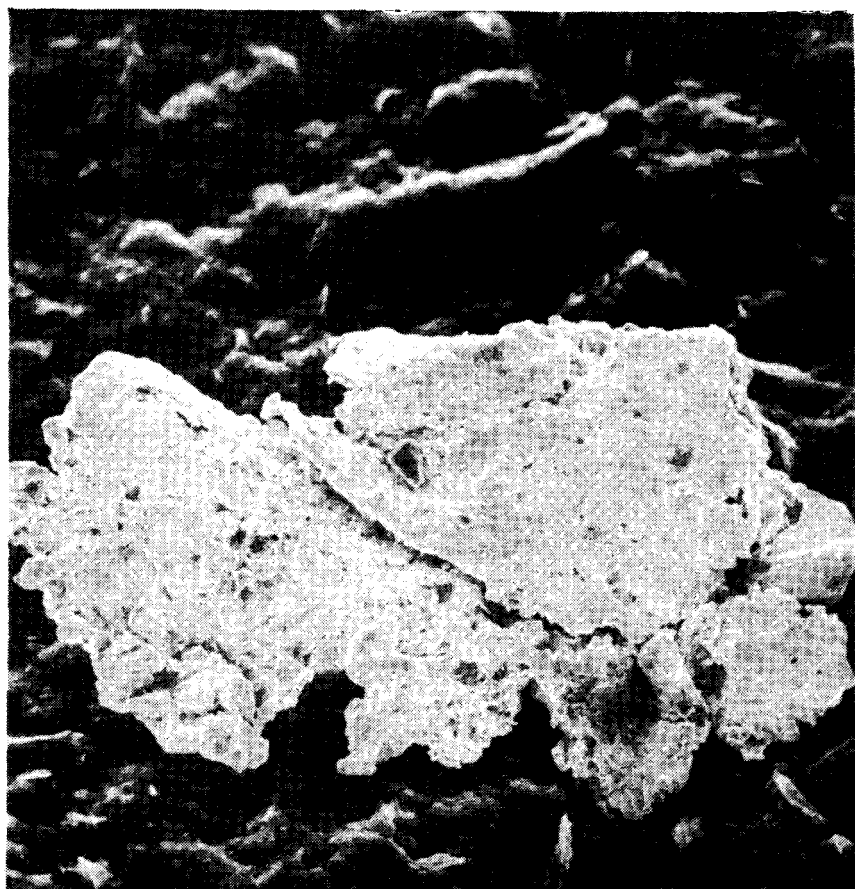


**Fig. 9—Scanning electron photomicrograph showing the surface of a pyrite crystal with small gold particles firmly attached to it, Ventersdorp Contact Reef, Western Deep Levels  
Magnification 180X**



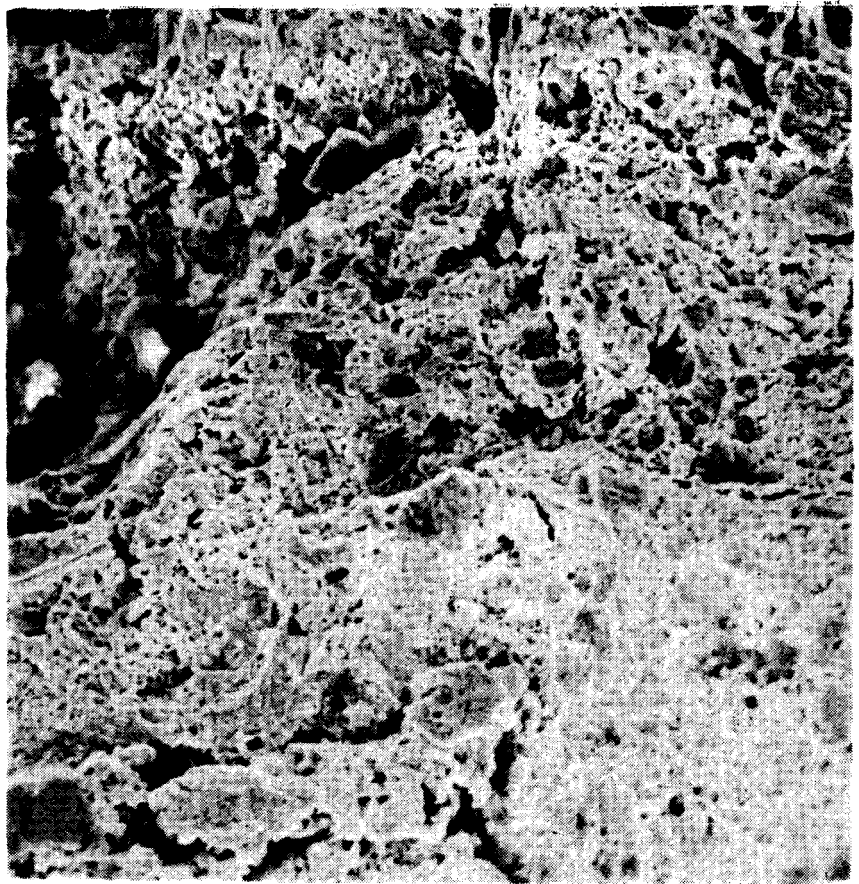


**Fig. 10—Pyrite pebble with thin coating of gold, photographed in a scanning electron-microscope. Magnification 510X**

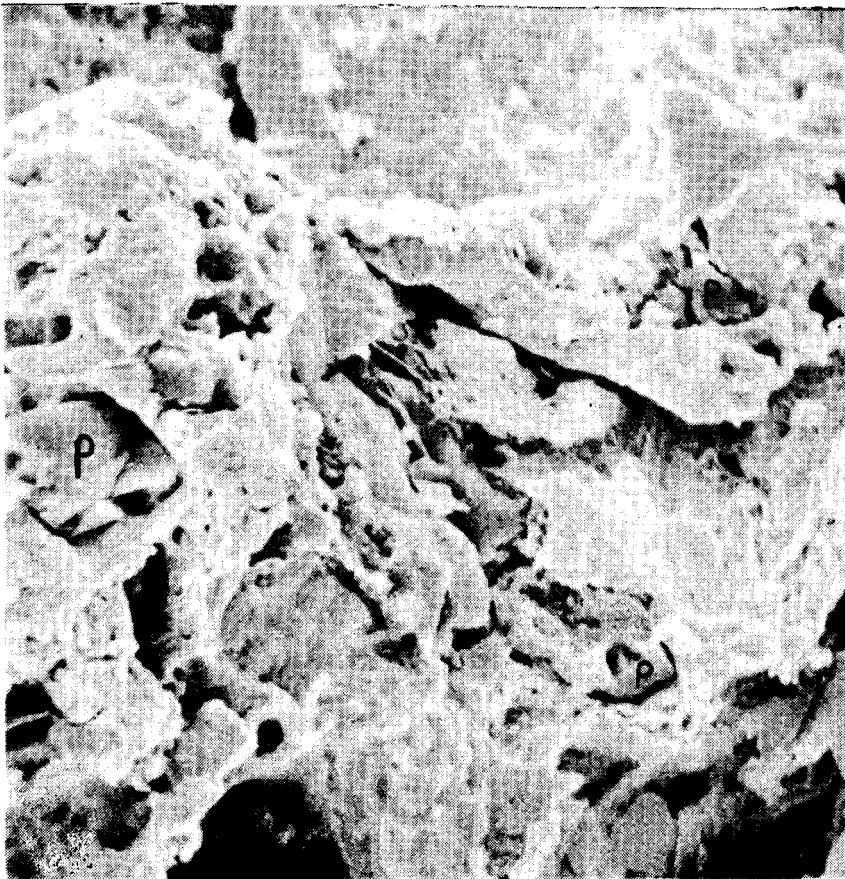


**Fig. 11—Gold particle flattened and distorted during the crushing process in a ball mill. Wet grinding with about 10 per cent solids Scanning electron microscope. Magnification 470X**

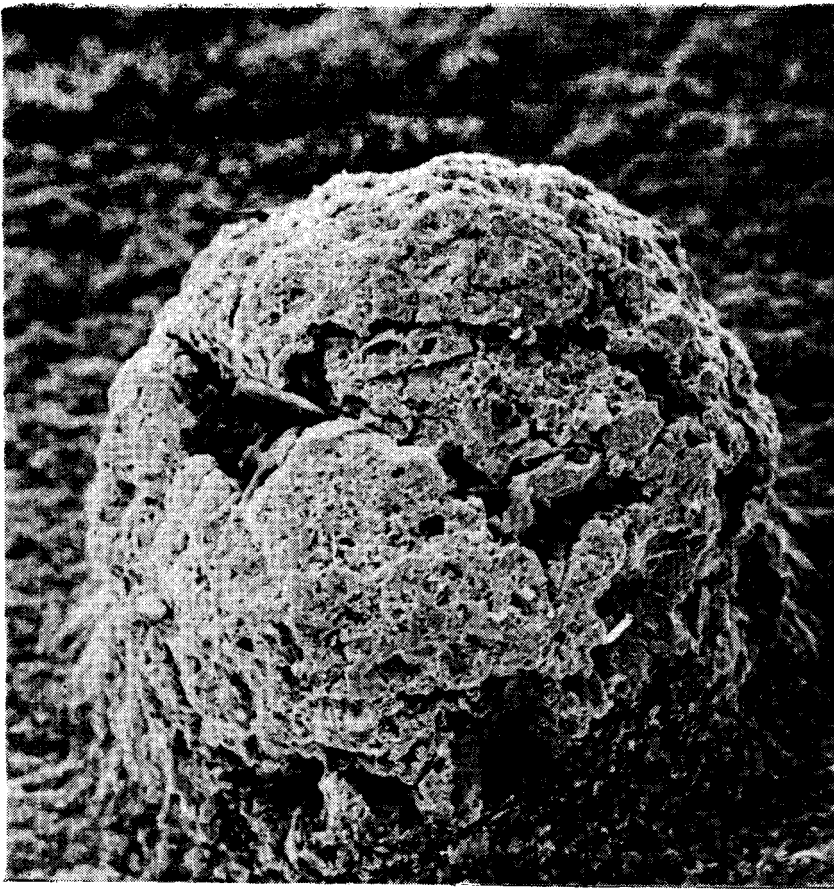




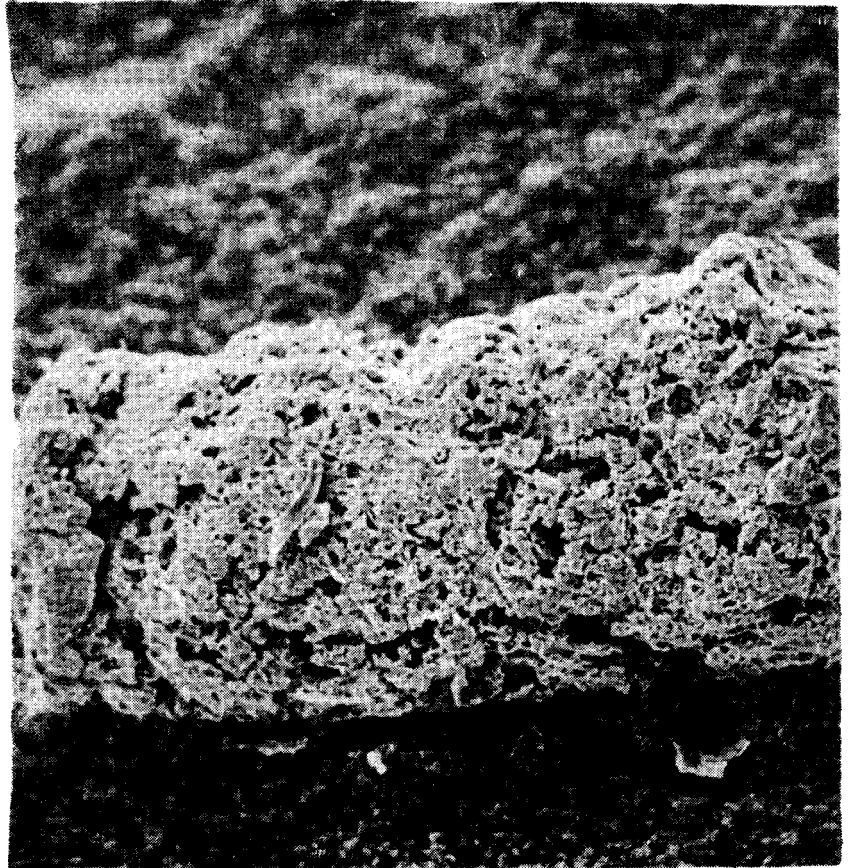
**Fig. 12—Part of the surface area of a gold particle flattened and distorted in a ball mill, showing a porous surface and small pieces of pyrite embedded in the gold**  
Scanning electron-microscope. Magnification 1050X



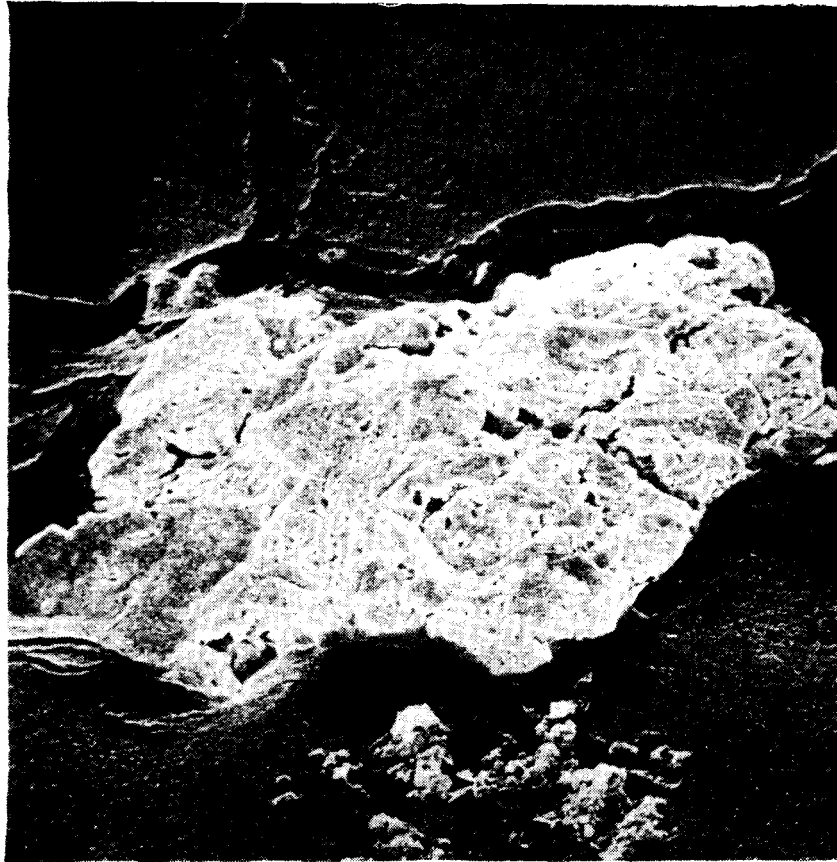
**Fig. 13—Part of the surface area of a gold particle taken from a sample of ore crushed in a hammer mill. The photograph shows intensely distorted gold with angular inclusions of pyrite (P)**  
Magnification 2250X



**Fig. 14—Scanning electron photomicrograph of a gold particle rolled and distorted during crushing of ore in a disc pulverizer  
Magnification 600X**



**Fig. 15—Scanning electron photomicrograph of a gold particle rolled to a cylindrical shape during crushing of ore in a disc pulverizer  
Magnification 620X**



**Fig. 16—Flattened and distorted gold particle extracted from a sample of classifier overflow, West Driefontein Gold Mine  
Magnification 620X**