

# GEOTECTONIC MOVEMENTS AND THEIR INFLUENCE ON THE HYDROGRAPHY OF INDO-GANGETIC PLAINS\*

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## INTRODUCTION

The seismic phenomena in relation to the geotectonics and structure of Extra Peninsula and occasionally of Indo gangetic plains have been dealt with by various authors such as Oldham (21), de Ballore (5) Dunn (7) Wadia (2729) Auden (3 & 4). Further various accounts of the changes in the pattern of hydrography and paleogeography of the Indo gangetic plains in Recent era have been published by Oldham (17), Pascoe (22), Pilgrim (22), and Krishnan (14) etc. Besides these there are a number of archeological findings of ancient towns like Pataliputra (near Patna) and Harappa Mohenjo Daro (in Rajasthan) which now lie buried down in the Indo gangetic alluvium. Notorious and unstable behaviour of the Indus, the Ganges and the Brahmaputra system of rivers from time to time are well known. Sudden devastrous floods of great magnitude resulting sometime even in the declination of complete civilization (26) have also been reported.

Many attempts have been made recently (8,24,25) to analyse the factors responsible for peculiar behaviour of rivers and exceptional floods in the Indo gangetic plains. Flood frequency studies at certain headworks (2) and the past flood data have revealed that floods of exceptional discharge and magnitude occur only a few times in a century. Strangely enough the above catastrophe has not been explained from the point of view of the geotectonic movements.

The manner in which these geotectonic movements are developed and their ultimate affect on hydrography could not be studied because of the inaccessability of the basement rocks which are covered by a thick blanket of alluvium. However, based on the information available from the recent geological (19), geophysical (11), geodetic (10), aeromagnetic (1) and seismological records it has been possible to visualize the nature of the underlying tectonics. The views put forward here are the result of a study of all the above mentioned evidences in the light of the past seismic and tectonic history of the Indo gangetic plains. An aerial and land survey were also undertaken by the author to observe the behaviour of the rivers of the Ganga and the Brahmaputra system specially during high flood seasons.

## STRUCTURE AND TECTONICS

Little is known about the exact nature of the geological history of Indo gangetic plains, because the whole expanse of these plains from the Punjab to Assam form only a thick deposit of Pleistocene and Sub Recent

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\*The term Indo gangetic plains also includes Brahmaputra Basin (9)

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alluvial deposits.

That the origin of these alluvial troughs has been intimately connected with the great orogenic movements of the late Tertiary times is a very widely accepted view. The idea of Eduard Suess (28) who considers it a "fore deep" i.e. a slight buckling down of the crust like a synclinalorium in front of the newly arisen Himalayas has also received a general concurrence.

A glance at the generalized North - South and East - West cross sections of the trough as shown in Figs. 1 & 2 will give a rough idea of the overall structure and tectonics of the Gangetic trough. Fig. 1 represents only a diagrammatic North - South cross section of the Gangetic trough. On the north are the Himalayas proper and near the southern edge of it a series of successive boundary faults. To the right is the alluvial trough proper, the floor of which at first slopes downwards to the point of maximum depth (15,000 - 20,000 according to Oldham)(19) and then rises gradually upwards to the southern limit of the alluvium and the northern fringe of the peninsular table land. The maximum depth of the trough lies between  $L 82^{\circ}$  to  $L 86^{\circ}$ .

As shown in Fig. 2 which is a diagrammatic representation of a longitudinal cross section in E.S.E. - W.N.W. direction the trough lies hinged at two places. To the west are the Aravallis and their postulated N.E.N. extension below the alluvium. To the east lies the North - East extension of Garo - Rajmahal series of peninsular rocks. Strike directions of these two formations are shown in Map. 1.

As elucidated by the geodetic evidences, Oldham (19) pointed out that the position of the southern boundary of the trough at the eastern end terminate where Assam range impinges on the boundary of the Himalayas. The trough has a width of about 80 - 100 miles near Jalpaiguri and Ramchandpur. In a westward direction the southern boundary of the trough is fixed by the boundary of the rock and alluvium at Monghyr. Later it follows the general course of the boundary of the Peninsular rock area till  $L 80^{\circ}$ . Near Agra and Delhi it runs almost N.N.W. and the boundary lies close to Hatharas. Westward of this line is merely a covering of a few hundred feet of alluvium over the rocky floor.

From the above description of the structure and general geomorphology it can be summarized that we have a fairly symmetrical trough which lies like an apron along the southern side of the Himalayas.

It may be pointed out that the trough whose form and dimensions have just been described is only a part of the great spread of alluvium known as the Indo-gangetic basin. The Indus basin, similar to the Gangetic basin though smaller in size runs along the foot of the hill ranges of the Baluchistan Arc. The two troughs are probably separated by a rock barrier, stretching under the plains of the Punjab to the Salt-Range as pointed out by the outcrops of old rocks in the Chimot and other hills which rise above the alluvium.

## SEISMOLOGICAL FACTORS

Tectonic distribution

The subject of the origin of the great potential energy inside the rocks and further the manner in which it is translated into kinetic energy ultimately resulting in earthquakes, is much too conjectural and is beyond the scope of the present paper. The distribution of the active seismic zones in India along the southern flanks of the Himalayas and the northern border of the Indian peninsula which has also been folded, faulted and over-thrust during the Tertiary era indicate that most of the earthquakes originate because of the marked instability of the tectonic units. So much so, actual fractures of rock are known to have accompanied the tremors during the Cutch (India) earthquake 1819, (20) the Chaman (Baluchistan) earthquake of 1892(29) and the Assam (India) earthquake of 1897 (21).

Instability of the Basement Tectonics

The tectonic units of India and their inter-relationship with the seismicity of different areas have been discussed earlier (4,5,7,27). Confining mainly to the Indo-gangetic troughs, the present paper aims to focus the peculiar disposition of the various geotectonic features in the light of the rock behaviour phenomena in tectonic processes by which it would appear that the state of great stresses and potential fractures must be present to exist below the Indo gangetic alluvium.

As discussed in the preceding section Suess's idea of synclinorium which has later been confirmed by the geodetic evidences (10,11) explains most of the causes of tectonic instability. Viewing back the origin of these synclineriums it has been stated (13,14) that they must have been formed by a slight buckling down of the crust in obedience to the pressure exerted on the borders of the peninsula by horizontal compressive forces.

As the rocks exposed at the surface are bent towards the south in the Himalayan Arc, towards the west and east in the Burmese and the Baluchistan arcs respectively the author is of the opinion that the direction of the horizontal compressive forces which were responsible for the downwarping movement, must have been in two directions i.e., East - West and North - South, perpendicular to each other. In such cases, when a mass is distorted into any new shape with respect to two compressive forces acting in two different directions, the dilation is only possible in one direction perpendicular to the two forces. Hence, the dilation must have been in a vertical position producing thereby - the anticlinoriums and synclineriums. Incidentally it may be mentioned here that the drop of the Garo Rajmahal Gap on the eastern side of the Gangetic trough and the Aravalli hills postulated extension on the west of it was probably the result of this vertical movement.

Obviously the elastic stresses developed at the time of this crustal deformation or distortion must be tensional at the outer arc and compressional at the inner arc of the synclinorium. As expected these stresses inside the thick elastic rock mass must have resulted in the shearing stress parallel to the surface which ultimately developed shear planes on

the flanks of the fold (Figure 3). This would naturally lead to the development of concentric shear planes with respect to the forces supposed to be still alive according to Oldham (19), Wadia (27,28), West (29) and other (5,13,14).

No doubt the process of elastico - viscous flow assumes that on these concentric shear planes the shearing stresses rise beyond the limit set for flows and cause big ruptures. The amount of kinetic energy released then or in other words the severity of the earthquake shock depends upon the type of rocks and the thickness of the strata involved at the basement.

In the light of the explanation of instability described above the area of maximum instability must lie along the axis of the asymmetrical Gangetic syncline which runs in E.S.E. and W.N.W. direction very near the foot hill zone of the Siwaliks. This has actually been observed during the great Bihar Earthquake of 15th Jan. 1934.

"The elliptical nature of the isoseismals strongly suggests the linear nature of the centrum or focal region and the occurrence on one or more fractures below the Gangetic alluvium between Motihari and Purnea may safely be postulated" (p. 220) (4)

It appears that Hunter (12) described this area running exactly in the line of the present author's asymmetrical synclinal axis (E.S.E., W.N.W) as an area of underload. He further stated (loc. cit.) that the stress differences are caused by the loading anomaly between the zone of underload and overload. He has not actually shown the direction of stresses but presumably the two areas shown by the two points in Fig. 4 drawn herein indicate that they must act into two different directions, creating zone of stress in between the two. If this is correct, the epicentre should not lie exactly below the area either of underload or of overload (loc.cit.) but in between the two.

The above view point is indirectly supported by the observations of E. A. Glennie (10,11) that the anomalies are not due to the low densities of the alluvium but due to a deep seated phenomena whereby the granite, basalt, and dunite layers of the earth crust have been depressed over this area and elevated further south.

Another noteworthy tectonic feature which deserves mention in this section is the existence of the Aravalli ranges extending across the region where the Gangetic trough was subsequently brought into being. This would certainly produce a pronounced effect on the instability of structures by introducing a variation in the strength of the earths crust and consequently a difference in the resistance which it would offer to the forces by which the trough was produced and also to subsequent subsidence. Similarly the interruptions on the eastern side of the trough can be visualized by the North - East extension of the peninsular rocks.

#### SECULAR CHANGES IN LEVEL

From Fig. 4 it will be noticed that the process of splitting up of the original layer into more and more independent arcs will allow continuous

bending of the strata without further increasing the stress inside the rocks so that the elastic state of the rigid rocks is never lost.

In support of the continuous existence of stresses to cause this further bending of the trough we find a general concurrence among geologists and seismologists that the Central Himalaya & Outer Himalayas and the Gangetic basins are under great stresses, which are maximum between the southern boundary of the Extra-Peninsula and the northern fringe of the Gangetic trough:

"At any rate, it is clear that the northern rim of the great trough is under considerable tectonic strain due to progressive downwarping with the greatest subsidence where it merges into the foot of the mountains" (28)

The stresses remain in the form of potential energy inside the elastic strain of rocks.

Huge quantities of sediments are brought down by the Himalayan rivers and deposited in their respective sedimentary basins. This process of erosion and sedimentation does create an additional stress over the basement rocks. These additional stresses go on accumulating as the process of sedimentation and erosion proceed for a number of years till they in conjunction with the original potential stresses overcome the elastic strain limit of the rocks when further splitting and rupture of the substratum takes place. It is mentioned (29) that sedimentation load does not play a significant role in stress formation. But the geological processes of erosion and sedimentation which have ultimately resulted in the deposition of thousands of feet of alluvium are not so insignificant and do create additional stresses which act like a trigger of a gun to release the stresses - to cause rupture - earthquake and ultimately subsidence.

Although it is difficult to estimate quantitatively the actual amount of differential movement of the upper crust in obedience to the downwarping at the base, it is quite certain that such a great thickness of alluvium must have been deposited by a process of secular subsidence and alluviation.

Such secular changes in level were actually observed during the earthquake effects of North Bihar in 1934 and a number of illuminating examples of subsidence have been reported (7).

The area of the belt of subsidence was reported (*loc.cit.*) to be 4,700 sq. miles in Bihar and extended for about 190 miles in a W.N.W. and E.S.E. direction which again is exactly the same as the direction of synclinal axis.

Examples of such secular subsidences are not rare in other countries also. New Madrid earthquake has afforded indisputable evidence of vertical subsidence and the area of sunk land are still preserved along the alluvial depressions west of the Mississippi Valley over a total extent of about 1000 sq. miles. The depression was reported to be 20 feet. (7)

The Cutch earthquake of 1819 (20) resulted in the elevation of an

area 50 miles long and 20 miles wide and 10-26 feet in height. Concurrently with this elevation, the area to the south subsided.

#### HYDROGRAPHIC INFLUENCES

Rivers alter their courses and exhibit peculiar behaviour at the slightest provocation. In the preceding description we have seen that the geotectonic movements which result in secular differential changes in ground level must have a pronounced effect on the hydrography of the Indo-gangetic plains. Ground water-table was raised and rivers changed their courses during the North Bihar earthquake of 1934.

#### River Courses

In obedience to these geotectonic movements rivers in Indo-gangetic plains have been changing their courses since late Tertiary times. These changes in fact have resulted even in complete reversal of the direction of flow of the chief rivers in the Indo-gangetic plains. The river named "Siwalik River" by Pilgrim (23) and the "Indo-brahm" by Pascoe (20) was a great north-west flowing river lying at the southern foot hills of Himalayas from Assam to the farthest north-west corner of the Punjab and then flowing towards the south met the gradually receding Miocene sea of Sind and Punjab.

Consequent to the Post-Siwalik movements a dismemberment of this river was brought about and ultimately three subsidiary systems - (1) the Indus (2) the five tributaries of the Indus and (3) the Ganges were formed. The Indus has been changing its course from time to time.

"The main channel of the Indus upto 1800 A.D. flowed through the middle of the Thar. In that year it split up into two channels, and of these (the Khedewari) which was the main waterway upto 1819 was blocked by an earthquake. By 1837 the Kakaiwari was the main stream but this also became blocked in 1867. In 1900 the chief channel was the Hajamro".(14)

There are both physical and historical evidences to show that the sacred Saraswati river of Vedic times - now almost a lost river - was once a mighty river and flowed through the eastern Punjab and the Rajasthan. An old bed some 600 miles in length is still traceable from Ambala through Bikaner and Bahawalpur to Sind. (17)

The Yamuna used to discharge into the Indus system, but due to the geotectonic movements in Sub-Recent times it took more and more easterly course and ultimately joined the Ganges at Allahabad (27).

The 'Sutlej' which was once an independent river never joined the river Indus but joined the Beas near the south-west corner of Kapurthala in 13th century. The Beas also had a different course which can still be traced.(14)

Patliputra is said to have been situated at the junction of five rivers- the Ganges, Gogra, Gandak, Son and the Pumpun. The city now lies buried beneath the alluvium near the modern Patna and the junction of these rivers with the Ganges are widely separate.

The Tista which was once a tributary of the Ganges, became a tributary of the Brahmaputra after the disastrous floods of 1787. The Brahmaputra which used to flow east of Madhopur jungle now joins the Padma much further west (14).

Similarly there are many other instances of great Recent and Sub-Recent changes in the course of rivers in the Indo-Gangetic plains. The Kosi in particular has shifted its course from time to time and has swept an area of nearly 4,000 sq. miles.

Regarding the hydrography of these plains to-day we find that it is directly dependent upon the various hydrostatic gradients which appear to follow the structural pattern of the floor of the troughs. As has already been discussed the Gangetic trough is hinged towards, north by the Himalayas, towards south by the Peninsular rocks, towards west by the Aravallis and towards east by the Garo-Rajmahal extension. Consequently four gradients lying approximately in S.W., N.E., S.E., and N.W. direction, and having the resultant gradient in E.S.E. - W.N.W. direction which is the general drainage of the Ganges, have been established. The resultant gradient of the Indus basin is towards south west.

### Floods

A query as to why we have had more and greater floods in the Gangetic basin during recent times has been a much discussed problem among hydrologists and engineers. Technical Sub-Committees (24,25) and high level committees (8) appointed from time to time could not trace satisfactorily the actual cause of sudden excessive flood cycles. It has been observed during the recent cycle of floods that the rate of rise of water has been very rapid, floods subsiding slowly and leaving water logged areas. New areas have been invaded by the inundating flood waters and the abandoned channels got new life. In addition it is reported that the floods mostly occur during the later part of the rainy season.

From the earlier discussion it is clear that it is very difficult to estimate quantitatively the actual amount of secular differential changes in ground level. But it is certain that these geotectonic movements do establish from time to time a new and significant hydraulic gradient equilibrium sufficient to cause disturbances in the original flowing and transporting capacity of the rivers of these basins. The maximum amount of subsidence in the Gangetic basin can be expected to be between  $184^{\circ}$  to  $186^{\circ}$  in E.S.E. and N.W.N. direction. Naturally the first and the maximum gradient in south west direction (Map 1) gets considerably increased with the differential rise of the hilly tracts lying towards the north. On the other hand the resultant slope in E.S.E. and N.W.N. direction after about  $184^{\circ}$  gets relatively reduced. In support of this assumption we find that the western part of the Gangetic basin is about 500 ft. above the sea level, while the level of the eastern part at Allahabad where the Yamuna meets the Ganges is only 340 ft. above the sea level. Allahabad is about 512 miles from Calcutta and therefore the slope works out to less than one foot per mile. In the light of these geotectonic movements the slope of one foot per mile gets further reduced which is difficult to measure by ordinary survey instruments.

As a result of these changes in various gradients rivers drain off their catchment area with a changed degree of efficiency. Rain water from hilly tracts is brought down with a higher velocity than before. This water further meets a reduced gradient in S.E.S. direction which ultimately results in sudden rise of the water level and all other phenomena connected with the recent floods.

The decreased slope and blocking up of the drainage helps in more underground percolation of water, thereby recharging of the subsurface reservoir becomes more efficient, till it gets almost saturated in the early part of the rainy season. This in conjunction with the slight rise of water table caused by the tectonic movements explains the recurrence of floods in the later part of the rainy season.

#### DISCUSSION

Silt deposition, deforestation, excessive rain fall, land slides or other causes are sometimes thought to be the main cause of the recent havoc of floods and the changes in the river courses.

Silt deposition is one of the factors which can decrease the slope. But the sudden excessive silt deposition can only be an effect to some other basic cause. The slow and continuous phenomena of silt deposition does not become effective so suddenly in all the rivers at the same time. Further any amount of silt deposition will not influence the slope as long as the river has got a movable bed. This is in conformity with the idea of Leet.

"If we go beyond casual observation and gather accurate data on width, depth and velocity and discharge of a stream from its head waters to its mouth for a particular stage of flow-say flood or low water - we find again that the change follows a definite pattern and that the depth and width increase down stream as the discharge increases."(15)

Suppose a silt particle is deposited at point A as in figure 5. This particle will tend to reduce the velocity of water from A to B according to the laws of sedimentation. Since deposition is directly related to the velocity same size fractions should be deposited gradually up-stream upto B and then upto C,D,E etc. In short the stream tries to maintain the original gradient in order to maintain the flow.

Deforestation, excessive rainfall, land slides, etc. can only be of local importance in one or two rivers but could not be on regional basis as has been happening in case of the Indo gangetic plains.

#### CONCLUSIONS

The following conclusions can therefore be drawn from what has been set out in the preceding sections.

1. The Geotectonic movements which were originally responsible for the formation of the Indo-gangetic plains as well as for the present state of great instability are due to the two horizontal compressive forces acting perpendicular to each other in north-south and east-west directions.

2. The two horizontal compressive forces have resulted in the formation of zones of concentric shear planes along the axis of the asymmetrical syncline of the Gangetic trough.

3. Earthquakes originate due to the rupture of the strata created by the tensional forces operating at the outer arc of the Gangetic synclinorium. The tensional forces are primarily due to the two horizontal compressive forces and secondarily to the process of erosion and sedimentation.

4. As a result of the geotectonic movements in the Indo-gangetic plains great amount of secular changes in ground level have been continuously taking place.

5. Hydrography of the Indo-gangetic plains has been profoundly effected since post-Siwalik times as a consequence of these geotectonic movements. Changes in the main drainage lines and recurrence of the flood cycles are attributed to the secular differential changes in the hydrostatic gradients of the rivers of Indo-gangetic trough.

#### ACKNOWLEDGEMENTS

The author wishes to thank Dr. D. N. Wadia, F.R.S., for his personal discussion with the author at the time of 'Earthquake Engineering Symposium' at Roorkee, the authorities of Geological Survey of India and the Central Board of Irrigation & Power for providing the necessary literature, Dr. V. S. Ramachandran and Mr. R. B. Sharma of Central Building Research Institute for the help rendered in preparing the manuscript.

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