Discussion.

The President. The PRESIDENT, in moving the vote of thanks, remarked that the Author had assumed a certain amount of knowledge of the subject on the part of the members, and that seemed reasonable in view of the fact that the Morro Velho gold mine had been worked by a British company for about 100 years. The difficulties of mining had been great, the inclination and size of the lode varying in an extraordinary way; and those difficulties had been successfully overcome by the adoption of the improved methods described in the Paper.

Mr. Bailey. Mr. T. H. BAILEY observed that he felt a little diffident in discussing the Paper, because it seemed to him that the general system that had been adopted at the mine was the general system in use at most ore-mines. Where did the originality mentioned in the Paper really come in? In the ventilation of such mines it was necessary to take advantage of the natural course of the air rising through the heat of the mine, and when the air was taken against the natural way of the current, difficulties were bound to arise. The Author admitted that the pits of the system were costly. Was not that because of the way in which the pits had been used? In all such mines the use of pits was well known as being a means of getting the ore in the cheapest way. In general, the Paper seemed to show that the apparatus suited the conditions, but often conditions were not considered when the apparatus was selected. The apparatus had to be suitable for the conditions to be attacked to ensure the most economical working results. Would the Author say exactly how he considered the methods he had adopted fulfilled that consideration?

Mr. Marriott. Mr. H. F. MARRIOTT observed that the Paper dealt with points which were especially interesting because the mine, till quite lately, had been the deepest gold mine in the world, and also because it was a very rich one. He thought it would have been helpful if the Author had given a longitudinal section and a plan,[1] so that the positions referred to in the Paper could have been grasped more readily. There was a good section of the mine in a recently-published text-book.[2] A remarkable feature of the lay-out of the

[1] These have been added by the Author (see Figs. 11, Plate 2).—SEC. INST. C.E.

[2] G. J. Young. "The Working of Unstratified Mineral Deposits," p. 24. London, 1927.

mine was that there were no less than five shafts and five crosscuts, involving ten separate handlings of the ore. How was it that, when the fourth shaft had been made and it had been evident that the rich ore still continued, one deep-level shaft had not been sunk directly to a depth of about 4,000 feet? It would have simplified the haulage very much, and the ventilation could have been in accordance with practice in other parts of the world. Throughout the Paper, whether in connection with the old method or the new method, he noticed that the Author mentioned a great deal of tramming of the ore along the levels and sending it up and down the raises or winzes; and he wondered how it was that the practice of rill stoping had not been applied instead of the method employed. It seemed, from the information he had been able to gather from the Paper, that rill stoping could have been applied in a good many parts of the mine; if that had been done the ore would have found its own way to the level below, without having to be raised by an expensive haulage-system, and the stope filling could have been dumped and would have found its way by gravity into the position required. A further advantage would have been that natural ventilation would have been effected more readily along the working-faces. In the new method (*Figs. 3*) the filling was still carried in trucks to its final position in the stopes. He would like to have more information upon that, and to know whether gravity could be used a little more instead of haulage. The adoption of the stall-and-wall method of winning the ore on the horizontal stretches conformed to the practice in some iron mines and others where large flat bodies existed. He noticed that filling was taken in and packed as the ore was extracted in the flat excavated places. Was it really necessary to support the roof permanently? If not, the pillars could be robbed backwards and the ground allowed to fall in, incidentally helping to break the ore. In *Figs. 10* the permanent way was shown in different positions relative to the lode. He did not know why those particular cross sections had been selected, but, without further information, they appeared to show rather expensive methods of driving a permanent way and to be not particularly safe. It was asking a lot to expect little blocks of mineral to support the roof safely and keep the permanent way open. Was it not possible to ascertain for some considerable distance ahead the direction in which the lode was going, to drive the permanent way so that it was safely in the foot wall, and to avoid so much bricking up and leaving the blocks of mineral in an apparently unsafe position hanging over the permanent way. The Author claimed an increase in efficiency of 30 per cent. for the reorganized method

Mr. Marriott.

Mr. Marriott. of working. It was, however, not possible to discuss that in any way, because no costs were given, and true efficiency could only be measured by increase of profit in the extraction of the mineral, after allowance had been made for the variation in grade. The value of the Paper would be greatly enhanced if it were amplified by the addition of detailed comparative costs of the old and new systems, based on the quantity of ore produced for a given period, showing its realized value, the over-all costs of production, and the profit distributed.

Dr. Horwood. Dr. C. BARING HORWOOD observed that the Paper was especially interesting because it dealt with a mine that few engineers had the opportunity of visiting. He agreed almost entirely with Mr. Marriott's remarks about stoping, but at the same time he realized that the great advantage of the new method of stoping employed in the Morro Velho mine was that the filling took place practically concurrently with the excavation of the ore, and was therefore kept close to the working-face all the time. The very great disadvantage of numerous handlings of the ore would be lessened if it were possible to adopt the method described by Mr. Marriott; but, doubtless, there were local reasons why that was not possible. What was the cost of the filling per ton of ore mined? It was not clear from the Paper whether the strike of the lode was east and west. He gathered that, as the pitch was 43 degrees, presumably eastward, the strike was also east and west. Unless the lode stood vertically, there must be also a dip or inclination north and south. What was that dip? Also, what was the average width of the ore-body, measured at right angles to its hanging and foot walls, and its average thickness measured from north to south? In the annual reports of the Company the assay-value of the ore-reserves was not given over any definite stoping-width; and therefore he presumed that the assay-value given was estimated as being the value per ton of ore to be extracted. How many times had the ore from the lower levels to be handled before it reached the surface? He had studied that question with the help of a diagram of the mine which the Company had been kind enough to let him have, and it seemed that it was handled between eight and twelve times before reaching the surface. The Author, in describing what he called the stall-and-wall method, stated that the ground did not stand well when the excavations were made in an east-and-west direction, but that if they were made in a north-and-south direction the hanging wall would stand securely over a distance of 15 to 20 feet. The country in which the lode occurred was stated to be schists. He therefore assumed from these facts that the strike of the lode was

parallel to the strike of the schists, namely, east and west. In the cases of lodes occurring in schists and striking parallel with them, it was quite usual for a lode to be either banded or more or less laminated parallel to its walls, and consequently in such cases excavations naturally stood better if made at right angles to the direction of that lamination instead of running parallel with it. That was doubtless the explanation in this case. He had seen a method of stoping similar to the Author's stall-and-wall method successfully employed at the Almaden quicksilver mine in Spain. The Author claimed that on the 23rd level the employment of the new stoping method increased the efficiency by more than 30 per cent., and that even better results were expected. Did that mean that 1·3 ton of ore could now be raised to the surface for the cost of raising 1 ton by the old methods? If so, that was an excellent achievement, on which the Author was to be congratulated. Although the Author had confined himself entirely to stoping methods, Dr. Horwood would venture to touch on several questions involved in mining at such a great depth. As the Morro Velho gold-mine was the second deepest mine in the world, it was natural to compare it with the deepest mine, namely, the Village Deep gold-mine, which at the end of 1927 had attained a vertical depth of 7,309 feet. It was a general rule with mineral veins, or lodes, that there was a more or less gradual diminution of their mineral content with increasing depth. Also there was a marked relationship between what was commonly called the strength of a lode, that was, its thickness and more particularly its length measured along its strike, and its persistence (and the persistence of its values) in depth. In this respect, in the case of each of these two mineral occurrences, the circumstances were unusual. In the case of the Village Deep the ore-body really consisted of a highly metamorphosed sedimentary conglomerate stretching over a distance of about 60 miles, approximately 30 miles on either side of Johannesburg, which had served as the upper portion of the channel up which deep-seated mineralizing solutions had circulated and deposited their mineral burden; therefore, it might be considered as a lode of great lateral extension, and it was reasonable to expect great persistence in depth not only of the lode but also of its mineral contents. Therefore, in this case the mine had rightly been laid out from the first to deal with big tonnages and for a long life. It had a main shaft with a vertical depth of about 4,000 feet, and below that there was a subsidiary inclined shaft to a further depth, and a second subsidiary inclined shaft to the bottom of the mine; so that there was very little handling of the ore from the bottom levels to the surface. The Paper did not give

Dr. Horwood.

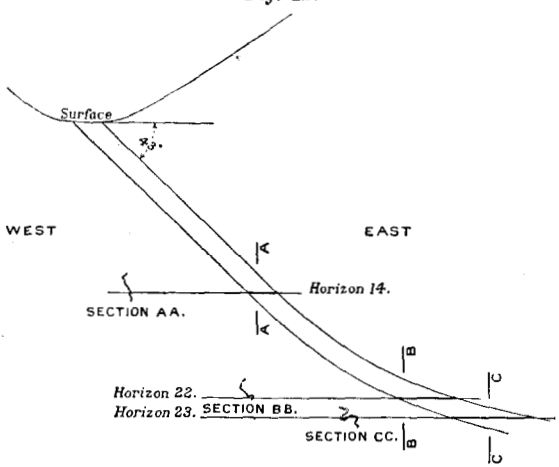
Dr. Horwood. the length, along the strike, of the Morro Velho lode. From the diagrams he had seen he assumed it was 700 or 800 feet; and the ore-body occurred in schists. Thus there would have been no justification for laying out that mine from the start for deep mining, because it was against all experience for a lode with such a slight lateral extension at the surface, and especially of its mineral tenor, to be very persistent in depth. Therefore the Company had rightly started mining in the way they had done; and later they had had to put down subsidiary vertical shafts. However, he agreed with Mr. Marriott that when the mine was 4,000 feet deep, and the Company had realized the very great persistence both of the ore-body and of its yield, the question of putting down a main, deep, vertical shaft might then have been considered. Probably it had been considered. Perhaps the Author would say whether it had been. He understood that the bottom of the Morro Velho mine was now at a vertical depth of 7,100 feet below the surface, and that at that depth the ore was still averaging about 10 to 12 dwt. of gold per ton! He could not imagine such great persistence in depth of so small an ore-body and of its gold in any other than a relatively plastic, yielding rock such as schist. He had no doubt that the Author must have formed his own ideas as to the reasons why that lode, and its mineral-contents, had persisted to such great depths; and his views on that point would be of great value. In 1926 the average yield per ton milled from the Morro Velho mine was 12·8 dwt., and the revenue, with £5,238 from the subsidiary properties, was about 54*s*. 6½*d*. per ton milled. The working-costs in Brazil, including Government duties and mine development, were 49*s*. 4½*d*., which left, after allowing for London charges, a profit of no less than 4*s*. per ton, which in all the circumstances was an excellent achievement. The total revenue in 1927 at the Village Deep mine amounted to only 23*s*. 6*d*. per ton milled, while the total working-costs were 22*s*. 11*d*., leaving a profit of only 7*d*. per ton milled. That was from the working of a mine which had reached at the end of that year a vertical depth of 7,309 feet, a truly wonderful performance! If the Village Deep mine had as rich a lode as that at the Morro Velho mine and the same yield of gold in depth as the latter, he had no doubt that by extending operations to the south of the present boundary the Village Deep would continue to be mined at a profit to a vertical depth of 2 miles, or 10,560 feet. When milling started at the Village Deep mine in 1905 the yield was over 7 dwt. per ton; it had gradually declined, with increasing depth, until for 1927 the average per ton milled was 5½ dwt. Would the Author

state the yield per ton of ore milled at the Morro Velho mine in the early years of the mine? Assuming that the pitch of the ore-body at the Morro Velho mine returned to its previous average inclination of about 43 degrees, and that the value of the ore did not decrease rapidly, but merely decreased in approximately the same steady ratio as in the past, to what economic depth did the Author think the Morro Velho mine could be worked? Another difficulty connected with deep mining was that of the increase in temperature with depth. At the Morro Velho mine, over the four hottest months of the year, as recorded in 1925, the mean air- and rock-temperatures increased, from the adit-level to the 23rd level, from 48° and 59·7° F. to 100·8° to 110·3° F. respectively. On the 37th level, near the bottom of the Village Deep mine, he understood the rock-temperature was 97° F., while the air-temperature was reduced by cooling to 85°; and that 4 or 5 tons of ice a day had to be sent down the mine to keep the air cool, in spite of a big "Sirocco" fan, with a capacity of 300,000 cubic feet per minute, and another fan underground. He would be glad if the Author would mention the methods of cooling the air and keeping it dry at the Morro Velho mine, as he believed there was a very interesting plant there for that purpose. He understood that at the Village Deep mine natives were not sent down to the lower stopes to work immediately, because if they were they died of heat apoplexy in a few days. They had to work in the upper stopes and gradually become accustomed to the heat of the mine before they went to the lower, and hotter, stopes. Was there any difficulty of that kind in the Morro Velho mine? Another drawback to deep mining (especially on the Rand, where the country consisted of hard, tough, siliceous quartzite) was the occurrence of what were known as "rock-bursts," due to the intense rock-pressure at excessive depths. At the Village Deep mine, in working out blocks of ore-reserves, it had been found advisable to leave standing about 10 per cent. of the blocks, on account of the danger of rock-bursts if all was removed. At the Morro Velho mine, where the country was schist, and where filling closely followed the removal of the rock, probably no trouble of that nature was experienced. Dr. Horwood.

Mr. H. M. Morgans remarked that he understood that the Morro Velho mine was in a mountainous country, and that the ore-body was somewhat as indicated in sectional elevation in *Fig. 12*. The cross sections shown came from *Figs. 2*. From *Fig. 1* it appeared that the ore-belt was about 450 feet wide, measured normal to its long axis in a vertical plane running east and west; the thickness, measured north and south, could be obtained from *Figs. 2*. He Mr. Morgans.

Mr. Morgans. thought the illustrations in the Paper would be improved if more dimensions and scales were given. *Fig. 1* was confusing, as Stage I and Stage II could not co-exist. Was the machinery underground driven by compressed air or by electricity? On p. 193 there was a statement which he found difficult to follow, namely: "At the same time, the width of the lode at these points had lessened considerably, whilst the grade of the ore had also deteriorated. Fortunately, to compensate for this, most of the ore-body lying between the eastern extremity and the centre at this particular level was wider than usual." It was very difficult to describe such a deposit so as to make it clear to the reader. *Figs. 3* showed the new system of mining the ore. When the western side of the

Fig. 12.



ROUGH SECTIONAL ELEVATION OF ORE-BODY, NOT TO SCALE.

ore-body was reached a chamber was made in the foot-wall to take the hauling-engine controlling incline No. 3. *Figs. 3B*, *3C*, etc., showed one of those chambers; but, as the ore was removed in vertical slices of 20 feet, there would be a foot-wall chamber every 20 feet of vertical height, and he thought the diagrams would have been clearer if all the chambers had been shown. *Fig. 5* apparently represented the transition-stage between the old system and the new; he would be glad if the Author would confirm that. What was the nature, thickness, and height of the temporary retention-walls in *Figs. 7* which formed successive sections of the filling as the ore was extracted? He found it difficult to say whether *Figs. 9* were sections on an east-and-west line or on a north-and-south line;

perhaps they might be either, or they might lie in any other vertical plane. *Fig. 10B* showed a roof of ore left over the " permanent way." Was it possible to extract that ore, and would not the road stand as well if it were roofed with steel girders to carry the filling above ? It seemed, also, that the piece of ore left on the nose of the wall in *Fig. 10B* was weak and might break down. If the road had been shifted to the left so that the wall would take a bearing under the country rock instead of under the ore it would have enabled the ore to be extracted and perhaps given a better road. A Paper on Morro Velho, written by one with the honoured name of Chalmers, was of great interest to every mining engineer. The way in which mining had been carried out was admirable, and he did not think the Author would have much difficulty in proving the originality for the methods employed. Mr. Morgans.

Professor HENRY LOUIS said he was afraid he was too old a miner to venture to criticize methods of mining in a district with which he was not thoroughly familiar. He agreed that at first sight there appeared to be quite a number of things that would strike a mining engineer as wrong, but he had no doubt that local conditions would account for that. It had been always the fashion to describe the Morro Velho deposit as a lode ; he knew it well by description, and had always spoken of it as an ore-shoot, which he thought was the more correct term. He gathered that that ore-shoot ranged from 700 to 900 feet long and from less than 1 foot to 15 or 20 feet wide ; it pitched fairly regularly at about 40 degrees, and at the same time dipped at widely varying angles, from a backward dip of about 45 degrees to about horizontal, so that there was a variation in dip of about 140 degrees. A mining engineer working that deposit had to adapt his methods to the conditions in which he found it, and that was one of the drawbacks under which the mining engineer laboured ; he had to take a mineral deposit as Nature had given it to him and make the best of it. In most other branches of engineering the engineer had some control over the nature of his raw material, but the mining engineer had none. The Author had been confronted by the difficulty that having had first a method well suited to steep-lying deposits, he had had to change his method of working when he reached a flat-lying deposit. He agreed with Mr. Marriott that in the steep-lying parts rill stoping would be quite a satisfactory way of working, but it would be impossible in the flat-lying parts. The method the Author was using was one with which Professor Louis was tolerably familiar ; it was described in American books as breast stoping or as horizontal cut-and-fill. There was an example of it in this country in the Weardale Lead Professor Louis.

Professor Louis. Mining Company's mine in Durham, for which he was Consulting Engineer, where a vein was being worked that was nearly vertical and off which there were practically horizontal shoots (known as flats) of lead ore which were also being worked. The vertical portion was being worked by stopes exactly as had been done in the old days at Morro Velho, and the flats were worked by a method of breast stoping very much like the one the Author had adopted for the flat-lying parts of his deposit. It seemed to him to be a logical and correct way of working. Like other speakers, he had been puzzled by the amount of manual labour required, but no doubt that could be perfectly well explained by the local conditions. In American mines where similar methods were used mechanical scrapers had effected an immense saving of time and money. The usual plan there was to make vertical shoots, blast the ore out in huge blocks, draw it into the vertical shoots, and have a "bull-dozing" chamber, in which the big blocks of ore were broken down small enough to be trammed away. He noticed that the Author had given the scraper a thorough trial and had found that it was not as good as hand labour. He had had experience of loading iron ore in the south of Spain, where men with baskets could put the ore on board ship more cheaply than any mechanical appliance could. He had also had the experience of working a mine in West Africa, where he found it economical to stop the rock-breaker and set the natives to break the quartz for the mill with hammers. He was therefore quite prepared to believe that there were conditions under which hand labour was cheaper than mechanical work, and he would be glad if the Author would give some figures on the subject. He did not press for costs; what he wished to know was the number of man-hours, the weight of explosive, and the power-consumption per ton of ore got out of the mine. He thought those figures would serve as a basis of comparison far better than money values, which required a very sound knowledge of all the circumstances of the case before one locality could be compared with another. There were other matters that might be open to criticism, but he had doubts whether it would be fair to criticize them without knowing all the conditions.

Mr. Jenkins. Mr. HENRY C. JENKINS thought that the Author had hardly done justice to himself. If he had given a little more information about the shape of the deposit and the difficulties in connection with it, it would have been easier for others to appreciate the difficulty of the task he had had. The mine was very deep and of peculiar shape, and the labour conditions were very troublesome. The late Mr. Chalmers and the Company had done wonderful work in the circumstances.

Mr. Jenkins. He did not think that it was worth while at the moment to go into the general question of the persistence of ore-deposits in depth, and he did not think those who held one view about it had ever satisfied those who held the other view. The lode had really persisted very well in depth and had been cited frequently to refute some arguments against persistence in depth. No doubt there were good reasons why the ore was handled so often. He had not seen the Morro Velho mine itself, but he had heard a great deal about it, and he understood that its position had caused a great deal of difficulty with regard to shafts. It had been almost unavoidable to handle the ore many times instead of once. In one mine he had seen in Australia a similar difficulty had been imposed on the management simple because of the lease conditions, which were such that the shaft could not be got down to the ore in any other way than in two or three pieces in the first place. In the Morro Velho mine the deposit was very deep, and he understood that it would have been difficult and costly to locate a single shaft to the present depth, even if the deposit were very much larger, large as it really was. How did the Author manage to prevent very flat ore-passes from choking? He thought it must be very difficult to carry out stoping because of the occasional flat intervals.

The Author. The Author, in reply, stated that he had not been empowered to publish the company's official plans, therefore the Figures were merely diagrammatic sketches, with the exception of the vertical sections (*Figs.* 2), which were to scale.

Mr. Bailey had criticized his use of the word "original." He might have been wrong, but the systems worked were original so far as he and his staff were concerned, and he had not seen them employed in other parts of the world, nor had he heard of their having been employed. He purposely had not touched on the subject of the control of ventilation because it was such a large one. It embraced cooling with a big current of air and a complicated system of induction and air-locks. Every minute about 80,000 cubic feet of fresh air was passed through the mine. The temperatures were very high at the bottom, and an endeavour had been made to improve the conditions by lowering the temperature of the ventilation air at the surface by a large cooling-plant; he believed the mine was very good in that respect. The system of cooling was only applicable under the conditions ruling at the Morro Velho mine. His father, before reopening it in 1892, had been careful to tap the old workings from a deep level in the "D" shaft and to draw off the whole of the water collected there. The present mine was exceedingly dry, and were it not that the

The Author. wet-bulb temperatures would be raised, watering of some places would have been resorted to. Fortunately, however, the dust at Morro Velho was comparatively harmless; the particles were not sharp, and miner's phthisis was almost unknown, a condition no doubt due to the big current of fresh air maintained through all the stopes. The average dry-bulb temperature on the surface was about 80°–85° F. during the wet season. The air left the cooling-plant at 42° F. saturated, but because the mine was perfectly dry the wet-bulb temperature did not rise rapidly. At No. 23 horizon level, which was the limiting point in the mine for which the present cooling-plant was designed, the dry-bulb temperature was 103° and the wet-bulb temperature 77° F. At the deepest point in the mine the dry-bulb temperature was 107°, and the wet-bulb just under 80°. Hot though that might seem, anyone coming out of a dead end into that air-current would feel positively cold, owing to the rapid evaporation. Considerable trouble was experienced with pneumonia among the miners, which was ascribed to the fact that men left the hot places at the end of a shift and travelled out against the cold downcast air without wearing their coats, and thus became chilled. That was borne out by the fact that before the cooling-plant began operations pneumonia was only prevalent in the cold season; the trouble could not be ascribed to the dust, which did not vary throughout the year. Fully 15 years ago an effort was made to cool the air at the working-faces by means of ice, but the air became so moist that in the end the miners begged for the discontinuance of the experiment, preferring a dry hot atmosphere to a slightly cooler but much moister one. The ventilation of the stopes could be explained by reference to *Figs. 3*. The air was admitted from some winze, generally 50 to 60 feet from the lode, to the foot of ramp No. 1. It ascended that incline, travelled along the stope from east to west, and descended ramp No. 3, whence it was led to the upcast winze. Air-locks in the lower horizon prevented air from getting up or down the central incline. The circulation was maintained by induced draught. There was a 200-HP. fan on the surface and a tandem fan of 200 HP. about 4,000 feet underground. It had been proved that an air-speed of 100 feet per minute did not suit the mine, and the speed had, with good results, been increased to 300 or 400 feet per minute, and higher where possible.

The reason why the ore was handled so many times was a long story. The mine had a comparatively small lode and would not stand development with large and very deep shafts. After the collapse in 1886 it had been difficult to raise capital to attack the lode at a depth of even 380 fathoms. At one time the company's

funds were so low that orders were received by the Author's father to stop the mainway altogether, with the result that ventilation became very bad and the heat excessive, and a good portion of the labour was lost. In the end capital had to be raised to continue the mainway that existed to-day; but there had been little opportunity for costly experiments or for the sinking of a mainway on a large scale. With the system of shafts and tunnels forming the mainway into depth, transport and movement of men in the Morro Velho mine were complicated and costly; but with that subject the Paper did not deal. The construction of a more rapid and efficient mainway into depth had received a great deal of study, with the object, if possible, of arriving at the best and most efficient means of constructing a mainway suited to the mine's requirements and compatible with the size of the lode and the company's position generally. As regarded the existing mainway, the shafts and tunnels of the system had served their purpose well, and it could be claimed with every justification that this general system had not been mis-used. That the company had been forced into developing its lode and reaching the various stopes throughout the existence of the new mine by means of a series of vertical shafts and horizontal tunnels was another matter altogether, being the outcome of the experiments and trials that had been made with inclined shafts in the early days of the mine. Finally, steady dividends had been paid almost continuously from the reopening of the mine to the present day, including the whole period of the war, in spite of the highly unsatisfactory mining conditions in Brazil; which was surely sufficient proof that the mine generally had been laid out with every consideration of the ruling conditions, and had been handled efficiently. Apart from the form of the present mainways, the necessity for frequent handling of the ore had been brought about by the formation of the lode which, as previously stated, did not allow dumping of mineral anywhere except into shallow ore-pockets. If winzes or raises and ore-shoots were employed they might at times be 200 feet away from the lode and at others they would cut right across the mineral. The Morro Velho country rock might be roughly compared to wood in its formation. When this rock fell from the side of the stope it was often in pieces 10 or 15 feet long and 2 or 3 feet wide, and for such lengths 1 or 2 feet in thickness; and it was the way in which the schist broke that had led him to examine the question with the object of ascertaining how it stood in openings driven in various directions. What might be referred to as the grain of that rock was parallel as in straight-grown wood, and

The Author.

The Author. across the grain it stood very well. The matter of the many handlings had been taken up recently and the difficulty had been partly overcome by the new stoping methods, suitable whether the ore-body was very flat or steep; but it had not been possible to do very much, and only the construction of a new mainway on the lines already arrived at could effect a great difference.

The Morro Velho lode did not lend itself to rill or shrinkage stoping as generally understood; in the former case the filling would not run over considerable lengths, owing to local transverse folds, and in the latter a caving of old stopes would jeopardize the safety of the mainways, though these were 100 feet or more north of the lode. Even with the system of filling employed, old stopes abreast of horizontal tunnels forming sections of the mainway had caused considerable difficulty and expense in the maintenance of those mainways in a satisfactory state. What, then, would have been the situation had they been inadequately filled, or allowed to cave? An underlie shaft had been put down in an attempt to overcome the difficulty of the various steps, but it had been very difficult to keep that shaft open. In one place an experimental concrete pillar, well braced by steel members, had been burst; then it had been entirely encased in steel $\frac{1}{2}$ inch thick, and that had been burst. The underlie shaft when the pitch of the lode was 42 degrees proved a complete failure, and the company was committed to the complicated system of vertical shafts and horizontal tunnels, and had not been able, for reasons of expense, to overcome it. A point had now been reached when there were more than 100 men on the mainways simply for handling cars and looking after traffic, and in addition to that it took the miners $1\frac{1}{2}$ hour to get to the deepest working-faces. The Author's father had in the last 5 years of his life studied every possible scheme for a direct route to the bottom. Deep shafts in tandem could not be put down, on account of the formation of the country. The native town was clustered in a valley at the outcrop, and it was necessary to go over a range of mountains to reach the lode on the other side. It would take far longer by any possible means of transport to get round to the other side of that range and down the main shaft than to descend by the existing means. He had tried to apply rill stoping as described by Mr. Marriott, but he had found it quite impossible. If the Morro Velho lode were a perfectly plain ore-body where the dip was not less than the angle of repose of the filling, it would have been simple to construct winzes or raises through which it would be possible to dump the filling to the stope-level, and the ore from that level to the permanent level beneath; but unfortunately in

the Morro Velho lode a condition was met with which could be best understood by reference to *Fig. 6*. It had been practicable to make ore-pockets such as those shown at B and D (*Fig. 6*), but to make deep ore-passes was not feasible, because the ore-body might have a cross fold of, say, 50 feet within a height of 50 feet above the lower permanent level. It had been questioned whether it was necessary to carry out such expensive filling and whether it would not be better to allow the roof to cave and so save the expense of filling. The cost of filling per ton mined was about 1*s.* 2*d.*, and little difficulty was experienced in obtaining it, except in some years when large quantities were required from the surface during the heavy rains. It helped to balance the ore raised and thus to reduce the power-consumption, which was very important at Morro Velho. Also, not only was there the danger to mainways previously mentioned, but it was found that if a break was allowed to occur on a stope it would run right up the block of mineral and give constant trouble, so the only economical way was to fill as closely as possible to the working-face. The system employed in Morro Velho, and referred to there as the diagonal cut and fill, was, in a sense, a modification of rill stoping methods to suit local requirements, the real difference being that filling was not, and could not be, dumped down raises or winzes on to conical filling tips, but was dumped from upper levels on two tips moving east and west and closely following the ore faces where the lode was locally steep. Again, the height of the filling-tips could not as a rule exceed 25 feet; this figure was the maximum that had so far proved to be workable in the Morro Velho mine, on account of excessive cross folding of the ore-body. Where the inclination of the lode changed locally, a short steep diagonal cut, or rill stope, automatically changed to a longer and flatter stope, and, as stated in the Paper, the system had proved extremely flexible and satisfactory. He was aware that methods conforming in some respects to the stall-and-wall method in Morro Velho were employed in some mines for the removal of ore; a case in point had existed some years ago at Broken Hill where dangerous ground was encountered. However, he was not aware that anything approaching the same method of filling the stopes from which ore had been removed, either in steep or in flatter places, had previously been carried out; in Morro Velho it enabled the removal of all pillars to be effected economically, whilst at the same time the hanging wall was prevented from breaking. The essential point in stoping the Morro Velho lode—that filling had at all times to be kept close to the face—had been appreciated by Dr. Horwood. That,

The Author.

The Author. of course, occurred in an ordinary rill stope on ore-bodies simpler in form, but it was only by the methods employed in Morro Velho that this important object could be attained in that mine. Rock-bursts would become so serious if the filling did not follow the ore-faces continually that the methods described had been adopted. By those methods no single pillar of ore was ever left standing in the Morro Velho mine. The whole of the mineral was removed and the whole of the stopes so formed were filled; in consequence rock-bursts on stopes had not, in comparison with some mines, been serious, though of course they did occur to some extent. It was quite common to hear in a stope a sound resembling a heavy explosion that locally shook everything; at such points the surface of the rock seemed to be disturbed and small splinters flew off, but the filling prevented serious trouble. At one place it was at times only necessary to tap the face with a pinch-bar to cause those sounds; after two or three repetitions the surface of the mineral was loosened and considerable quantities would fall or could be barred down cheaply without the use of explosives. The miners employed on ore-getting in that stope in no way feared such a condition; on the contrary they were always glad when the cut reached the place referred to, as considerable tonnages were more often than not available without the necessity for drilling and blasting.

He understood Mr. Marriott's remark, as to the safety of the system by which the development of a new level was now carried out, to imply doubt whether the arch of mineral left was secure. In the past the Morro Velho lode had been opened by simply constructing a driving in mineral, and possibly undercutting the foot-wall, and then that space had been heavily timbered with very strong wood of a specific gravity of about 1·25. The timbers were 13 inches square, and it had been quite common to find, in a level timbered only a year or so previously, that it was necessary to replace many of those timbers by two timbers, because the original ones had been badly crushed. Steel girders 10 inches deep and 7 feet long had been tried, but they had, in the end, always been badly distorted by the end thrust. Steel had, in fact, proved to be of little use for securing workings for important sections of the main-way. In the days when the lode was much steeper such a method of securing the permanent level as that employed in the deepest stope in the mine would hardly have been practicable, but at the present day, when the transverse inclinations rarely exceeded 17 degrees, that method had so far proved quite satisfactory. In some stopes in the mine the permanent way had been driven in the footwall,

notably in horizon No. 23, but that method had proved exceedingly expensive, while at the same time the all-important objects of obtaining satisfactory working-conditions during development and making preparations for stoping conjointly with development, were not attained. He did not consider that it was necessary to go into the question of costs, as it was possible by a far simpler means to prove that the claim for at least 30 per cent. increase in efficiency was justifiable. In 1925, when it was attempted to mine No. 23 horizon by the old methods, 88 men were employed, and the tonnage per month obtained from that stope was 1,415, or 16 tons per man. When the experiments with the methods that were finally adopted throughout the mine were begun, the same stope with 111 men produced 2,200 tons per month, or 19·9 tons per man. After the system had been generally adopted in that stope, the figures became 103 men and 3,131 tons per month, or 30·39 tons per man, showing an increase of 14·39 tons per man, or 89·9 per cent. When the Paper was written, the records for 1927 were not complete, though an improvement exceeding 30 per cent. was apparent. Records for the whole year, however, showed an improvement of 89·9 per cent. over the year when older methods were in operation, which methods were in fact practically unworkable. It would therefore be seen that the claim for 30 per cent. increase in efficiency as regarded that stope was a moderate one. However, in the upper stopes the increase could not be so great, because when the lode was generally steeper and pressures were less, the older methods were satisfactory, and even to-day they had not, in one important stope, been abandoned. Since the change of system the No. 24 horizon had been laid open and was producing a large tonnage. Further, there was convincing evidence at that level that the older methods could not have been employed. The Author.

The width of the ore-body—the measurement between the hanging and the foot-walls—ranged from 18 inches to 15 feet; generally its average width was 7 to 8 feet. The strike was 750 to 1,000 feet in length and approximately east and west. He could give no reason whatever why the value of the lode had continued to the present depth; in fact the lode had frequently been referred to as a freak. Dr. O. A. Derby, for many years head of the Geological Survey of the State of S. Paulo and an authority on the mine, when consulted by the Author's father 30 years ago on the possibility of the continuance of the yield of gold with increasing depth, had replied that radical changes were unlikely as long as the lode remained in the schist, at any rate, to a depth then considered workable. The

The Author. question of the dip of the lode was difficult to answer; in the past the average dip was about 70 degrees to the north, but the pitch had flattened to 15 to 17 degrees, and the cross folding of the lode caused different sections of it to dip in different directions; thus in No. 23 horizon the eastern portion dipped to the south, and the western to the north.

The assumptions by Dr. Horwood regarding the number of times ore was handled from the lower levels to the surface, and that the strike of the lode was parallel to the strike of the schist, were correct. It was not, however, a case of excavations in the lode not standing, it was rather the removal of the mineral in such a manner as to expose large areas of the weak hanging wall which produced dangerous conditions and uneconomical mining. The assay values given in the annual reports were the assay values of the ore mined during the year. Dr. Horwood had admirably expressed the policy covering the construction of the mainway at Morro Velho, by his clear comparison between two totally different mines, namely, the Village Deep and Morro Velho. The former had certainly justified the enormous expenditure entailed in the construction of exceedingly deep shafts and the laying out of the mine for outputs on a great scale, but the latter had not. Long before the mine had reached a depth of 4,000 feet, the question of continuing the mainway by other and presumably more economical means had been thoroughly gone into. Owing to the mountainous nature of the country, only inclined shafts, if feasible, would at that time have provided an improvement over a repetition of vertical shafts and horizontal tunnels, but the trial inclined shaft became so troublesome, owing to the treacherous country rock, that the idea was abandoned. At that time it became necessary to develop considerably more power, and, owing to the difficulties of transport and the wild rugged country, entirely devoid of roads, the cost of developing power was very great; £100 per horse-power-year was not an excessive figure for power developed on the river owned by the company from its source to below the power-stations. The policy of the company had always been to do as much as possible out of revenue, whilst paying a reasonable dividend. The soundness of that policy was proved by the fact that at the present time the total share issue amounted to £646,265 out of an authorized capital of £800,000; whilst the company possessed vast iron properties, power-stations, a thoroughly well-equipped mine with at least 6 years reserve of mineral, and cash investments amounting to £200,000. Had it not been for this policy, large dividends might have been paid, but the

company's position would not have been as happy a one as it was. The Author.
It was estimated that by the construction of the direct-route scheme previously mentioned, if the size and value of the lode did not change, it should be economical to work the mine for another 25 to 30 years. That would necessitate the installation of a second large cooling- or air-drying plant underground; probably at about the No. 23 horizon level. If the present pitch of the lode continued, probably mining could be continued to a depth of 2,000 feet below horizon No. 24, or a total of about 8,900 feet, but that figure was of course purely hypothetical. There was no knowing what new process of air-conditioning might be invented in the next few years now that mining generally demanded something of that nature, and the matter was being given careful study.

Mr. Morgans's assumptions with regard to the lode were correct, and his diagram explained the case admirably. He agreed with Mr. Morgans that *Fig. 1* might have been clearer if the two stages of stoping had been shown separately. He also agreed that *Figs. 3* might have been improved by showing the previous pockets for the accommodation of the western incline hoist at levels where previous slices of mineral had been removed. *Fig. 5* did represent the transitional stage between the old and new methods, when inclined working-ways had replaced vertical winzes, but when the manner of stoping was the original one. The temporary retention-walls shown on *Figs. 7* were quite lightly and rapidly constructed, and were about 18 inches in thickness over an average height of 5 to 6 feet. It was an almost invariable rule that where the mineral lay very flat it was narrow; quite often the width was reduced to 3 feet, which would then represent the approximate height of the filling-retaining walls, and in such cases the thickness of the walls was reduced. *Figs. 9* were intended to represent sections in any direction the lode might be following.

A great deal of winding had been done by compressed air, but that had been replaced to some extent by electric winding. All the rock-drills were worked by compressed air. There had been few places where the use of scrapers could even be thought of, owing to ruling conditions, and, the experiments that had been made having shown unsatisfactory results, the only tests now being made were with scraper loaders for use in tunnel-driving. It had been ascertained that: (1) the delays that occurred in fixing up scrapers for clearing a face continually moving forward did not warrant their use; (2) the scraper was responsible for the inclusion of a great deal of small broken country rock with the ore,

The Author. thus lowering the grade; (3) it necessitated constant repair and the frequent attention of mechanics; and (4) the saving in ordinary labour, having regard to the small tonnages that could be handled at any one place by scrapers, was negligible; whilst additional mechanics had to be employed. Thus the device was not economically applicable for the loading of ore in the mine. Ore-passes could only be used, if at all, over very short lengths. Generally, ore-pockets at the base of the ramps were the only possible means of transferring ore economically from the stope-levels to cars in the permanent level. If the construction of long ore-passes in mineral were attempted, sections would occur where ore would not flow. It was even difficult to keep the working inclines, or ramps, in close contact with the mineral, although they followed the direction of the lode parallel to the pitch. It was often necessary to cut away the country rock on one side and packwall the other to keep those places straight enough for the raising and lowering of cars. It had been found that 300 feet was about the limit of length to which those ramps could be efficiently worked. When they became too long the stope-level was reformed. That operation was carried out when necessary by employing a central wall or timber sets where convenient for short distances, in much the same manner as a new stope was formed.

For 1927, 392 lbs. of dynamite and 441 primers were used daily for the total requirements of the mine, including development.

The men employed on the stopes getting the ore, tramming it to the ore-pockets, tipping, and placing filling, worked 2,084 man-hours daily. The actual number of men-hours for the mine was more than double this figure; but that was due to the nature of the mine, which necessitated the employment of a large number of men under the headings of development, transport, winding, construction and maintenance of airways and emergency escape for miners, as well as general labourers, making a total of 3,172 man-hours. The breaking-in of new men gradually, particularly those who had come from cooler climates, had been adopted. Such new hands were taken into old stopes which had been practically worked out, and which were of course at higher levels in the mine; as they became acclimatized they were moved to the deeper parts. The power employed was 3,460 HP. It was estimated that the proposed direct route would dispense with 200 men, which, apart from cost, was all-important in a country where mine labour was scarce.

There would be no difficulty in removing the roof of the ore left for the permanent way during the formation of new stopes. That

matter had received careful consideration before the introduction of the methods described. The Author.

In conclusion, he wished to express his thanks to those who had taken part in the discussion of his Paper and had added to its value by suggestions and comparisons.

Note on the Operations of the St. John del Rey Mining Company, Ltd.[1]

The company commenced operations in Brazil in 1830 near the old city of St. João del Rey, in the State of Minas Geraes. Its operations were not successful, and in 1834 it acquired the Morro Velho mine, situated about 80 miles from the old capital of the State of Minas Geraes, for £56,434 12*s*. The ore was difficult to treat, and its analysis did not vary greatly, as the following table illustrates :—

	1899–1900	1910–1911	1917–1918
	Per Cent.	Per Cent.	Per Cent.
Gold	0·00196	0·00218	0·00192
Silver	0·00052	0·00059	0·00051
Silica	24·10	19·63	22·56
Iron	31·47	31·10	22·63
Arsenic	2·32	2·65	2·98
Sulphur	13·52	15·48	13·34
Alumina	3·00	3·26	2·13
Manganese Oxide	1·30	1·11	1·30
Lime	3·08	4·43	2·13
Magnesia	6·51	4·50	6·29
Copper	0·21	0·21	0·12
Carbonic Acid and Oxygen	14·49	17·63	19·59

Although changes have occurred in length and width of the ore-body, on the whole it maintained a remarkable regularity in size and gold-content until horizon No. 23 was reached. Fluctuations in returns were accounted for to no small extent by the unfavourable mining

[1] Abstracted from a Note accompanying the Author's reply to the Discussion. —Sec. Inst. C.E.

The Author. conditions in Brazil, where an almost constant labour-shortage was one of the most serious difficulties. During the first 5 years of the company's operations practically no profits were made.

The mine was, in its early days, worked down from the surface in one huge excavation, the walls of which were supported by massive timberwork and pillars. In 1867 it was destroyed by fire, and 6 years later the lode was again laid open at great expenditure by the sinking of shafts A and B (Figs. 11, Plate 2). Unfortunately, however, the same system of working was adopted, with the result that, as the pressure increased with the size of the excavation, the timberwork began to crush, causing frequent hindrance to mining operations. The returns in consequence fell; in 1883-84 a loss was incurred, and in 1886 the mine collapsed. The Author's father, then Superintendent, explored the surrounding country in the hope of finding other productive lodes, but no discovery of importance was made. Finally he brought forward a scheme for re-opening the mine from the surface. This employed two vertical shafts, C and D (Figs. 11), each 382 fathoms deep, placed at a safe distance to the north of the lode instead of leading into it, as in the previous re-opening, and arranged for working the mine on an entirely new system. All the mainways into depth were, and are to-day, to the north of the lode, entirely outside of it. The lode was attacked at several different levels at once, and, as the mineral was removed, the space so formed was filled with earth lowered from the surface and, when convenient, with debris from the driving of development tunnels and the sinking of shafts, etc.

The difficulties contended with in this, the last, re-opening were very great, owing not only to the then exceptional depth, but also to water that had accumulated up to the surface in the old excavation above the new shafts and workings. However, the shafts were sunk without trouble at the average rate of 78 feet per month; the water was partly drawn off from the old excavation by large bailers working in the A and B shafts, and was finally drained by a borehole and suitable hydraulic connections at the lowest point of the excavation, where the pressure encountered was 649 lbs. per square inch when the borehole entered the excavation. The water from this borehole was led to pumps worked by a hydraulic engine situated at adit level and working under a head of 492 feet.

The lower section of the mainway and downcast was in the form of underlie, or inclined, shafts, following approximately the pitch of the lode. This method of providing the mainway failed in the upper sections of the mine when the pitch of the lode was steep, owing to the treacherous nature of the country rock, and it finally proved far more economical and safe to proceed with vertical shafts and horizontal tunnels.

The temperature of the rock increased at the rate of about 1° F. every 140 vertical feet and was 127·3° F. at the moment of opening the last and deepest level. Fortunately, however, it fell rapidly after thorough ventilation was arranged.

The cooling and drying of the ventilation air was effected by passing it through a number of large revolving steel drums, partly submerged

in water; these drums are formed with annular spaces which offer an extremely large surface to be wetted by the chilled water; the air passing through them is cooled and gives up a considerable part of its moisture. The cooled and partly dried air passes to the bottom of the workings, thence through the stopes, thus providing more satisfactory atmospheric conditions everywhere underground. The air-current after leaving the stopes passes into the upcast shaft and to the surface. The heated water from the revolving air-coolers is returned by pumps to large receivers in which are the evaporator-coils of a large ammonia refrigerating-plant. The Author.

The power at the time of the re-opening was entirely hydraulic, but nowadays it is hydro-electric and is transmitted from the company's own plants on the Rio de Peixe, 20 miles from the mine. Within the mine itself electricity and compressed air are exclusively used. For local power and dressing-water, 28 miles of watercourse brings the mountain streams to suitable heads at the mine.

The total capacity of the air-compressing plant is about 10,000 cubic feet of free air per minute. Compressed air is supplied to the mine at 60 lbs. per square inch. In the past most of the rock-drills and stopers used were made at Morro Velho.

The mineral received from the mine is landed at the adit, and hauled to the mill in mine-cars by chain haulage working on a gradient of 10 degrees. The ore passes over a weighbridge and thence through a breaker to a picking-table where poor stone is thrown out. Rejection now amounts to only 2½ per cent.; formerly it was as high as 20 per cent. The picked ore, after passing through second-stage stone-breakers, is delivered by elevators and a special ore-distributing arrangement into stamp-bins. The stamping-power consists of a 120-head battery of 750 lbs. average weight per head, and a 20-head battery of 1,250 lbs. weight per head. The mineral is crushed in water to pass 60-mesh sieves (3,600 holes per square inch). From the stamps the crushed mineral, or sand, passes over the concentration-strakes. These strakes carry long strips of coarse canvas, having a total area of 17,126 square feet, on which the heaviest particles of the sand and free gold are caught. The whole area is automatically washed to remove the heavy sand and gold, the gold-bearing concentrates undergoing further reconcentration when the small quantity of sand remaining is removed.

About 70 per cent. of the total gold-content is extracted by this method. The sand separated is reground in tube-mills and treated with cyanide of sodium in the usual manner. By this second process about 21 or 22 per cent. of the gold is extracted. The remaining 8 or 9 per cent., which passes away in the tailings, has not yet paid for recovery. The quantity of bullion in a ton of mineral varies from year to year, but an average for the last 2 years is 5·952 oitavas of gold and 1·160 oitava of silver.[1]

At present the company employees 3,300 workpeople, and the population of the native town, which amounts to 13,500, is dependent on the mine.

[1] An oitava = 3·586 grams, or 55·340 grains; 8·6735 oitavas = 1 ounce troy.

The Author. Recently the State Government lowered the export tax on gold mined by the company, but almost at the same time the Federal Government imposed custom-house dues from which the mining industry generally had for many years been exempt. Thus, in one way or another, the company pays in Brazil in taxes at the present time £16,500 per annum.

The totals of the results of the Company's operations from 1835 to 1927 are:—

Tons raised	5,216,006
Tons crushed	4,972,530
Produce	£12,071,226
Dividends and tax paid	£1,564,522
State tax, railway freight, etc., on gold and silver from 1886 to 31st December, 1927	£480,161