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A note on the Godavari valley earthquake

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ABSTRACT. The Godavari valley earthquake of April 1969 has been studied in the light of the known geology, tectonic history and geophysical information of the Godavari valley region. The region near the neck of the Godavari Rift Valley where the epicentres are located, underwent three periods of tectonic disturbance. The net effect is that the region is structually disturbed and accumulation of stresses can be expected there. Negative gravity anomalies, observed in the region, may be accounted for the decrease of effective strength. Movement of underground water might have aided in reducing frictional resistance. Thus, the probable mechanism can be sliding and slipping along pre-existing faults and shear zones.

1. Introduction

At 8·55 P.M. on 13 April 1969 the entire Andhra Pradesh was rocked by an earthquake of moderate intensity which was followed later by a milder tremor. The earthquake has thrown the Kottagudem Thermal Power Station near Bhadrachalam out of commission. Between 15 and 19 April, there occurred as many as four mild tremors and more than fifteen aftershocks. Again on 1 May 1969, there was another tremor at 0·56 A.M. of moderate intensity. The S.P. intervals of seismic records of 13, 15, 18 and 19 April and 1 May from Visakhapatnam Seismological Observatory place the epicentres near the southeastern end or the neck of the Godavari valley (Fig. 1).

It is known that the area under discussion has been experiencing minor earth tremors from time to time. Two of the recorded events in the past are the 1956 tremor and the 30 July 1968 earthquake. Seismic activity, in general, shows that deformation of the crust is currently taking place. Further, it is a well known fact that Godavari valley is a tectonically disturbed region. Hence one can state that the 'immediate' cause of the Godavari valley earthquake is reactivation along pre-existing fault planes or shear zones. An attempt has been made in this note to explain the possible 'ultimate' cause of the earthquake on the basis of known geology, tectonic history and geophysical information of the region in question.

2. Evolution of the rift valley

A possible mode of evolution of the Cuddapah-Gondwana rift valley is proposed by Dar and Viswanadhan (1964). According to them, Peninsular shield during its evolution accumulated sedimentary deposits along regional depressions called troughs or rift valleys. In this rift valley, Cuddapah age rocks (Pakhals etc) were deposited first. This was succeeded by lower Vindhyan sediments after a period of quiescence. Prior to the deposition of Gondwanas, a second phase of crustal disturbance deepened and extended the length of this trough. In the last period of deposition during Cretaceous, sediments were laid down in the narrow arms of the Cretaceous Sea extending into parts of the filled-up Cuddapah-Gondwana trough.

3. Structure and tectonics of the southeastern end of the Godavari Rift Valley

The southeastern end of the Godavari Rift Valley is conspicuous in that its structure is entirely different from that of the main rift valley. In the vicinity of Ansettipalle and Paloncha (Fig. 1) the lower Gondwanas occupied a narrow strip of less than 8 miles in width as against a 50 mile wide rift in the northwest. This narrow strip and its southeastern extension are underlain by crystalline schists while the Pakhals are missing altogether. A reasonable explanation should be that the Godavari Rift Valley terminated near Ansettipalle and that the Gondwanas in the southeast are

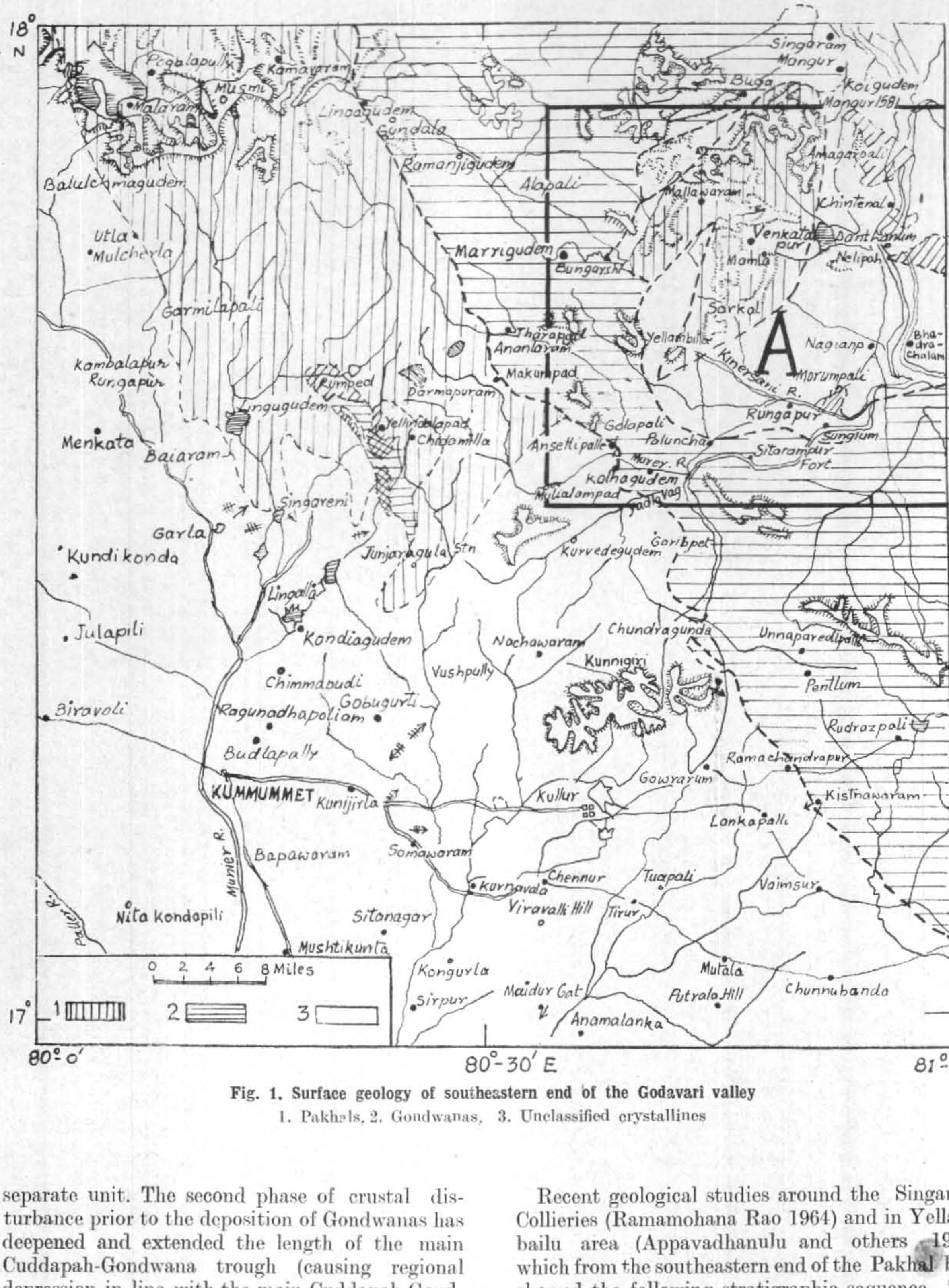

Fig. 1. Surface geology of southeastern end of the Godavari valley
1. Pakhals, 2. Gondwanas, 3. Unclassified crystallines

separate unit. The second phase of crustal disturbance prior to the deposition of Gondwanas has deepened and extended the length of the main Cuddapah-Gondwana trough (causing regional depression in line with the main Cuddapah-Gondwana trough in the Archaeans) to the southeast of the rift valley which became the collecting ground for the Lower Gondwanas,

Recent geological studies around the Singareni Collieries (Ramamohana Rao 1964) and in Yellambailu area (Appavadhanulu and others 1967) which from the southeastern end of the Pakhal belt showed the following stratigraphic sequence. The Archaean schists and the gneisses (Lower and middle Precambrian ?) in the area are folded and unconformably overlain by the Pakhal sediments

(Upper Precambrian ?) subjected to intense folding and shearing subsequently and before the deposition of the Gondwanas. The Gondwanas overlie the Archaeans and the Pakhals. Though, out of line, it is to be noted that the Pakhals are the time equivalents of Cuddapahs of the type area and they cannot be correlated because they are lithologically dissimilar.

The Pakhals at the southeastern end of the belt are said to be structurally disturbed and metamorphosed. Different structural trends meet in the vicinity of Singerani collieries (Krishnan 1961). Presence of carbonaceous and argillaceous quartzites (Appavadhanulu and others 1967) in the Pakhals is of particular relevance. The NE-SW trend of the fold-axes of Pakhals suggests that the post-Pakhal disturbance may be related to Eastern Ghats orogeny. The thrust faults near the southeastern end of Pakhal belt also have NE-SW trend in general. The same course of the Godavari river can be expected for the movement of underground water along the floor of the valley. Movement of water through faults and shear zones reduces frictional resistance until finally movement takes place (Evans 1967).

The region near the neck of the Godavari Rift Valley underwent three periods of tectonic disturbance. The first, a pre-Pakhal orogeny, which affected the gneisses etc., is probably of middle Precambrian age. The second period of disturbance is also pre-Pakhals which is responsible for the formation of Godavari Rift Valley. The third one is the post-Pakhal disturbance which is related to the Eastern Ghats orogeny.

4. Geophysical inferences

(a) *Gravity anomalies* — The General nature of the rift valleys and their associated gravity anomalies can be summed up as follows —

(1) Width of the rift valleys is more or less uniform ; (2) Rift valleys are generally associated with—50 milligal gravity lows ; (3) The negative anomalies tend to occur as separated, closed minima and (4) small gravity highs flank the gravity low. Vening-Meinesz and Heiskanen (1958) explained the gravity high flanking the gravity lows as due to the uplifting over the boundaries of grabens, if they were formed according to the tensional theory of graben formation. The presence of small gravity highs flanking —50 milligal low in the Bouguer anomaly map of Godavari valley (Qureshy and others 1968) proves that the Godavari valley consists of graben structures. One significant feature of the Bouguer anomaly map of them is that the gravity anomaly pattern, southeast of Venkatapuram is different from that to the northwest. The anomaly trends in the southeast are not related to the main rift valley but are parallel to the Eastern Ghats trend. A regular gravity pattern is absent at the southeastern end of the Pakhal belt owing to the intense disturbance to which this region is subjected. Qureshy *et al.* (1968) also indicated that their map of south India shows northeast trending gravity lows all along the east coast.

(b) *Geothermal measurements* — King (1881) had already referred to two hot springs near the southeastern end of the Godavari valley. One is situated on the left bank of Godavari river a few miles below the temple of Bhadrachalam. The second spring is situated in a valley about 30 miles to the northwest of the first one. Geothermal investigations, conducted by the N.G.R.I., Hyderabad, showed that the area under discussion is characterised by anomalously high heat flow values. One significant feature is that vertical gradients are very high locally wherever coal seams and carbonaceous shales are present (Verma *et al.* 1967). Appavadhanulu *et al.* (1967) reported the occurrence of carbonaceous phyllites and quartzites as conformable, impersistent bands immediately above one of the lower quartzites in the Pakhal succession in Yellambailu and Sarakal areas. The downward temperature gradient generally, is the result of earth's cooling. Horizontal temperature gradients usually act as 'trigger effects' (Vening-Meinesz and Heiskanen 1958) for getting the convection current systems started besides initiating earthquakes. In the region under discussion, the carbonaceous strata in the Pakhals may provide the horizontal temperature gradients.

5. General mechanism of earthquakes

Whenever the stress is high within the earth, it will be expected to be mainly of the nature of a hydrostatic pressure. The strengths of the earth's material set an upper limit to the distortional stress but not to the pressure. Immediately on reaching this limit, there will be fractures and hence an earthquake. Also, with increase of structural heterogeneity, stress concentration will take place at a greater number of points resulting in a number of microfractures. Further, fractured rocks can support stress and can be refractured and produce earthquakes similar to those emanating from unfractured terrain. Moreover, earthquakes occur not only because elastic stresses increase but because the effective strength of the crust decreases in the regions of existing fractures without change of other conditions.

6. Godavari valley earthquake

The S-P intervals, surface effects of the earth tremors and the presence of P_g phase on the seismic records, which suggests a level of weakness in the crust-all point to one conclusion : that the foci of the tremors lie within a zone marked by 'A' (Fig. 1), which is subjected to three periods of disturbance as mentioned in Section 3. It was reported that the ground in Kothagudem, Marrigudem and Burgumpahad areas have developed cracks. For earthquakes, wherein tectonic ruptures are visible on the surface of the earth, they are probably connected with the formation of dislocation or sliding on pre-existing faults, shear zones or other discontinuities. The dissimilarity in the trends in the valley and elsewhere of Bouguer anomaly map of Qureshy *et al.* mentioned in Section 4(a), leads to the inference that the region 'A' in Fig. 1, might be a terminus or junction of at least two sets of fault trends. Closure of the —50 milligal gravity low near the neck of the Godavari Rift Valley and the reported presence of costal anomaly trends (Qureshy, Plate 1 1968) speaks of the fact that the region 'A' is a victim of the Godavari rift event and Eastern Ghats orogeny as explained in Section 3. The collecting grounds of the Cuddapah-Gondwana rift valley and Cuddapah basin are Archaean Complex basement. Whereas differential subsidence and rolling of beds occurred in the Godavari rift, sinking and downbuckling took place in the Cuddapah basin. This explains the relative strengths of the basement in the two regions. Under these circumstances, one may expect the development of lateral compressive forces, the magnitude and direction corresponding to the two regions being different. The region A, which is the meeting ground of the Godavari rift and the Cuddapah basin, when the extremes are extended (rocks of Cuddapah age occur to the northeast of A), then will have a resultant force component. The shearing resultant component gives way to rupture followed by crushing and sliding, on reaching a limit. Thus, a shearing force resulting from two unequal lateral compressive forces due to unequal isostatic under-compensations leads to an earthquake. Thus far, we have the following facts.

(1) The region under discussion is subjected to disturbance during three periods. It may be a terminus or a junction of at least two sets, or even more, of fault trends. The net effect is that the region is structurally disturbed and is accumulating stresses.

(2) Deficit of material or difference in the density contrast which accounts for the decrease of effective strength is evidenced by the negative gravity anomalies (Qureshy, Plate 1 1968).

(3) Movement of underground water might have aided in reducing frictional resistance.

In view of the disturbed nature of the region, the probable mechanism can be sliding and slipping along pre-existing faults and shear zones at about 5·5 km depth (Rao and Prakasa Rao, 1970) Trigger mechanism, (Savarensky 1968) which releases the energy built up either by unequal isostatic under-compensation or due to accumulation of shear stresses or both as in the present case, is either an additional force or a variation of the effective strength in the material. Reduction of frictional resistance along fault planes and shear zones in the first place and horizontal temperature gradients, discussed in Section 4 (b), might have furnished the necessary energy in starting the rupture.

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