The Effect of Underground Work on the Erythrocyte Count of Europeans Working on the Rand Gold Mines

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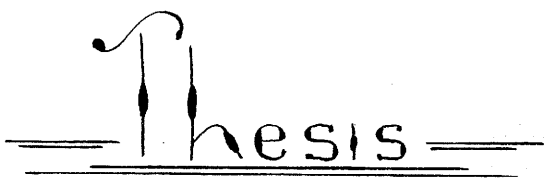

Thesis

The Effect of Underground Work on the Erythrocyte Count of Europeans Working on the Rand Gold Mines.

Introduction & History.

Altitude is a climatic factor under which a rarer atmosphere obtains, as regards the oxygen percentage, than that at sea-level.
A characteristic effect of low atmospheric pressure is the malady known as "mountain sickness".
It was shown by Paul Bert in I878, that the physiological effects produced by low atmospheric pressure are simply the result of the diminished partial pressure of oxygen, & the consequent imperfect aeration of the arterial blood.

A new arrival at an altitude of I2,000 feet or more is liable to an attack of "mountain sickness". Strauch (30) calls attention to the fact that "mountain sickness" befalls some individuals at a lower altitude, some at a higher altitude, but for all there is a critical line beyond which escape is impossible. In some it may occur at I0,000 feet while only a few can venture to I9,000 feet without the experience.
The subject may feel exhilarated at first, but later his lips become blue, he is unusually sensitive to cold, feels light-headed & may have a headache; later the appetite fails & there is likely to be nausea & vomiting. There is always depression, more or less muscular weakness, & sometimes complete prostration.
This condition may last a day or two, when the attack passes over.

Barcroft (I) states that there are 2 classes of anoxaemia, i. Acute, ii. Chronic. In the chronic type there is an oxygen want, perhaps not very great, but the condition may be continued over months. He classifies the chronic types of anoxaemia as the anoxic, anaemic & stagnant.

In the first the pressure of oxygen in the blood is too low & the haemoglobin is not saturated to the normal extent; in the second, the quantity of haemoglobin in the body is too small, but the oxygen-pressure is normal; in the third the blood is normal, but supplied to the tissues in insufficient quantities. It is the anoxic type that occurs at high altitudes & this, according to Barcroft is the most difficult for the organism to circumvent, since the rate of delivery of oxygen to the tissues depends upon the pressure of the oxygen in the blood.

A marked adaptation to this anoxaemia occurs in subjects living at high altitudes.
The acclimatisation to altitude appears to consist chiefly in the following changes.

I. The respiration is accelerated in proportion to the altitude, so that the difference between the atmospheric & alveolar oxygen-tensions is diminished. (2)(3).

The acceleration, although initiated by a fall in alveolar oxygen tension, appears to reach its full development & continuous character chiefly as a consequence of plasma bicarbonate diminution, which gradually reaches an extent that would occasion similar hyperventilation at sea-level.
This excess ventilation washes out carbon dioxide from

the blood, with the result that an alkalaemia occurs which must be compensated for. This is done by the kidney, which excretes a less acid urine & less ammonium. The urine may even become alkaline. In this way the kidney eliminates excess of base, keeps the blood reaction fairly constant, & thus permits oxygen lack to continue to stimulate the respiratory centre.(4)

Haldane(5) has formulated a theory that a deficiency of oxygen in the air breathed, as at high altitudes, may stimulate the pulmonary epithelium, after a time, to secrete oxygen actively from the lungs into the blood, so that the arterial blood may leave the lungs with a higher oxygen tension than that found in the alveolar air. He maintains (6) that this function is improved by exercise. This theory has not been confirmed. In Barcroft's "glass case experiment" (7), he lived for 6 days in a glass respiration chamber in which the oxygen pressure was gradually lowered. During this time the haemoglobin value of his blood rose from 95 to 105. His alveolar oxygen tension was 48 mms of mercury, but the arterial blood was dark in colour, that is, no evidence of oxygen secretion was obtained.

2. There is an increase in the number of erythrocytes per cmm, & in the haemoglobin content of the blood.

3. These 2 factors however do not appear sufficient to explain the difference between the recent arrival & the hardened mountaineer. The central nervous system of the latter functions more normally than that of the novice at the reduced oxygen tension, & the muscles of the mountaineer can accomplish more work. There are unknown tissue factors in the acclimatisation.

Possibly an increase in the muscle haemoglobin, such as Whipple (8) has observed in highly active, compared with sedentary, dogs, may play a part in the adaptation of the muscles.

As early as I878 Paul Bert predicted that the blood of man & animals living at high altitudes would show a greater oxygen capacity than that of individuals at sea-level. A little later in I890, Viault reported an increase in the number of erythrocytes of individuals living in Peru, at an altitude of I4,400 feet; while Muntz found that the blood of animals living at an altitude of 9,400 feet in the Pyrenees, contained a larger percentage of iron than that of those at low levels.

In the present century many workers have collected data which give the same indications. Acton & Harvey (9) observed the erythrocyte counts of 75 healthy adult Indian males, at Kasauli in the sub-Himalayan range, & found that " the mean was higher than that usually given for an erythrocyte count in a healthy individual at sea-level, viz., 5.6 million as against 5.0 million ".

The Anglo-American Pike's Peak expedition in I9II (2) proved beyond any reasonable doubt that the total quantity of haemoglobin in the body & the total number of erythrocytes which the blood as a whole contains are increased by residence at high altitudes.

Major Hingston (I0) obtained similar data on natives living on the Pamir plateau, as well as on members of his own party who had become acclimatised during their journey. In the Pamir valley at an altitude of I3,500 feet after acclimatisation a series of counts made on 3 types of people who had

ascended with the party were observed, viz., Englishmen, & the 2 native tribes living on the slopes, the Kashmiris & Gurkhas.
The results are shown in table I.

Table I.

Race.	Counts in millions.
English.	7.402
Kashmiri.	7.70
Gurkha.	7.I4

After living at higher altitudes on the mountains of Pamir, even for 2 days, there was a considerable increase over the above counts.

Originally there was some discussion as to whether the increase in haemoglobin content & erythrocyte count was proportional.
Schneider (II) states that it is to be expected that as more exact methods of determining the haemoglobin come into use, it will be shown that the"colour index" is not changed with altitude. That is the 2 changes run parallel. The data obtained by the Pike's Peak expedition (2) confirm this view..

It has been claimed that this increase is apparent but not real. The corpuscles only appear to have increased owing to some change in distribution of the elements of the blood. Or it has been thought that the blood becomes more concentrated owing to the greater excretion of water at these heights.

These views have not gained wide acceptance.
They are not easy to reconcile with the appearance of an increased erythrocyte count only after staying for some time at a higher altitude.
Moreover if the change were merely a relative one it is not likely that it would be permanently established, in those who live their whole life at a high altitude.
Again it was definitely shown by the Pike's Peak expedition (2) that the increased percentage of haemoglobin was apparently due in part, during the first few days, to concentration of the blood; but afterwards entirely to a large increase in the total amount of haemoglobin (determined by the carbon monoxide method.)
They also observed a slight <u>increase</u> in the blood volume.

Barcroft (3) showed by the method of staining with cresyl blue, which shows up the young reticulated cells, that there was definite evidence of increased formation of red cells at high altitudes.

It has been almost universally accepted that the increase in number of erythrocytes is the direct result of the fall in barometric pressure.
In 1921 however, Kestner put forward a theory stating that the effect of high altitude on the erythrocyte count is not due to reduced oxygen pressure, but to increased solar radiation, acting through breathing nitrous oxide set free by the sun's rays on the atmosphere of higher altitudes, which, getting into the blood stimulates the blood forming organs.

That a low oxygen pressure in the atmosphere does lead to an increase in haemoglobin was definitely shown in Barcroft's " glass case experiment " mentioned above.

Schneider (II) states that the usual response during residence at high altitudes consists of a rapid increase in the number of erythrocytes & percentage of haemoglobin during the first 2 - 4 days followed by a more gradual increase that requires several weeks or even months to establish equilibrium.

Richards (I2) at the suggestion of Haldane carried out a series of observations on himself, at I5,000 feet in Bolivia. In 5 days his haemoglobin increased from an average of IOI % to I29% on the Gower-Haldane scale; & then rose gradually for $2\frac{1}{2}$ months to I46%.

Barcroft (I3) describes another factor to be considered in connection with the high oxygen capacity of blood of individuals living at a high altitude, in addition to the mere concentration of red cells. It is not due to the increased alkalinity of the plasma as first suggested, since Hasselbach & Lindhard have shown that the pH of blood remains the same at low & at high altitudes. Barcroft gives the following explanation:

At high altitudes the alveolar carbon dioxide pressure is less, hence the carbon dioxide in the plasmabecomes less, thus lowering the concentration of hydrogen ions in the plasma. Chlorine ions diffuse from the corpuscles, bringing the pH of the plasma back to normal, but making the reaction in the interior of the corpuscles more alkaline, & hence having a greater capacity for combination with oxygen.

As each tissue has on the average 3 times as much oxygen carried to it as it requires, the reason for the increase in the quantity of haemoglobin at high altitudes may not be obvious. According to Barcroft (3) it is not the deficiency of the actual quantity of oxygen in the blood which causes the symptoms in the mountains, but a deficiency of the pressure at which the oxygen is transported. The result of the increased haemoglobin is an increase in the average oxygen pressure in the capillaries.

On returning from a high altitude to a low one, there is a decrease in the erythrocyte count. This was observed by the Pike's Peak expedition (2) & Hingston (IO) gives the following set of figures obtained on his return to sea-level from the Pamir plateau.

Table II.

Date.	Altitude.	Count in Millions.
August IO.	I3,000 Ft.	7.402
August 20.	9,450 ".	7.36
August 23.	8,500 ".	6.96
August 28.	8,000 ".	6.I2
September 6	4,390 ".	5.68
September 20	500 ".	5.82

Thus the erythrocyte count shows an increase at high altitudes, & decreases as the altitude approaches sea-level.

The Rand is at an approximate altitude of 6,000 feet above sea-level & the normal erythrocyte count shows an increase over the sea-level value. On the Rand gold mines the men work at levels varying from the surface to sea-level or lower. That is, for a portion of their lives they live at an altitude below the surface level.

The speed of the change of altitudes from the surface to the respective levels, & vice versa is very rapid. The men are conveyed in skips which travel at an approximate speed of 2,000 feet per minute so that the lowest depths can be reached within I5 minutes, allowing for stoppages at intermediate levels.

The object of the present research is to observe whether working at these lower levels for a fraction of their lives, causes any decrease of the erythrocyte count of miners, as compared with the normal count for the altitude of the surface.

The normal count for the Rand is given as approximately 6.0 million erythrocytes per cmm. This is the standard used by the South African Institute for Medical Research, Johannesburg. Fitzgerald (I4) states that there is a I0% increase in the amount of haemoglobin for every I00 mms fall in barometric pressure. The barometric pressure at this altitude averages 24.35 inches (6I8.49mms) (26). Therefore assuming that the number of erythrocytes increase in proportion to the haemoglobin (II) & taking the erythrocyte count at sea-level to be about 5.2 million per cmm, the count for this altitude according to this reckoning would be 5.9 million erythrocytes per cmm.

At Colorado Springs (altitude 6000 feet) the number is stated to vary between 5.5 & 6.3 millions (3I). Starling (I5) on the other hand gives an average erythrocyte count on subjects living at Arosa, which is at an altitude of I8,00 metres (about 5,900 feet) as 7.0 million.

The sea-level value is somewhat over 5.0 million per cmm according to recent authorities. Foster & Johnston (I6) obtained a mean of 5.2635 million on examination of I00 subjects.
Osgood,quoted by Anderson in the report of the Haffkine Institute, (I7) gave an average of 5.4 million based on examination of I37 healthy young American males.

Experimental.

The subjects from whom the samples of blood were collected were men working on the Rand gold mines. Their usual period of work is 8 hours per day, that is they spend approximately one third of their lives at a given depth. The men selected had worked not less than 2 months at the particular level, thus allowing for any adjustment of the erythrocyte count which might take place at that depth.
They were all of European extraction, of robust constitution & in fit condition. They were selected as they presented themselves for the half yearly medical examination which the miners undergo to qualify for a further term of work underground.
Only those passed as medically fit & in good health were investigated. A strict lookout was kept for

men suffering from hookworm. Any showing signs of this infection, or with a history of the infection, were rigidly excluded.

The samples of blood were collected at about the same time each day, viz., between 9a.m. & I0 a.m. The work extended over a period of about I2 months, from May I93I to May I932.

The men from whom the blood was taken had been on the surface for different periods of time before the samples were collected. In the largest number of cases, about 70%, the time which had elapsed between their last period underground & the collection of the sample was I8 hours.

In order to ascertain whether these different periods which elapsed before the collection of the blood, had any appreciable effect on the means for the various levels, the following procedure was carried out:

For each level the counts were grouped according to the number of hours which the men had been on the surface before the samples were collected. The means for each group were then computed, & are shown in table III.

Table III.

Level 0 - 2000 Feet		
Period SinceLast Shift in Hours.	Number of Observations.	Mean Count in Millions.
4	8	6.II
II	7	5.66
I8	84	5.80
48	I4	5.84
60	5	5.43
Level 2000-4000 Feet.		
4	I5	5.7I
II	I3	5.84
I8	75	5.7I
48	I5	5.9I
Level 4000-6000 Feet		
4	I0	5.45
II	9	5.77
I8	86	5.62
24	5	5.73
48	8	5.45
Level Below 6000 Feet		
4	8	5.83
I8	28	5.54

From this it would appear that the different periods of residence on the surface before collection of the samples do not affect the ultimate means appreciably.

The procedure in the collection of samples of blood was as follows:

A fairly deep puncture was made in the pulp of the middle finger, so that the blood flowed freely with very light pressure(This was to avoid squeezing which tends to force out serum, thus diluting the blood) The first drop of blood was wiped away with cotton-wool. (As this drop tends to be more dilute than that which follows) The method of dilution of the blood was one described by F.H.Joseph (I8).
It has been used by the routine laboratories of the South African Institute for Medical Research, Johannesburg for many years, with highly satisfactory results.
The method was as follows:

Fine bore glass capillary tubes were made & calibrated by means of mercury to a capacity of .02cc . one of these tubes was filled from a drop of the blood which entered the tube by capillary attraction.
The end of the capillary which had been in contact with the drop of blood was carefully wiped with cotton-wool, & the tube thus completely filled was dropped into a small corked test tube containing I.98 cc of Hayem's diluting fluid. The tube was then inverted repeatedly for some time to ensure thorough washing out of the blood from the capillary tube. The blood was thus diluted I in I00. A small volume of the diluted blood was then mixed with an equal volume of Hayem's diluting fluid giving a dilution of I in 200 which was a more convenient dilution for enumeration.

The type of Thoma-Zeiss haemocytometer with grooves straight across the middle of the slide, was used, instead of the type with the circular groove. My experience is that the former type is easier to use, as the counting chamber is much easier to fill, & the chances of the blood overflowing into the grooves are much less, than with the latter.

After thorough mixture sufficient of the diluted blood (Iin 200) was run under the coverslip to fill the compartment in the centre of the slide completely, but not to overflow into the grooves on each side. Strict attention was paid to the rule that bubbles should be absent from the preparation. The slide was allowed to stand for 2 to 3 minutes before counting, to allow the erythrocytes to settle. Eighty squares of the Thoma-Zeiss slide were counted, which means that some 450 to 600 erythrocytes were counted in each individual case.

There was no marked anisocytosis & poikilocytosis was not observed in any of the samples used. These facts are significant as indicating the absence of an anaemic condition in the subjects (I9) (20).

To test the degree of error of the observations, a series of counts were done in pairs, taking one sample from the subject's right hand & the other from his left hand. These results are shown in table IV. The differences are so small as to be negligible. Hence the error of collection was small.

Table IV.

Showing Counts on Samples Collected Simultaneously From the Subjects Right & Left Hands.

	Counts in Millions.	
No.	Rt Hand	Lt Hand.
I	5.78	5.74
2	5.96	5.92
3	3.63	3.67
4	4.I7	4.24
5	5.62	5.70
6	6.05	6.06

Note: Cases 3 & 4 are pathological.

Table V. gives the results of a count of 80 squares of a Thoma-Zeiss haemocytometer. The blood was diluted 200 times. It includes calculated values obtained by Poisson's formula which is a theoretical expression by, which the probable distribution of the erythrocytes per unit volume may be calculated. If this be compared with the observed values, it should serve as a valuable test of observational & technical accuracy.
The computation is expressed in the formula:

$$e^{-m}\left\{1+m+\frac{m^{2}}{2!}+\ldots\ldots\frac{m^{r}}{r!}+\ldots\ldots\right\}$$

(m = mean of frequency distribution.)

Table V.

0	I	2	3	4	5	6	7	Erythrocytes per Square.
0	0	2	4	6	I5	I3	I9	No. of Squares, Observed.
.08	.74	2.08	4.92	8.74	I2.4I	I4.69	I4.90	No. of Squares, Calculated
8	9	I0	II	I2	I3	I4		Erythrocytes per Square.
II	I4	7	7	I	0	I		No. of Squares, Observed.
I3.5	I0.54	7.4I	4.78	2.83	I.55	.78		No. of Squares, Calculated

From this table it seems evident that the observed & calculated figures do not differ greatly. χ^2 & P were determined to test the goodness of fit of theory to observation (22).

The following values were obtained:

$$\chi^2 = 8.26$$

$$P = .69$$

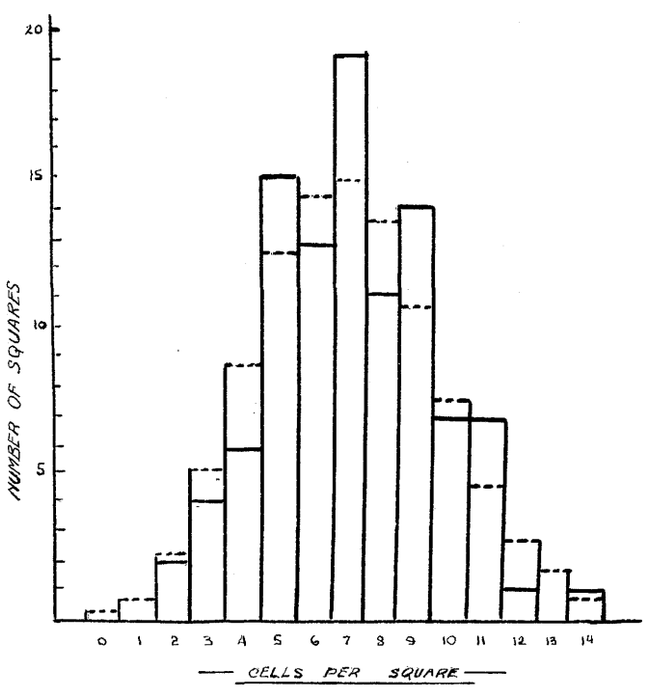
Hence the 2 distributions cannot be considered significantly different. The 2 distributions are shown graphically in figure I.

From the foregoing it may be assumed that the obtained results conform more or less to theoretical requirements.

Figure I.

Continuous Line-Actual Observations

Broken Line - Calculated Values.



To compare the above mentioned method of collection & dilution of blood with the more usual method, a comparative series of counts was done.
Specimens were collected in the Thoma-Zeiss diluting pipette, a second sample being taken & diluted as described.
The results are shown in table VI.

Table VI.

Showing the Counts in Millions on Duplicate Samples of Blood, Collected by the Thoma-Zeiss Method & the Capillary Method.

Thoma-Zeiss	Capillary	Difference.
6.52	6.54	+.02
5.77	5.74	-.03
5.67	5.78	+.II
5.75	5.66	-.09
5.86	5.78	-.08
6.09	6.I0	+.0I
6.I3	6.I5	+.02
5.8I	5.80	-.0I
5.9I	5.92	+.0I
4.92	4.90	-.02
5.93	5.96	+.03
5.89	5.92	+.03
5.7I	5.72	+.0I
5.76	5.73	-.03
4.90	4.88	-.02
5.83	5.74	-.09
6.42	6.33	-.09
6.39	6.28	-.II
6.28	6.34	+.06
5.82	5.88	+.06
6.35	6.40	+.05
6.05	5.99	-.06
6.56	6.53	-.03
6.59	6.59	.00

Standard Deviation of Differences .058

Standard Error of Differences ±.0II8

Total Positive Difference .4I

Total Negative Difference .66

Mean Difference $\frac{dI - d2}{N}$

$= -.0I04$

That is, the capillary method tends to give slightly lower results than the Thoma-Zeiss method, but the difference is not significant when compared with the standard error. For a difference to be significant it must be at least twice as great as its standard error(2I).

A series of counts was then done on the same sample of diluted blood. These results are shown in table VII & it will will be observed that the standard error & standard deviation of the variations are of the same order of magnitude as those of the differences in the preceding table. Thus one is justified in assuming that the capillary method of dilution is as accurate as the Thoma-Zeiss method.

Table VII.

Showing the Erythrocytes in Millions Obtained in IO Counts from the same Sample of Diluted Blood.

Counts	δ	δ^2
6.I2	.093	.008649
6.04	.0I3	.000I69
5.99	.037	.00I369
5.94	.087	.007569
6.06	.033	.00I089
5.93	.097	.009409
6.II	.083	.006889
6.06	.033	.00I089
6.0I	.0I7	.000289
5.9I	.II7	.0I3689

Mean 6.027

Standard Error ±.022

Standard Deviation .07I

In order that the observer should not be biased when counting samples of blood from men working at lower levels, the following procedure was adopted: After collection of the blood each tube was marked with an identification mark. A piece of paper was fixed around the tube so as to obscure this mark. After each sample was counted, the paper was removed & the identification of the sample recorded.

To obtain a control value, a series of II8 counts was done on men working on the surface.

A total of 508 counts was done altogether, representing samples from men at the surface & those working underground at varying depths down to sea-level or lower. The depths were arranged in steps of 2000 feet. The same number of observations was made in each division excepting that at the level below 6000 feet, at which depth it was not possible to obtain the requisite number of subjects.
The means for each group together with their standard errors were computed & are shown in table VIII.

Table VIII.

Mean Erythrocyte Counts in Millions for Various Depths.

Depth in Feet	Mean	S.E.	Range Max.	Range Min.	Number of Observations
Surface	6.04I	±.049	7.62	4.69	II8
0 - 2000	5.82	±.047	7.35	4.49	II8
2000 - 4000	5.72	±.052	7.32	4.57	II8
4000 - 6000	5.6I	±.044	6.63	4.06	II8
Below 6000	5.66	±.086	6.94	4.89	36
					508

The relationship of the above means is shown graphically in figure II.

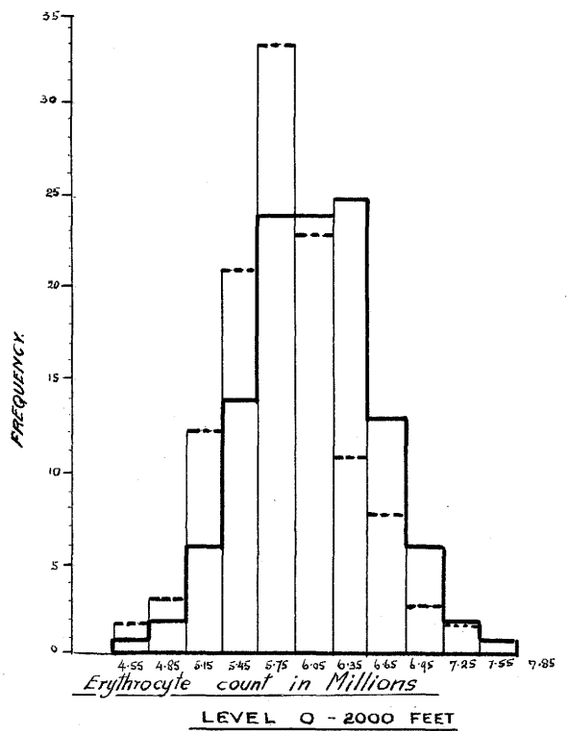
Figure II.

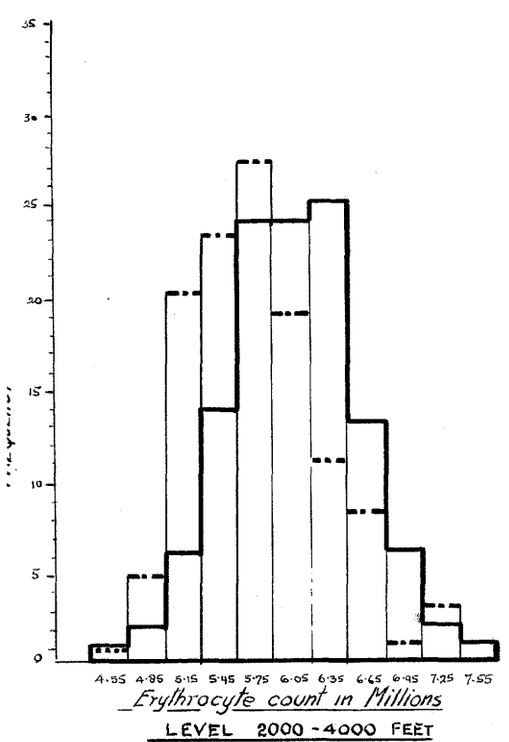
Chart Showing Class Frequencies of the Erythrocyte Counts for the Various Levels compared with" Surface " Values.

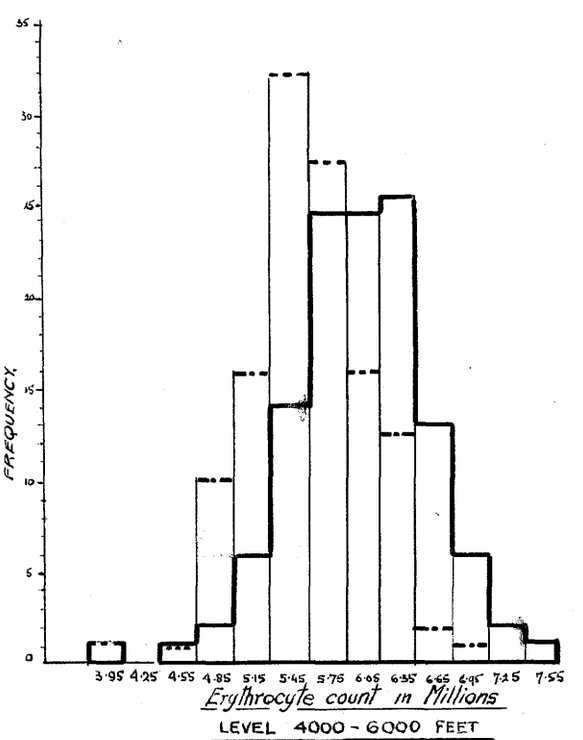
Continuous Line "Surface" Values

Class Value 0.3 Million.

Broken Line Values for Various Levels.







The standard errors of the differences between the means of the various depths & the surface value were also computed & are shown in table IX.
As mentioned above, for a difference to be significant it must be at least twice as great as its standard error.

Table IX.

Depth	Difference	S.E.
0 - 2000	.22I	±.068
2000 - 4000	.32I	±.070
4000 - 6000	.43I	±.065
Below 6000	.38I	±.097

The coefficient of correlation between the depth & erythrocyte counts was calculated, together with its probable error. The value obtained was:

$$r = -.1373 \pm .033$$

Although the value is small, it is more than three times its probable error & hence it is "certainly" or at least "almost certainly" significant (23).
It is negative which indicates that as one value increases the other decreases.
That is in this case as the depth increases, the erythrocyte count tends to decrease.

The ages of the men ranged from 20 to 60 years, but by far the greatest number fell between the range 20 to 35 years.
With a view to ascertaining whether age had any appreciable influence on the erythrocyte count, when computing the means for different levels, age groups were arranged for the various levels over steps of 5 years.
In each group the mean of I5 counts was computed.
The results are given in table X.

Table X.

Showing the Mean Erythrocyte Count in Millions for Different Age Groups at Various Levels.

Depth	20 -25	25 - 30	30 - 35	Number of Observations per Group
0 - 2000	5.93 ± .2I7	5.65 ± .I4I	5.95 ± .063	I5
2000 - 3000	5.85 ± .I46	5.97 ± .I73	5.97 ± .I63	I5
3000 - 4000	5.7I ± .22I	5.83 ± .I59	5.65 ± .I02	I5
4000 - 5000	5.65 ± .099	5.83 ± .I09	5.77 ± .099	I5

The coefficient of correlation between the ages & counts was calculated, together with its probable error. The value obtained was:

$$r = -.292 \pm .046I$$

The minus sign indicates that there is a tendency for the count to decrease as the age increases. Also as the value is greater than 3 times the probable error it is "almost certainly" significant, but the correlation is small. The mean ages for the various levels were computed & these differ very little as shown below.

Table XI.

Showing the Mean Ages for the Various Levels.

Level	Mean Age	σ
Surface	28.0 yr.	9.I73
0 - 2000	3I.0 "	9.I67
2000 - 4000	3I.8 "	8.944
4000 - 6000	30.6 "	8.740
Below 6000	30.2 "	7.I52

Judging from the above results the age factor would not appear to affect the conclusions.

Discussion.

From the mean counts shown in table VIII, there seems to be a distinct tendency for the erythrocyte count to decrease as the depth at which the men work increases, that is as the altitude at which they are temporarily living decreases.
The significance of this decrease is also enhanced by the standard errors of the differences, shown in table IX. In this case all the differences are more than twice their standard error & are hence significant.

The coefficient of correlation between the depth & counts is very small, but as stated above it shows a tendency for the count to decrease with the increase in depth.

Of the 2 methods of computation, the former, viz., the computation of the means & the standard errors of their differences is much more conclusive than is the indication given by the computation of the coefficient of correlation.

The mean of the depth below 6000 feet is higher than that for the depth 4000 to 6000 feet.
This may not be significant however, as the number of cases is much smaller, & the discrepancy may be due to random variation. On the other hand as the temperature at these low levels is usually high, this increase may be due to concentration of the blood caused by sweating (24).

There have been various suggestions regarding the cause of the increase in the number of erythrocytes at a high altitude & the decrease on returning to sea-level.

The following are the theories for adjustment to a high altitude:

a. An increased concentration of the blood.

b. Increased haematopoietic activity of the bone marrow.

c. The existence of a reserve or dormant supply of erythrocytes.

d. A lengthening of the life of the erythrocytes. There is no experimental evidence for this theory however.

e. An unequal distribution of the erythrocytes.

Scott (27) however was unable to find masses of erythrocytes stored away anywhere in the body, & believes that the capillary blood is the same as that in the large vessels.

It is quite possible that one of the initial factors in the rise of the erythrocyte count is a loss of fluid from the blood, as an exposureto low atmospheric pressures causes a concentration of the blood (2).

There is no doubt whatever that the final & persistant cause of the increased erythrocyte count is due to increased haematopoietic activity of the bone marrow. As mentioned earlier in this paper numerous workers have provided evidence to substantiate this fact.

As regards the existence of a reserve supply of erythrocytes which can be called on in times of stress a certain amount of evidence is available.

Schneider & Havens (32) in I9I5 found that by abdominal massage, there was primarily an increase of erythrocytes brought about by passage into the circulation, of corpuscles ordinarily stored away. Later Barcroft (28) definitely showed that the spleen formed a sort of "parking space" where a large volume of corpuscles might be stored, & which could be forced into the blood stream in times of need, by the contraction of the spleen.

Barcroft (3) summarises the methods whereby additional cells may be set free in the circulation, in the following scheme:

Possible methods of increasing the erythrocyte count.

- Emergency
  - Abstraction of water.
  - Opening of capillary areas.
  - Contractionof spleen.
  - Unrecognised methods.
- Final — Activity of bone marrow.

In connection with the decrease in the number of erythrocytes on returning to sea-level Hingston (I0) says: " The production of new corpuscles during ascent is the result of a continuous stimulus which the rarefied air is always exerting on the blood forming mechanism of the body. During descent a person is all the time passing into a denser atmosphere & consequently this stimulus is removed. The number of corpuscles in the blood diminishes as a consequence of disuse ".

Again a rapid increase in blood volume occurs on return to normal pressure, which would reduce the count.(2)

According to a recent text book (29) the reserve red cells when not required any longer are demobilised & returned to the splenic pulp. The spleen appears to regulate the number of red cells in use at any time. By means of its reticulum it can enmesh & retain many corpuscles; & in times of need it can expel them into the circulation.

Hence the decrease in the mean erythrocyte count with the increase in the depth of working, which was observed in the experiments detailed, is probably a normal physiological adjustment to the differences in altitude.

Alternatively, a decrease in the count might be due to unhealthy conditions should such prevail underground.
The former supposition is the more likely, as it is improbable that the conditions underground would be such as to cause a reduction of the number of erythrocytes.

Mavrogordato & Pirow (25) state the present better cooling figures on the Witwatersrand mines are about I2 wet-kata, & that a really adequate wet-kata reading for conditions on the Witwatersrand would be I5 to I7

As mentioned above, one would expect this increased temperature to concentrate the blood, due to loss of body fluid through perspiration, thus tending to increase the number of erythrocytes per cmm in the blood (24).
This would act in the opposite direction to the effects described, but might possibly account for the increased blood count at the levels below 6000 feet.

Conclusion.

I. The experiments detailed show that the erythrocyte count of miners working underground on the Rand gold mines decreases as the depth of working increases.
The discrepancy of the mean for the level below 6000 feet, may be due to diminished blood volume, although it must be admitted that the number of observations at this level was small.

2. This decrease is probably a physiological acclimatisation to lower altitudes.

References.

I. Barcroft, J. Lancet, I920, cxcix. ii, 485.

2. Douglas,C.G. Haldane,J.S. Henderson,Y. & Schneider,E.C. Phil. Trans. Roy. Soc., London, I9I3, B, cciii, I85.

3. Barcroft,J. The Respiratory Function of the Blood. I. Lessons from High Altitudes. 2ed., Cambridge, England, I925, University Press.

4. Samson Wright. Applied Physiol. 3 ed., I929, 344.

5. Haldane,J.S. Respiration. New Haven, I922, Yale University Press.

6. Haldane,J.S. Acclimatisation to High Altitudes. Physiol. Rev., I927, 7, 363.

7. Barcroft, Cooke, Hartridge, Parsons & Parsons. Journ. Physiol., liii, I920, 450.

8. Whipple,G.H. The Haemoglobin of Striated Muscle. (i) Variations due to Age & Exercise. Am. Journ. Physiol., I926, 76, 693.

(ii) Variations due to Anaemia & Paralysis.
Am. Journ. Physiol., I926, 76, 708.

9. Acton,H.W. & Harvey,W.F. Biometrika. viii I9II-I2,280.
The Increase in the Number of Erythrocytes with Altitude.

I0. Hingston,R.W.G. Indian Journ. Med. Res., ix, July - April, I92I-22, I73.

II. Schneider,E.C. Physiol. Rev., i, I92I, 63I.

I2. Richards,J. Phil. Trans. Roy. Soc., London, I9I3, B, cciii, 3I6.

I3. Barcroft,J. The Significance of Haemoglobin. Physiol. Rev., I924, iv, 329.

I4. Fitzgerald. Phil. Trans. Roy. Soc., London, I9I3, B, cciii, 35I.

I5. Starling,E.H. Princip. of Human Physiol., 3 ed., I920, II52.

I6. Foster & Johnston. Proc. Soc. Exp. Biol., I93I, xxviii,9, 929.

I7. Anderson. Report of the Haffkine Inst. for I929 (printed I93I) 26.

I8. Joseph,F.H. S.Af. Med. Record. I922, xx, 282.

I9. Gulland & Goodall. The Blood. A Guide to its Examination & to Diagnosis of its Disease. I9I2, 46,48.

20. Clinical Interpretation of Aids to Diagnosis. I930, i, 69. (Published by the Lancet Limited.)

2I. Fisher. Statistical Methods for Research Workers. I930, 3 ed., 45,46.

22. Elderton. Biometrika. I90I-2, i, I55.
Tables for Testing the Goodness of Fit of Theory to Observation.

23. Pearl. Medical Biometry & Statistics.
I930, 2 ed., 283.

24. Peters & Van Slyke. Quantitative Clinical
Chemistry. I93I, 733.

25. Mavrogordato,A. & Pirow,H.
Journ. of the S.Af. Inst. Eng., I927, xxv, No.7.

26. Official Year Book of the Union of South Africa.
I929-30, No.I2.

27. Scott,F.H. Amer. Journ. Physiol., I9I7, xliv, 298.

28. Barcroft,J. Recent Knowledge of the Spleen.
Lancet. I925, i, 3I9.

29. Samson Wright. Applied Physiol., 3 ed., I929, 224.

30. Strauch,A. Amer. Journ. Med. Sci., I9II, cxlii, I05.

3I. Mayer. Clinical Application of Sunlight &
Artificial Radiation. Bailliere I926, II2.

32. Schneider,E.C. & Havens,L.C.
Amer. Journ. Physiol., I9I5, xxxvi, 380.