Geophysics in Tropical Africa

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Professor Neville Skinner is from East Anglia and was born at Lowestoft, the most easterly point of England. However, both he and his wife have spent the greater part of their lives in the continent of Africa.

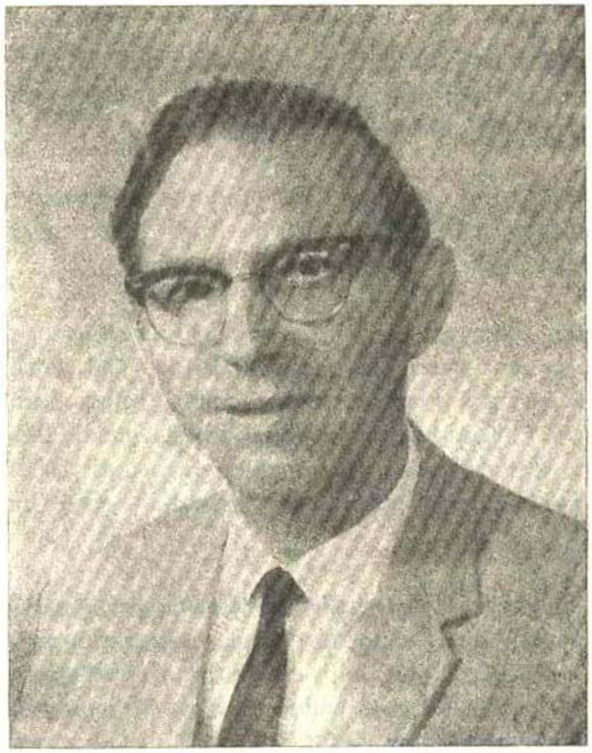
As a student at Nottingham University, he was a keen athlete and sportsman and represented his University at many sporting events; he still enjoys tennis, squash and swimming.

After graduating with First Class Honours in Physics, he enlisted for National Service and served with the Royal Electrical and Mechanical Engineers in Malaya.

Following this, in 1952, he went to Nigeria to join the staff of the Physics department at the University of Ibadan and remained there until 1962 when he was appointed as the first Professor and Head of Department of Physics at the newly established Ahmadu Bello University, Zaria, northern Nigeria. He remained there until 1969 when he came to Kenya to take up his present post with the then University of East Africa.

Professor Skinner has travelled widely and participated in scientific conferences in many countries. He places great importance on research in academic training, with emphasis on research relevant to the country's needs. His own active research in geophysics has entailed travelling throughout Kenya, often to the more remote areas. In addition to visiting the Universities in the neighbouring countries, he has served as External Examiner in Physics to the Universities of Zambia, Lesotho, Swaziland, Botswana, Ghana and the West Indies and so has had the opportunity of seeing the university physics departments in these countries and of having useful discussions over mutual interests, problems and developments.

His main interests, away from Geophysics, are Ornithology and Philately.



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GEOPHYSICS IN TROPICAL AFRICA

Introduction

A professor giving his Inaugural Lecture can take one of several approaches. If he gives it soon after taking up the Chair he often takes this opportunity to explain his own approach to his discipline and how he would expect it to develop during his tenure of the professorship. My case is a little different in that I have already held the Chair of Physics in this University for a number of years and have had the opportunity not only of developing work that was going on when I arrived but also of initiating new work and assessing the results.

The field of physics today is a vast one — so large that no physicist can claim to have a close knowledge of all branches. My own special interest has always been in geophysics which, as the name implies, is that branch of my subject which involves the study of the physical properties of the Earth, including its interior and its atmosphere. In this lecture, I hope to give you some insight into the scope of this discipline, and to explain with the help of a few specific examples why it is a very relevant and practically useful subject to study in Kenya. I shall conclude by indicating the way in which geophysics might develop in the future in this University in relationship to the other earth sciences with which it has close links.

What is Geophysics?

Some of the branches of geophysics with which I shall be concerned include the following:

a) **Geomagnetism.** This is the study of the magnetic field of the Earth, including its ancient variation (palaeomagnetism). The fact that the Earth has a magnetic field is familiar to most people through the directional properties of a compass needle. Strangely enough, the origin of the field is still not fully understood, although there is no doubt that it is primarily due to a complicated system of electric currents flowing in the liquid part of the iron core of the Earth. Smaller components of magnetic field are due to electrical current systems in the upper atmosphere, and to the natural magnetism of near surface rocks.

b) **Seismology.** This is the study of the propagation of earthquake waves in the various parts of the Earth's interior. Their speed depends on the nature and density of the material through which they travel and our knowledge of the structure of the Earth's interior is based largely on seismic evidence. Figure 1 shows the main divisions into a thin crust, a mantle which is mainly solid but includes an upper somewhat plastic zone, and a core, the outer part of which is liquid but with a solid interior. The divisions are based on changes in the observed velocity of seismic waves, which in turn indicate changes in rock density and it is seen that in the core, rocks are about 4 times as dense (i.e. heavier for the same volume) as they are at the surface.

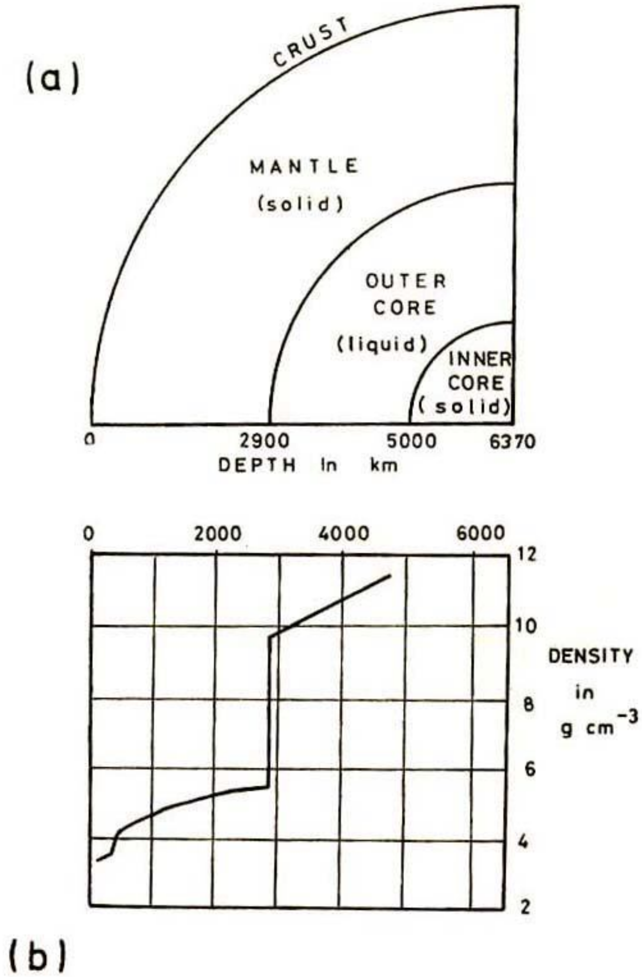

Figure 1. (*a*) *The internal structure of the Earth. The crustal thickness is about 35 km under the continents and much less under the oceans.*
(*b*) *The variation with depth of rock density based on seismic wave velocities.*

c) **Gravity.** This important property of the Earth ensures that we all remain attached to it. One of the basic laws of physics relates to the attractive force existing between any two bodies. It is a very weak force compared to many of the other forces in physics but it depends on the relative masses of the two bodies so that the only gravitational force with which we are normally familiar is that which binds us to the most massive body in our close environment in the Universe — the Earth. The acceleration of a freely falling body under gravitational forces is an important quantity in geophysics and is usually simply called *the gravity*. It varies with latitude and altitude, and with the density of underlying rocks and this latter property makes it an important geophysical exploration tool.

d) **The physics of the upper atmosphere.** The atmosphere above an altitude of about 60 km is rendered electrically conducting by the ionising action of electromagnetic waves from the sun, particularly those in the ultra-violet and X-ray parts of the spectrum. Incidentally, the absorption of this part of the solar spectrum by our atmosphere makes it possible for life to develop and exist on Earth in its present form. An important property of this part of the atmosphere (known as the ionosphere), is its ability to reflect short wavelength radio waves and, as Figure 2 illustrates, this makes possible long distance radio-communication by multiple reflections between the Earth's surface and the ionosphere.

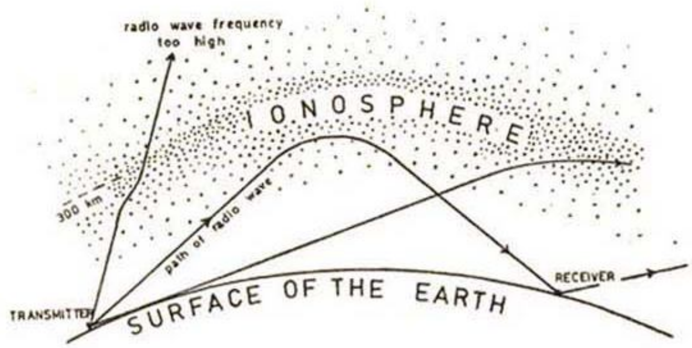

Figure 2. Illustrating the reflection of radio waves in the ionosphere.

In the widest sense, geophysics would also include meteorology but, as this branch of geophysics is the responsibility of another department in this University, I will not attempt to deal with this aspect.

From my point of view this is a great convenience in that the science of meteorology, although firmly based in physics, is probably the least understood of all the geophysical sciences, and the most difficult to explain in simple terms.

Geophysics, like many other branches of physics, has its pure and applied aspects. The 'pure' branch is concerned with finding out as much as possible about the structure of the Earth and the atmosphere and in proposing suitable theories to explain what is observed. Many of the basic concepts also have their practical applications, for example, in radio-communication and in exploration for natural resources. The latter is so important that the principles should be elaborated immediately. The only certain method for investigating what materials lie beneath the Earth's surface is to drill bore-holes. This is costly and depth limited. By making surface surveys of physical quantities such as the gravity and magnetic fields, heat flow, electrical conductivity, radioactivity, and the propagation of seismic waves, it is possible to detect zones of anomalous behaviour and to make interpretations in terms of models showing variation of rock structure with depth. This can be done at various scales of operation including detailed surveys of small areas of interest to detect, for example, near-surface ore bodies or hot areas, and at the other extreme, on a global scale, to investigate the deep structure of the Earth's interior.

The importance of Geophysics in Africa.

Because of their geographical locations, physicists in third world countries generally feel isolated from their colleagues and from new developments in their discipline. (For example, scientific journals often take 3 months to arrive in Kenya). If they are experimental physicists with interests, for example, in nuclear physics or high energy particle physics, there is the added disadvantage that there is no possibility of obtaining funds on the scale necessary to buy the sophisticated equipment which is needed to do competitive up-to-date research in these fields.

In geophysics the situation is very different because the local environment becomes the research laboratory and it is a positive advantage to be able to work in remote areas which have not previously been studied. This was very quickly appreciated by physicists in the first universities opened in tropical Africa and geophysics research was initiated as long ago as the early 1950's. I feel well qualified to discuss these matters since I have had the privilege of being involved in various aspects of geophysical field-work for the whole of this period, first in Nigeria and Ghana and subsequently in Kenya. Another advantage in doing geophysics compared to other branches of experimental physics is that the equipment is relatively simple and cheap, and can often be borrowed, since overseas organisations are very interested in obtaining access to basic geophysical data on a global scale. An important aspect of the work is the operation of various types of geophysical stations for the continuous monitoring of, for example, the magnetic field variations, seismic waves, and variations in the intensity of the ionosphere. In developed countries, these somewhat routine operations are usually undertaken by government agencies. In Africa, the Universities have taken on this task and in Nairobi all of the above types of station have been operated by either the Departments of Physics or Geology. Local geophysicists have thus had the benefit of early access to unique research data and this has been a tremendous stimulus to research. However, the burden of operating a routine station is an onerous one and we regard this as a temporary solution; we look forward to the next stage of evolution when these functions can be taken over by some organisation, perhaps a government department, in just the same way as basic meteorological data is collected at present. The necessity and desirability for maintaining and even extending the present network of stations can be illustrated by a recent example—the rather severe earth tremor felt in Nairobi and over a large area of southern Kenya on April 5, 1978. The only seismic station in Kenya is that operated by the Geology Department of the University and at least 2 or 3 more stations are needed in Kenya to monitor local earthquake activity and enable the positions of earthquake epicentres to be pinpointed. Many of the foregoing remarks would apply to any third world country. In tropical Africa we have the added incentive to do geophysical work provided by two natural features, namely the great Rift Valley system of eastern Africa, and the crossing of the continent at a geographical latitude of about 10°N, of the magnetic equator—where the Earth's magnetic field lines are horizontal. Figure 3 shows the relative positions of these two features and it is seen that in Kenya we are well placed to study both effects. Let me try to explain why these two features are important and then through some actual case studies describe some of the investigations and results.

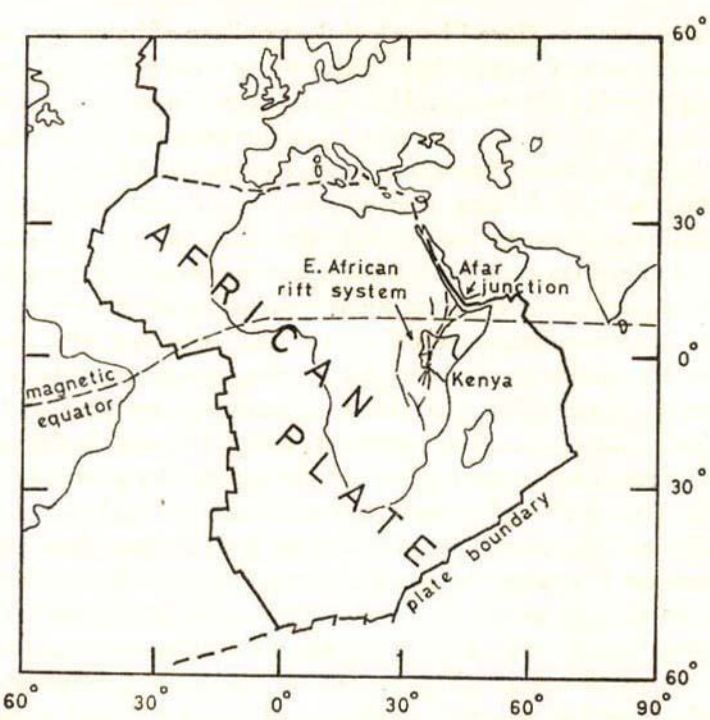

Figure 3. The African Plate showing the positions of the magnetic equator and the east African rift system.

We normally think of Africa as being bounded by its natural coastline. The modern geophysicist on the other hand regards the Earth's lithosphere as divided into about six major and a number of minor plates of thickness 70-100 km, the boundaries of which are marked by narrow belts of intense earthquake activity. Typically each of these rigid plates contains both continental and oceanic crust and may be imagined as 'floating' on a less rigid zone of underlying partially melted rock known as the asthenosphere. Relative plate motions, popularly known as continental drift, occur over time scales of 100's of millions of years and most of the main surface structural features of the continents and oceans are readily explainable in terms of 'plate tectonics', many of these being associated with behaviour at plate boundaries. This theory which has evolved rapidly over the last twenty years is now firmly based on geophysical evidence. So far as the African continent is concerned we should therefore think rather of an African plate with boundaries down the Atlantic and Indian Oceans and through the Mediterranean countries. The East African Rift Valley is seen to be linked at the Afar junction to the plate boundary down the Red Sea and Gulf of Aden, and the significance of this has been the subject of much speculation. The most drastic thought appears to be—Is the African plate beginning to fracture down the Rift Valley? —and I will discuss this matter more fully in the light of present geophysical evidence, later in this lecture.

The other great natural feature that I mentioned earlier is the magnetic dip equator. Its position differs from the geographical equator because the magnetic axis of the Earth is at present at an angle of about 11° to the spin axis, and in Africa the separation of these two equators is particularly large. The main effect of the dip equator is seen in the ionospheric part of the upper atmosphere. It is found that an intense electric current is caused to flow in a narrow belt of latitudes within ±5° of the magnetic equator at heights of about 100 km. This has implications with regard to radio propagation in this zone, which lies to the north of Kenya. A further effect is the creation of an immense fountain-like motion of charged particles in the upper ionosphere as illustrated by Figure 4. This results in a double humped distribution of electron density with latitude and Nairobi lies close to the position of the southern crest, and is thus in an extremely good position to study this phenomenon.

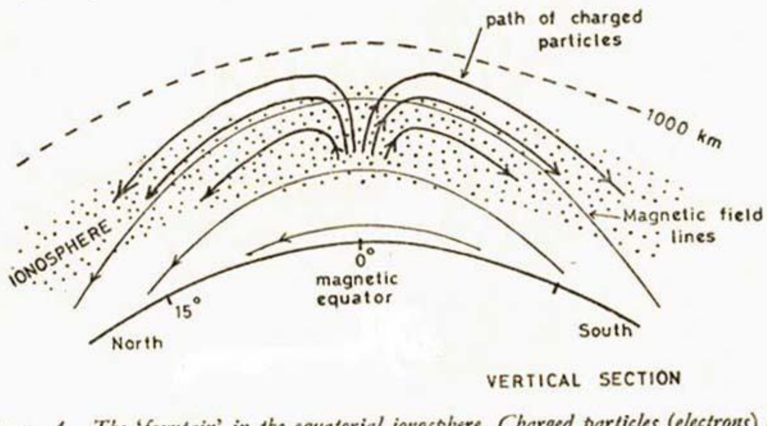

Figure 4. The 'fountain' in the equatorial ionosphere. Charged particles (electrons) are forced upwards near the magnetic equator and diffuse along magnetic field lines to latitudes ±15°.

Finally, but not least important, there is the need to train African geophysicists in exploration techniques as such trained personnel are needed by the Mines and Geological Department, the Ministry of Water Development, the Ministry of Works, the Geothermal Project and by companies in the private sector. Techniques include the interpretation of both surface and airborne geophysical surveys. A start has recently been made, with Canadian assistance, to make an airborne geophysical survey of all parts of Kenya which have potential mineral resources. This will identify areas where ground follow-up is needed to accurately locate sites for drilling and the full period of exploitation is likely to be lengthy. Geophysical methods, especially the measurement of electrical conductivity, also offer some of the best ways of locating underground water and steam reservoirs.

A few case studies.

It would be impossible within the time available to survey the whole of the geophysical work that has been done in tropical Africa, and I shall limit my discussion to a few case studies.

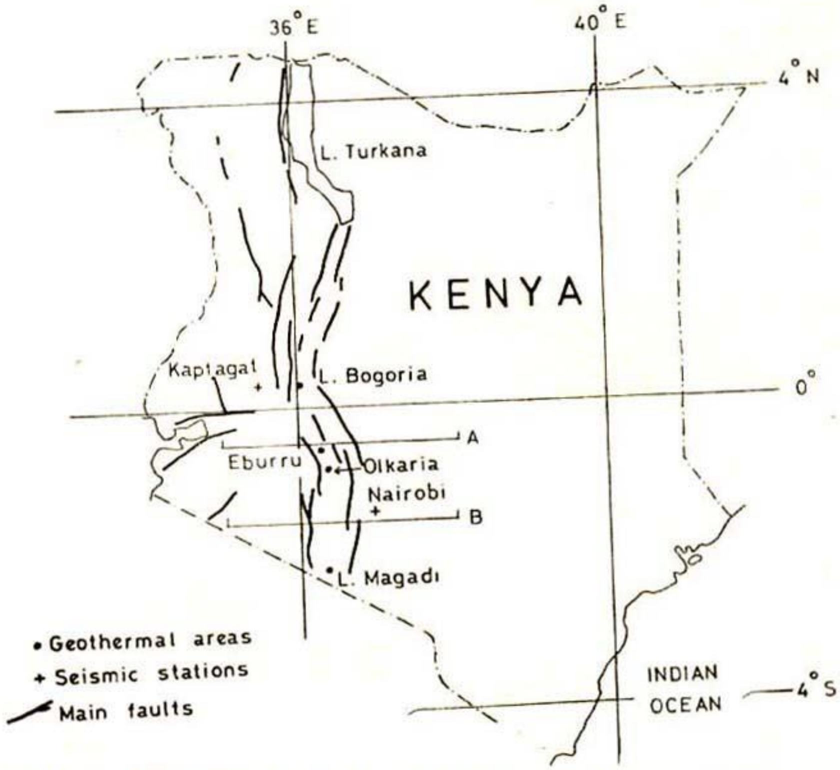

Figure 5. Map of Kenya showing the main faults of the Rift Valley and the positions of geothermal areas and seismic stations. Sections along A and B are shown in Figure 6.

a) The East African Rift Valley.

As a geographical feature and spectacle this is familiar to all people who know central Kenya. The first point one should appreciate is that it is a relatively 'young' feature and is still evolving. We believe that about 70 million years ago, doming or swelling of the crust began to form the Kenya highlands. (70 million years may seem a very long period but is small when compared to the age of the Earth—4,500 million years—and so geologists regard this as a relatively young event). The stresses in the crust caused by this swelling were relieved by cracking or faulting, causing vertical displacements of crustal blocks, and the geological history has been one of repeated cycles of uplift and faulting over the whole period. About 30 million years ago massive volcanic eruptions began, in what is now the Turkana area of northern Kenya. These took the form of flood eruptions from fissures, and later there were eruptions from more conventional volcanoes such as Longonot, Menengai, Suswa in the Rift and Mt. Kenya to the east.

Volcanism is still going on in Kenya and the last eruptions were less than 100 years ago and certainly there will be more volcanic activity in the future. On the whole, the younger volcanic episodes have tended to occur further south. The map in Figure 5 shows the positions of the main Rift Valley faults in Kenya. Figure 6 shows vertical sections across the Rift Valley at latitudes of 0°30' S. and 1°30' S. It illustrates all the features I have mentioned—the doming, the faulting and the volcanism. To see these features in proper perspective it should be remembered that the vertical scale is about 20 times larger than the horizontal. Even so, the vertical escarpments are impressive and are 1.5 km. high in places, and the thickness of lavas frequently exceeds 1 km.

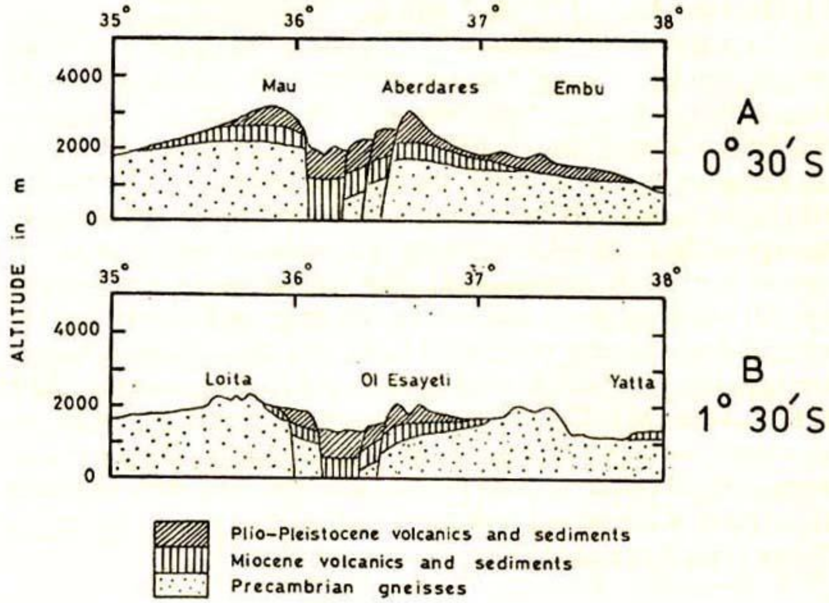

Figure 6. Vertical sections across the Rift Valley at latitudes 0°30'S and 1°30'S. (Taken from Baker, Mohr and Williams, 1972).

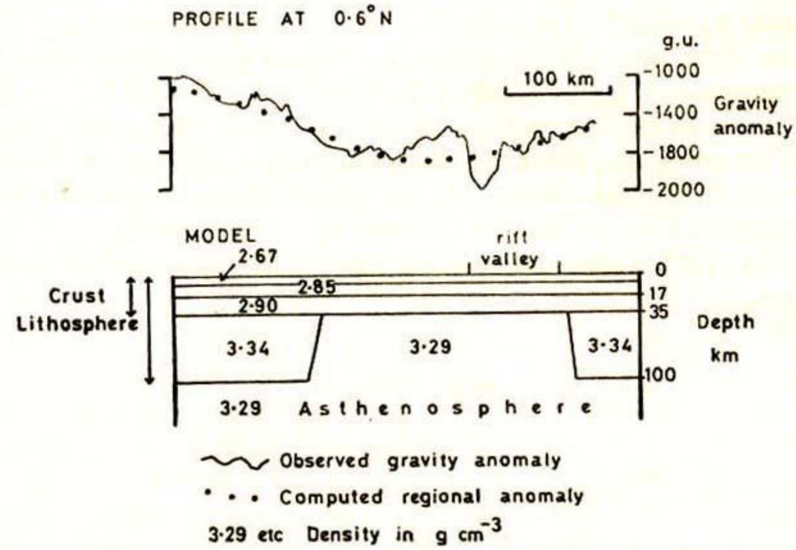

Figure 7. The upper diagram shows the broad negative gravity anomaly under the Kenya dome. The lower diagram shows a structural model which is consistent with this gravity anomaly. Note the density contrast below depths of 35 km. (After Fairhead, 1976).

The main geophysical evidence for the structure of the Rift Valley comes from gravity and seismic measurements. Gravity can be measured at the surface of the Earth by using a very sensitive form of spring balance and Kenya has now been surveyed fairly comprehensively. Geophysicists from the University of Leicester have recently produced a gravity map from which the effect of altitude and latitude have been removed so that the gravity variations displayed should depend mainly on variations in density of underlying rock formations. One of the main features of this map is a large zone of low gravity which coincides broadly with the Kenya highlands region. The known *surface* variations in rock density are insufficient to explain the intensity of this feature and models have been put forward similar to that shown in Figure 7 which hypothesize lateral variations in density in the upper mantle, below a depth of 35 km. This could represent a swelling of the asthenosphere—the relatively hot zone on which the lithospheric plates 'float'—implying that the African plate is thinned in this region. Close inspection of the gravity data reveals that in addition, along the axis of the Rift Valley, there are small local gravity highs, (see Figure 8), which may be interpreted as intrusions of hot material derived from the relatively denser asthenosphere, and which reach to within a few km of the surface. Supporting evidence for great heat near the surface in the form of hot springs and steam jets are seen in these areas, examples of which are the Hell's Gate area south of Lake Naivasha and at Lake Bogoria. The presence of very young lavas only a few hundred years old is also indicative of underground heat in these areas and they offer considerable potential for the exploitation of geothermal energy.

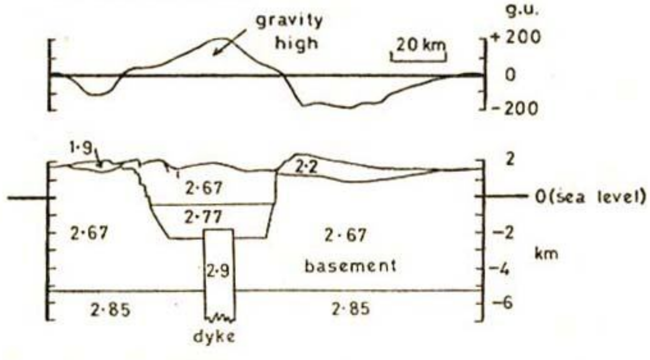

Figure 8. Illustrating the interpretation of the axial gravity highs in terms of a denser intrusive dyke. (After Fairhead, 1976).

Major changes in subsurface density as envisaged by the aforementioned interpretation of the gravity data should also affect the speed with which earthquake waves propagate in the East African zone, and the seismic evidence strongly supports the gravity model. For example, earthquake waves from very distant earthquakes as received at seismic stations such as Nairobi, and the temporary station operated for a few years at Kaptagat, are found to be slowed down if they have passed through the relatively low density zone in the upper mantle beneath the Kenya dome. The structure of the crust beneath the Rift Valley is also being investigated by seismic experiments, in this case using small explosive charges as the sources of 'earthquake type waves', and early experiments confirm the thinning of the crust under the Rift Valley and its very complex lateral structure compared to that outside the Rift. Whether the thinning of the crust is the forerunner of a major fracture in the African plate is still not clear and is the subject of much debate amongst geophysicists. The rate of widening of the Rift Valley appears to be very slow—only a few mm per year—so that the matter is not one to cause immediate anxiety. It could be, however, that over the next few tens of millions of years a new East African Plate may be formed. In the meantime we should take advantage of the cheap energy that geothermal steam in the Rift Valley can provide to help balance our energy budget. The first geothermal power station in Kenya will soon be built at Olkaria, south of Lake Naivasha. Geophysicists should continue to explore other promising areas such as Eburru, Lake Bogoria and Lake Magadi so that the full extent of the geothermal resources can be assessed. When it is realised that a single good steam well can generate about 5 M W of electric power, and that the maximum demand in Kenya at present is about 200 M W, the impact that geothermal power could have on the economy can be appreciated.

b) The 'fountain' in the ionosphere

As stated earlier, the other great natural feature of geophysical interest in tropical Africa is associated with the magnetic equator. Although Kenya lies to the south of this feature, the ionospheric effects do extend over our region, and particularly the effect of the fountain of charged particles, which I described earlier. This results in a redistribution in density of charged particles (electrons) with latitude at certain times of day and in view of the practical importance of the ionosphere with regard to radio-wave propagation it is important to study this phenomenon on a broad regional basis.

My department has been involved in one method for doing this which involves measuring the intensity of very weak red and green light emissions from the ionosphere. These light emissions depend basically on the charge density and height of the ionosphere and originate in a chemical recombination process. They are so weak that they cannot be measured during the daytime because they are swamped by the very much greater intensity of sunlight and, even at night, measurements are restricted to moonless, cloud-free nights, at locations where there is no interference from man-made lights. With the kind permission of the National Museums of Kenya, we chose the prehistoric site at Olorgesailie in the Rift Valley for our measurements and from there the ionosphere within a radius of about 600 km can be 'seen' and its light emissions recorded as a function of the direction in which the instrument is pointed. We were able to produce sky maps of light intensity similar to that shown in Figure 9. This shows the kind of latitude variation that we expected near the southern crest of the anomaly, and measurements of sky brightness variations through the night have enabled us to study the growth, movement and decay of the southern crest due to the fountain effect. To our surprise we found that there was also a large longitude effect, with strongest light emissions very consistently from the west, from the ionosphere at 250 km above Lake Victoria. The explanation for this is still not forthcoming and it illustrates a common feature found in physics research that an experiment, whilst solving one problem often raises another.

Another tropical effect in the ionosphere (and one which may have some connection with the 'fountain') is that its ability to reflect or transmit radio waves *cleanly* diminishes at night. In other words, the ionosphere at night is more like a rough reflector than a good mirror and this leads to distortion in the quality of radio signals—known as fading. Anybody who has listened on short wave radio to transmissions from Europe, especially in the important listening period between sunset and midnight, will have noticed that the volume often rises and falls rapidly with time, causing a pulsation in speech which makes it difficult to understand, and music becomes intolerable to listen to. A good quality receiver can overcome some of these problems but not completely. We have studied this phenomenon at Nairobi and can now predict with some confidence the times at which it is likely to be the

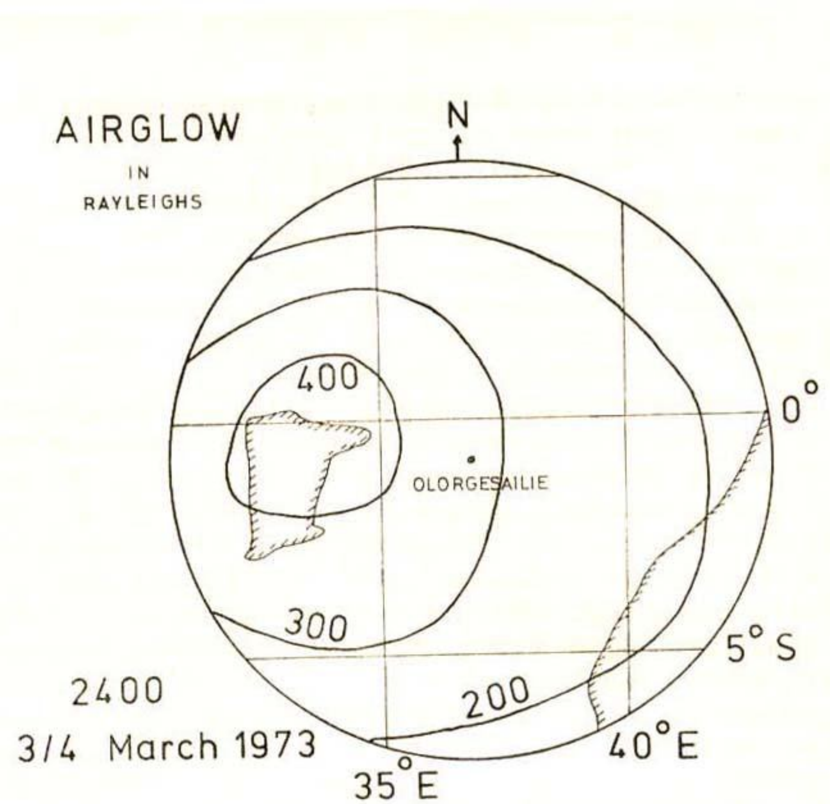

Figure 9. Contours of airglow intensity seen from Olorgesailie. Maximum airglow is frequently over the Lake Victoria area.

most severe. An interesting sideline to this work arose soon after the Mount Longonot satellite station went into commercial operation in 1971. As you may know, this communications link is via a geostationary satellite which is located 22,000 miles above a point on the equator in the Indian Ocean as shown on the map in Figure 10. The frequencies used—about 4,000 Megahertz—are about 400 times as large as those used in normal radio broadcasting, the reason being that it was thought that such high frequencies would be unaffected by the ionosphere. (Similar frequencies incidentally are used in many radars). The engineers at Longonot were puzzled by unexpected fading of their signals in the evening hours and contacted us for a possible explanation. We undertook an experiment for a month or two in which we found near perfect correlation between fading of the Longonot signals and roughness in the ionosphere over Nairobi and it became clear that even at these high frequencies the ionosphere was affecting the signal quality. Whilst this did not solve their problem, which for-

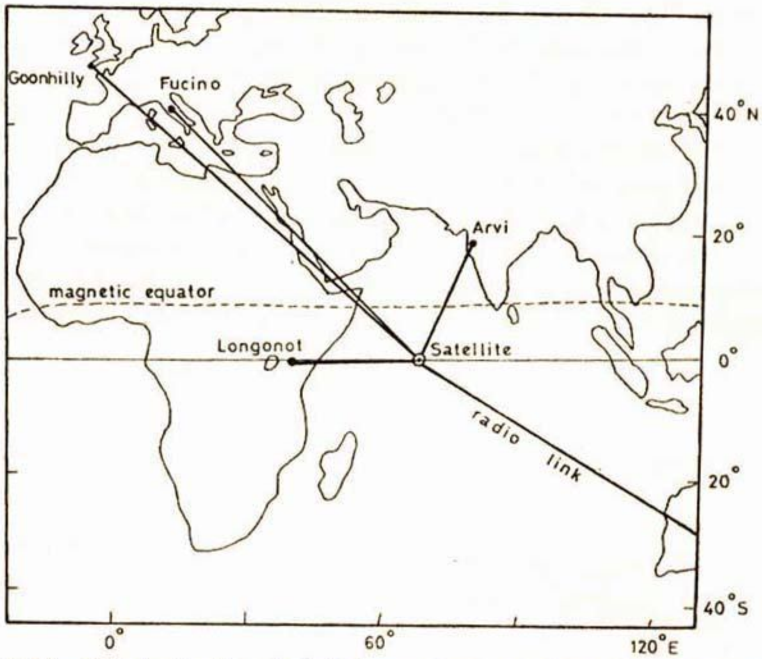

Figure 10. Map showing the radio links between Longonot and other parts of the world via the geo-stationary satellite above the Indian Ocean.

tunately was not too severe, it did enable us to predict when such disturbance in transmission would be expected.

c) Palaeomagnetism

I mentioned earlier the present concept that the Earth's surface is divided into a number of large and small plates and that these move with respect to one another, i.e. there is continental drift. Much of the supporting evidence for this comes from a study of the ancient magnetic field of the Earth, a record of which is preserved in certain rock structures. The basic principle of palaeomagnetism, as this study is called, is that when a hot rock—for example, a molten lava flow—cools below a certain temperature (about 600°C) it becomes weakly magnetised in the direction of the prevailing magnetic field of the Earth. This magnetism is preserved provided the rock is not reheated or disturbed. There are methods available for assessing the ages of such rocks and we can therefore make deductions about the direction and magnitude of the ancient magnetic field at various known times in the past. Such measurements enable one to deduce the apparent position of the magnetic poles of the Earth in past time and by inference the positions of the geographic poles which are always close, although not coincident, to the magnetic poles. (Strictly speaking the magnetic poles are always moving slowly with respect to the geographic poles, but if one takes the average position of the magnetic pole over many thousands of years it will coincide with the appropriate geographic pole position). When pole positions are measured for rocks of a wide range of ages and plotted on a map they are found to follow an apparent polar wander path, as shown for example in Figure 11 on which is plotted the polar wander path for the African plate for the past 500 million years. This

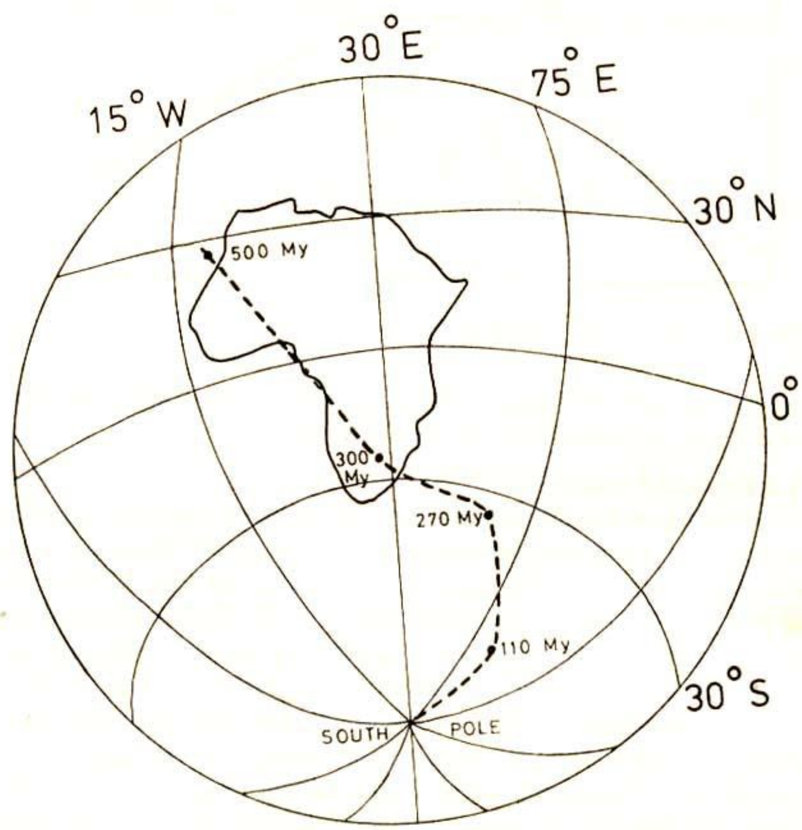

Figure 11. The apparent polar wander path for Africa for the past 500 million years. This indicates that an ice cap probably covered the Sahara 400 million years ago.

can be explained in various ways—the spin axis of the Earth may have changed direction—physically this is most unlikely. It seems certain that the correct explanation is that the African plate has moved with respect to the poles so that, for example, 400-500 million years ago the pole position was in West Africa and a huge ice cap must have covered the Sahara, rather like the situation in present-day Antarctica. In fact there is geological evidence of glacial conditions in the Sahara, and in southern Africa, which supports this contention. When palaeomagnetic and other evidence from all the continents is synthesized and reconciled the remarkable picture emerges that the land masses that we know today were formerly grouped together into a single 'super continent' called Pangaea. Over the past 300 million years continental drift has occurred by a process called sea-floor spreading and the main continental land masses have redistributed themselves into their present positions. The rates of movement are of the order of only a few cm per year, but of course over hundreds of millions of years drifts of many 100's of km can occur.

The fact of continental drift is not merely of academic interest; it is an extremely important factor to be considered in terms of mineral exploitation. The occurrence of valuable deposits on one continent can lead to the assumption that they might also occur on another, several 1000 km away. An example is the occurrence of diamond fields in Sierra Leone in West Africa and their counterparts in north-eastern South America. The oil prospector is also very interested. Present ideas for oil formation are that oil is formed by bacterial action on organic matter in marine sediments and that this takes place mainly in tropical areas within 30° of the equator where organic matter is most plentiful. The prospector may devote much energy to locating geological structures suitable for trapping oil but this will be to no avail if the rocks he is studying were not once in the right latitudes to allow the formation of oil and natural gas. The oil fields of the Persian Gulf, Central America and North Africa exist only because these parts of the world were once lying much closer to the equator, as shown in Figure 12. This shows the positions of continents about 150 million years ago and it is seen that East Africa was still far from the equator at that time. It seems likely that East Africa has entered tropical latitudes only during geologically recent times and for this reason some palaeomagneticists believe that the chances of finding oil in large quantities appear to be marginal. Nevertheless much effort and investment has been put into the search for oil in Kenya, and certainly no country can afford not to examine areas where the geology is suitable and where there is at least an outside chance of success.

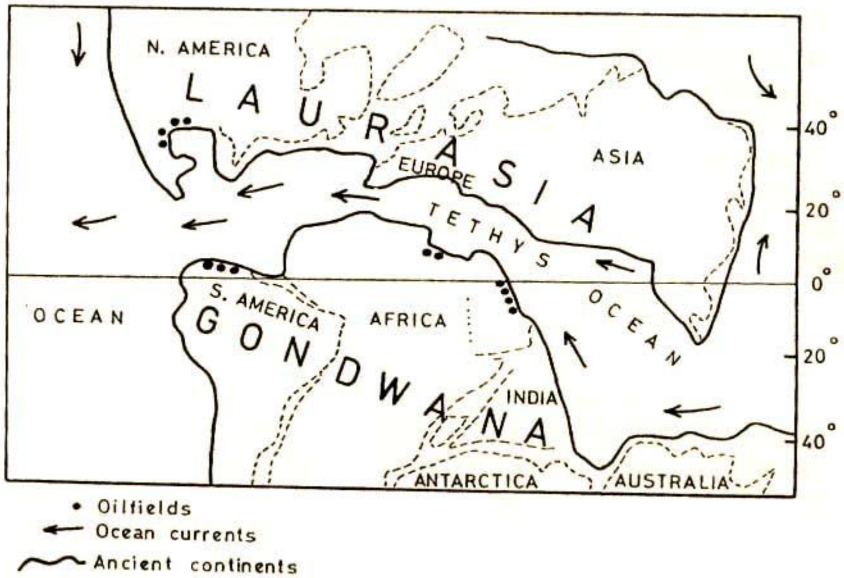

Figure 12. A reconstruction of the continents about 150 million years ago. The 'super-continent' Pangaea has split into Laurasia and Gondwana. Oil deposits occur along the ancient Tethys Ocean. (After Irving, North and Couillard, 1974).

There is another interesting and important result from palaeomagnetic studies. It is found that roughly one half of the rocks collected in the world are magnetised in the present direction of the Earth's field, whilst the other half are in the opposite sense. The implication of this is that the Earth's magnetic field periodically switches round completely, and a compass needle which at present points to the North would point to the South during reversed epochs. Measurements over a long dated series of rocks shows that reversals occur at rather irregular intervals of the order of 100's of thousands of years. The last reversal appears to have been about 700,000 years ago, and for the past few million years the dates of reversals are well known. A practical application of this work in which the Department of Physics has been involved has been the dating of sediments in which hominid fossils have been found by Mr. Richard Leakey's team in the Koobi Fora area east of Lake Turkana. The sequence of reversals in a sedimentary succession is carefully measured and this is then matched to the reversal time scale so that the best fit is obtained. Radiometric dates of various tuff horizons are used to calibrate these measurements.

Another aspect that has aroused considerable interest is in connection with what happens during an actual reversal which may take a thousand years or so to complete. Does the field die away in magnitude and then grow again in the opposite direction, or does it just swing around? If the former occurs then the Earth might be without any magnetic field at all for certain periods of time and this could have important consequences, because our magnetic field acts as a shield against the particle radiation from the sun, known as the solar wind. Most of this is normally deflected away by our magnetic field and cannot reach the Earth's surface. During a reversal it seems at least possible that greatly increased solar radiation will reach the Earth's surface and this could conceivably cause genetic mutations which could alter the form of living organisms. Perhaps this is why the dinosaurs died out? It is a fascinating field of conjecture.

The importance of Geophysics as a discipline in the University

I think that it should be clear from the examples that I have given that geophysics is both a relevant discipline for study in an African University and one which is important for national development. In this University, in the Department of Physics, we have had a long standing research interest in several branches of geophysics—palaeomagnetism and ionosphere since the early 1960's and more recently in applied geophysics. About one half of our present lecturing staff are geophysicists of one kind or another. We have trained many Kenyan M.Sc.'s and Ph.D.'s and several of these are now on the University staff here and at Kenyatta U.C. We have close ties with the Mines and Geological Survey Department and the National Museums of Kenya, and with research groups from several overseas Universities who have conducted fieldwork in Kenya. We already constitute a viable group of scientists who can interact with one another and with overseas colleagues. The introduction of the course unit degree structure within the Faculty of Science in recent years has enabled us to introduce some geophysics teaching at the undergraduate level so that students are made aware of the possibilities for later work in this field. Because of the flexible nature of our new degree programme such students can take appropriate supporting units in geology and mathematics which are essential for the training of geophysicists.

Looking to the future, I would like to see more emphasis on Applied Geophysics—applied that is to exploration for natural resources. The training for this should be done through joint M.Sc. programmes with the Department of Geology and in order to develop this branch of geophysics properly we need a good range of exploration equipment. Such equipment is not used continuously, however, and a good solution to this problem would be to set up a national pool of equipment, which could be used by geophysicists from the University and various government institutions.

Academically, the growth of geophysics within the university physics department has been a natural one, particularly during the period when the department has been relatively small. However, geophysicists often feel stronger ties with other earth scientists than with colleagues in more fundamental branches of physics and a logical development for the future might be to form a School or Faculty of Earth Sciences within the University comprised of the disciplines of geology, geography, meteorology, geophysics, geochemistry and hydrology. To be effective, this should have both undergraduate and post-graduate teaching functions, but students would still need a good grounding in the basic sciences of physics, chemistry and mathematics. In the meantime, I feel that within the present programme in the Faculty of Science a sound start has been made in training geophysicists who will have the necessary background to investigate further such vital and fascinating topics as:

a) what further natural resources in the form of minerals, steam and water remain to be discovered in Kenya?
b) how can radio communication be improved in this part of Africa?
c) is the eastern part of the African plate breaking away to form a new plate and, if so, when?

I am sure that geophysics has an exciting and challenging future in Kenya.

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