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RECENT EARTHQUAKE SERIES IN KOYNA REGION—A POSSIBLE MECHANISM AT THE SOURCE*

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Abstract

The occurrence of the recent earthquake series, with a peak event of magnitude around 6 on Richter scale, in Koyna area poses a number of problems. It is difficult to relate this occurrence to measurable movement along fault of known activity in recent times. Besides the energy associated with this earthquake also preclude the possibilities of surface structural or load changes as a causative factor.

In this note an attempt has been made to build up a possible source mechanism for this event. On the basis of geological evidence regarding intense volcanic activities in the past a thermodynamically possible process, capable of releasing neccessary energy, is put forward by applying the principle of energy transfer during permissible phase transition in crust and mantle. This hypothesis can explain most of the features of the present series of events.

Introduction

On 11th December, 1967, a severe earthquake affected parts of Deccan Peninsula, so long considered seismically stable. United States Coast and Geodetic Surveys determined following parameters for this event :

Epicentre	...	17.66 N : 73.93 E
Depth of focus	...	33 kms
Origin time	...	04 h. 21 m. 24.3 s. I.S.T.
Magnitude	...	6.0 (U.S.C.G.S.)

About 100 peoples died, over 1300 were injured and major property damages were reported. No satisfactory mechanism to explain the occurrence has yet been evolved. The region affected by this earthquake is characterised by horizontal bedding planes that remained practically undisturbed during long geological epochs. In fact the assumption that Deccan Peninsula is seismically stable is based partly on this fact of observation and partly on a tacit acceptance of the principle of fault movement as the cause of all major earthquakes. As against this, the catalogue of destructive earthquakes (A.D. 7 to 1899) compiled by Milne (1911) mentions as many as three severe earthquakes from Deccan region during the nineteenth century. The present event is the third of its kind during the present century—earlier two being the Coimbatore earthquake of 1900 and the Satpura earthquake of 1937. There are, thus, reasons to believe that the seismic activity of Deccan is such that these events do not result in marked structural changes of the surface geological formations. Important seismic belts of the world are believed to possess typical surface structures associated with fault movements.

Reid (1910) explained the occurrence of the San Fransisco earthquake of 1906 on the basis of release of locked up strain energy in an active fault. Since then movements along active faults were considered as cause of all major seismic events even though in many cases no manifest fault movements were observed. The basis for such association probably was the success of Byerley's correlation of compression and dilatation distribution of first

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movements of earthquakes with fault plane direction. With the increase in the number of seismological stations equipped with high sensitive seismographs a better perspective of first movement analysis has now become possible. In a recent review Stauder (1964) indicated possibilities of widely different quadrantal interpretation for the same earthquake. This is contrary to the unique fault plane solution of the Reid-Byerley hypothesis. Further Evison (1967), from statistical studies on 68 well recorded earthquakes, found that first motion data indicate predominant compression for certain categories of earthquakes, while for certain others they show predominant dilatation. He interpreted this information to indicate that the mechanism at the source of earthquake may not, in all cases, be of the type of movement along faults. As second solution, Evison (1963, 1967), therefore suggested volume changes accompanying polymorphic transition in the crust-mantle as a possible energy source for earthquakes. The transition that he considered permissible, were, however only solid-solid transition. Events at Koyna area points towards a source much more localised than in so called tectonic earthquakes with manifest fault movements. The purpose of the present study is to suggest a possible energy source for this earthquake series.

Nature of Seismie Activity of Deccan Area

From record of past activities, it seems that swarm activities play a dominant role in the seismic behaviour of Deccan and adjoining areas of Saurashtra and Rajasthan. It may be of interest to note that while in other active regions of India, major earthquakes are usually preceeded by a period of relative quiescence the major Koyna earthquake was preceeded by a gradual increase in seismic activity of an otherwise stable region. In fact the main event may be considered as the physical peak of a series of activity. There are many regions of the world where swarm activities are recorded and most of these regions have history of volcanic activity–dormant or active. It would therefore be responsible to consider volcanism as a correlating phenomena for understanding the occurance of such earthquakes.

The character of seismic phenomena of Deccan and adjoining areas may be summarised as follows :

1. The frequency of occurrence of earthquakes in general, and destructive events, in particular, is not very high.
2. There is not much evidence of wide spread tectonic movement of crustal layers in the region as the bedding planes show near horizontality.
3. Swarm type of seismic activity predominates in this region.

Any explanation for the earthquake phenomena in Deccan area should thus be built on these facts of observation.

Volcanism of Deccan Area

Large parts of Deccan and adjoining regions were subjected to intense volcanic activities in the past, eruptive phase of the activity apparently covered a period of over 25 million years and bulk of surface manifestations probably ceased around 50 million year ago. The flow composed of primary basalt, welled out through long cracks or fissures and due to general crustal weakness, the location of activity shifted continously. The resultant series of superimposed lava flows ultimately led to the formation of lava plateaus (Figure 1) of the so called Icelandian type. One of the significant difference between Deccan and Icelandian volcanism is that while in Iceland the flow of lava, after a repose of many million years, revived again in Pleistocene time ; there is as yet no definite indication of such revival in Deccan area.

The relationship between intense eruptive phase of a volcano and the associated swarm type of earthquake activity is now well established. Not much work have, however, been reported on earthquake activity associated with pre and post eruptive stages, but it is reasonable to expect that changes in volcanic manifestations are charccterised by changes in the nature of associated phenomena like earthquakes. In his studies on Japanese earthquakes, Imamura (1939) recognised two distinct type of earthquakes, associated with volcanism and designated a class of earthquake resembling the so called tectonic events as "non-eruptive" earthquakes. Mallet considered these as results of "uncompleted efforts to establish a volcano".

Formation, Growth and Decay of Volcanism

Recent studies on properties of rocks under high pressure and temperature confirms the possibilities of phase transitions of rock materials at great depths. The formation mechanism of basalt magma and their final transfer from mantle to surface has not yet been fully understood. Friggs and Handin (1960) in their studies on the mechanism of deep seated earthquakes ; proposed a shear melting hypothesis according to which the corners of a microflow or some blade like mineral grain can act as locations for superposed tensile stress under the action of distorting forces. The resultant pressure drop may induce a solid to pass into liquid phase. This hypothesis, may be extended to explain the formation of primary magma pool in upper mantle. Once formed, the stability, growth and activity of the pool depend upon thermodynamic conditions of phase stability. Yoder and Tilley (1962) determined such conditions in this melting diagram of basalt compositions as given in Figure 2.

The stability of the formed magma (liquid phase) generally increases with reduction of pressure at constant temperature or increase of temperature under constant pressure. Any increase of temperature is improbable as no heat source is available. But reduction of pressure is possible through adiabatic expansion of magma. Such mechanism leading to fissure formation following solid-liquid transition was recently discussed by Robson, Barr and Luna (1968). The magma pool can thus be sustained, first through the repetition of shear melting forces and then through adiabatic expansion of magma and opening out of fissures. According to Newton (1966) basalt magma is generated by partial fusion of peridotite mantle at depths of 80–250 kms. As the force system sustaining the growth of volcano is not continuously applied, the internal structure of a volcano follows a complicated pattern and may be visualised as shown in Fig. 3.

Decay in volcanic activity on the other hand starts with the weakening of internal forces. The first manifestation of such effect is the gradual reduction of intensity of mass transfer. This is followed by a period when there is a thickening of magma mass due to gradual fall in temperature. Low total heat capacity of materials within vents and fissures and high temperature contrast in the upper parts of the crust first results in sealing off vents and fissures. The resultant isolation of the system quicken the pace of pressure rise within the system and hasten the passage of the magma to a critical stage (Fig. 2). The final stage of the process is reached through the transformation of the magma to a stable solid phase.

From the point of view of energy balance the activity of volcano is thus not confined to eruptive phase only. It starts long before eruptive stage and continues till entire magma returns to the normally stable solid phase.

Earthquake Associated with Volcanism

From the foregoing discussions it will be seen that it is only during the eruptive phase that energy balance is maintained through bulk mass transport. Other factors on

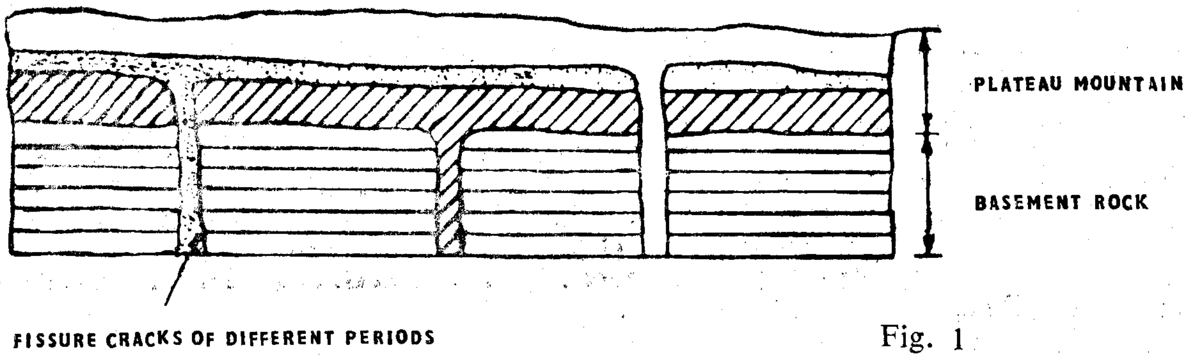

Fig. 1

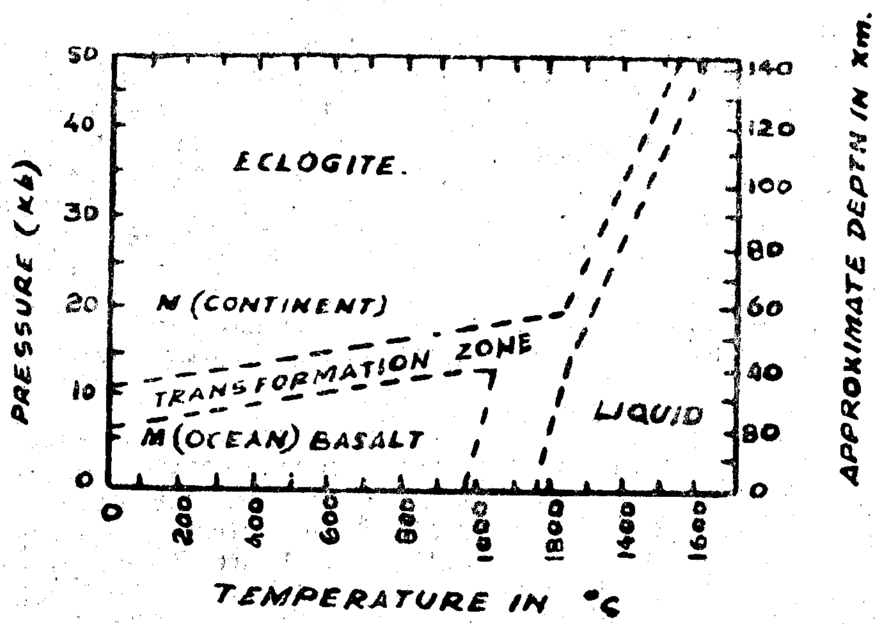

Fig. 2

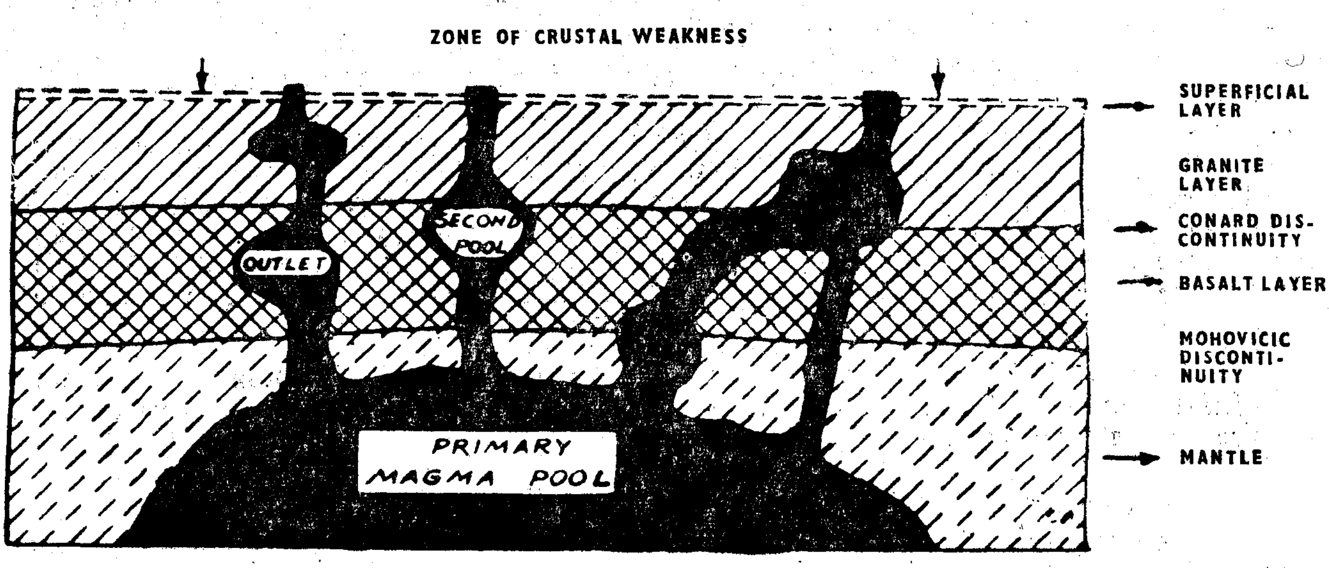

Fig. 3

the debit side, including earthquakes, play insignificant part. Accordingly, eruptive phase is not accompanied by major earthquakes. During pre-eruptive stage, on the other hand, the energy balance is obtained through phase transition and induced volume and structural changes in crust and mantle. The involved process is such that it may cause large scale upheavals and major earthquakes.

The process of decay of volcanism, on the other hand, is characterised by energy dissipation. From consideration of accompanying earthquake phenomena slow processes of heat transfers play insignificant part; but the process of liquid to solid transition, involving sudden release of large energies, is important.

The transition of the heterogenously composed material of the pool will commence slowly at first, in batches, and gradually increase to maximum and finally fall off. This will be because of different critical stages for different batches transformation. The accompanying earthquakes will thus have the character of the so called swarm type of activity.

The total energy release from a spherical magma pool, may be represented by the following simple equation :

$$E = \tfrac{4}{3} \pi r^3 \rho_{T,P} L_{T,P} J \text{ ergs} \quad (1)$$

where r — radius of the sphere.

$\rho_{T,P}$—Sp. gr. of the magma, at the temperature and pressure of the material of pool at the critical stage.

$L_{T,P}$—energy of phase transition of magma materials.

J — Joules heat equivalent.

In reality this is an integral equation of the type.

$$E = \Sigma \Sigma m' L' J \quad (2)$$

where summation are with respet to m′, L′

But as both ρ and L. vary only within narrow limits an average value may be sufficient for the purpose. At present no reliable data for P and L are available but by taking values suggested by Matuzawa (1964), energy of phase transition of a magma pool of 1 km diameter comes to the order of 10^{25} args. This energy is sufficient to account for a swarm in which major earthquakes are included.

Application of the Principle : Koynanagar Earthquake

It is necessary to consider in this connection evidences in support of location of magma chambers within the crust and upper mantle. Gorshkov while studying a number of Japanese earthquake records observed the absence of 'S' phase. He presumed the existence of magma chambers in those paths and from that identified and calculated the depth, size and shape of magma chambers. Hayakawa (1961) recently observed that in India, we have not any active volcano, but we have big areas of Deccan trap, which is the remains of old volcanic activity and also we have a broad distribution of granite and charnockite. From physical properties of such rocks, we can study the nature of magma". There are at present no definite evidences in support of existence of magma chambers in Deccan region but none the less the possibility of such occurrence can not equally be ruled out with existing information on the subject. Thus, on the basis of the principle postulated in earlier chapters, it is possible to arrive at the following general conclusion on the recent earthquake series at Koyna area.

1. The earthquake may be directly traced to volcanic activity in the last phase of decay. The present series originated from the reverse phase transition of magma pool.
2. Frequency of the earthquake in the Deccan region depend upon the frequency of phase transition of pools. Limitation in the number of such pools determine the frequency of earthquake occurrence. The low frequency of earthquake in general and larger events in particular indicates low occurrence of magma pools in critical stage of phase transition.
3. The so called 'tectonic forces' may not have direct bearing on the recent upheavals in this area.
4. Swarm type activity is the normal feature of the thermodynamic process postulated above. This is partly due to the heterogenous composition of the magma and partly due to release of mechanical stresses that develop during sudden phase transition of large volume of magma.

Discussion

The Koynanagar earthquake rudely disturbed the applecart of complacency in regards to earthquake occurrence in Deccan area. The question asked is–what precautions are necessary to overcome future earthquake hazards in this area? This question is asked with the tacit belief that earthquakes at Koynanagar indicate the development of new forces. It, however, appears possible that instead of development of new forces, the earthquake is indicative of degeneration of force system that will give the region increasing stability. However, this does not mean that earthquake will not happen in future. It only means that the frequency of occurrence of such events in future may not rise but may actually fall. The philosophy of earthquake insurance is based upon a correct assessment of the earthquake risks and relative economics of the protective measures. From this point of view, is it necessary to introduce protective measures in a general way? It is felt that the occurrence of Koynanagar earthquake should not itself be considered as evidence regarding increase in activity in the region. As such any programme of introducing additional insurance for structure in the region should be scrutinised properly. Of course, it should simultaneosly be made obligatory that all constructions, whose failure may mean a general hazard to public life and property, should have, in their design substantial earthquake resistance factor. Nuclear Power stations, other Nuclear installations, dam across rivers etc. should only be put under this category. The exact value of such factor can be worked out only after necessary data are obtained.

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