Mechanical analysis of dyke pattern of the Pachmarhi

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The Dykes arrond the Pachmarhi

Abstract - It is possible to explain the shape of the remarkable Dyke pattern surrounding the Pachmarhi, by an analysis of stresses if a regional-stress system in which the direction of greatest principal pressure was parallel to the line of symmetry exhibited by the Dyke pattern superposed on a local-stress system is assumed. This local-stress system is caused by hydrostatic pressure exerted by the intrusive mass of the Pachmarhi. For simplification of the computations a circular hole is assumed at the position of Pachmarhi. The mountain front west of the Pachmarhi provides an unknown boundary condition, which however can be described with satisfactory results by the assumption of an image source. On the basis of the assumption that the

relation between stress field and Dyke pattern is the one proposed by Anderson (1951, Chap. 3) it is then possible to compute the Dyke pattern. This computed Dyke pattern agrees in many respects with the observed Dyke pattern.

Dykes are commonest in the Mahadeva range from the Dhudhi River to khapa and fairly common in the region south of the Mahadeva range as far west as the Chandkia Golandoh fault .These Dykes are varying in size from thin tachylitic veins to mighty intrusions 100 meter or more in width, and extending for many kilometers. Most of them run in an east-north-easterly direction, and are associated with faults. In many cases they are not continuous, but form elongated lenticles in the fault planes. Many of the larger Dykes bifurcate forming two lesser ones. This probably takes place where two pre-existing lines of weakness cross.

Proofs that the Dykes follow fault planes are by no means easy to collect. The best evidence was obtained from the region between the Hard river and Kodali trap flows have been frequently faulted against the Gondwanas, and the fault lines are particularly easy to see, on account of the sudden change in the rocks on either side of them. In many places along these fault planes I found lenticular Dykes, often stretching for kilometers. Other unmistakable instances of faults associated with Dykes were noted between Chandkia and Golandoh, and north of Basania ($22°22'$: $77°53'$). In the latter place there is at first a strong fault breccia with marked change of dip on either side. If this be followed to the west the breccia is replaced by a Dyke, which is also associated with a striking change in the dip The Dykes do not lie along fault planes. The great Dyke crossing the Mahadeva range north of Bori is a good instance. This is perhaps the most massive Dyke in the whole of the Satpura, though by no means the longest. It zigzags right across the strike of the Gondwana rocks from one side of the Mahadeva range to the other, and seems to be connected with large sill-like intrusions on both sides of that range. Nowhere is there any marked change of dip, or alteration in the nature of the rocks on either side of this great intrusion. How it reached its present position I do not know, but there is no evidence whatever that it occupies an old fault plane.

Multiple Dykes

Multiple Dykes were noted in a few places. One of these was on the Dudhi river near Jargon ($22°39'$; $78°41'$). In this case the older rock, a coarse ophitic dolerite, has been broken up by a newer medium-grained Dyke, and is now seen as great angular blocks of weathered material surrounded by fresh black trap. A little farther on this Dyke splits into two, and it is probable that its multiple nature can only be observed near the junction.

The explanation of multiple Dykes of this kind seems to be that contraction on cooling tends to produce fissures near the centers of Dykes, which can act as channels for any later intrusions. Confirmation of this is sometimes obtained, where sections of tachylitic veinlets are examined. These often have cores of secondary calcite suggesting the presence of open cavities formed along their central axis subsequent to consolidation. Such cavities were probably due to shrinkage on cooling.

Another good case was noted at Keria (22° 33′: 78° 10′), where non-porphyritic medium-grained dolerite 30 meters wide forms the centre of a Dyke about 100 meters wide, the outer edges of which are composed of coarse porphyritic dolerite. That this really is a multiple Dyke is clear, since the central part has two tachylitic margins.

A feature of all the multiple Dykes observed by me is that the newer central portion is finer in grain than the outer edges. This may be due to the higher thermal conductivity of dolerite as compared with sandstone, or may be only a question of the size of the different parts of the multiple Dykes; for the newer central portions are almost always the smaller. Probably both factors come into play.

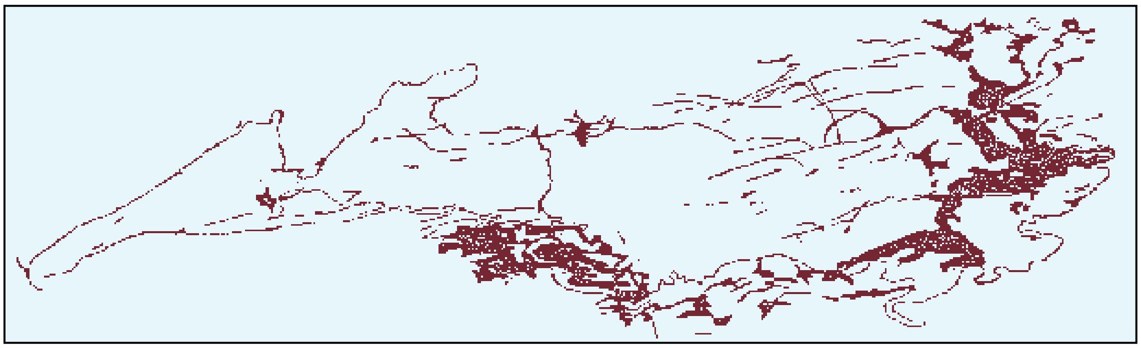

Figure.1-System of Dyke surrounding the Pachmarhi

Apophyses from Dykes

Some of the Dykes cut sharply through the surrounding rocks, while others put out numerous apophyses and veinlets, which ramify in all directions, but never extend for any distance from the parent mass. I suggest that when the pressure of the magma is greatly in excess of that in the surrounding country rock, it forces its way along rapidly as one large intrusion. When, however, the two pressures are almost equal any slight variations of magmatic pressure might result in the formation of minor apophyses along lines of weakness in the country rock. At the limits of extension of all intrusions their magma pressure must have been almost equal to the pressure in the country rock. That is, the conditions must have been most favorable for the formation of minor apophyses. This is possibly the explanation of the swarms of minor Dykes seen near the ends of major ones

Composite Dyke

I have seen only one instance of a large Dyke made up of two rocks differing noticeably in their mineral constituents. This composite intrusion was traced westwards with occasional breaks from a kilometer south of Lukadhana (22° 24′: 78° 34′) to a kilometer east of the main road crossing over the Denwa river near Nandia. Strictly speaking only the western end of this Dyke is composite, for the more basic part is not seen east of Jamundhonga. The general direction of the Dyke is east by north, which is also the strike of all the normal dolerite Dykes. In its composite part this Dyke consists of three portions, each of which has a width varying from 0 to 30 meter. The acid part, which is almost everywhere the central part, is a porphyrite, and the two outside portions are dolerites. East of Jamun-Dhonga the dolerite Dykes disappears, but the porphyrite thickens greatly, and ranges up to 100 meter in width.

The explanation for the origin of remarkable Dyke system at Pachmarhi in fallow possibly, the cause for this swinging around an east-south direction is that the forces that near the stocks produced the radial fissuring opened up, at a greater distance from the stock the latent tension fissures produced during the compression that had folded the sedimentary beds into a broad syncline before the stocks were injected, *i.e.,* the Dykes availed themselves of latent tension breaks across the axis of the fold.

From a mechanical viewpoint a more satisfactory explanation can be given by an analysis of the Dyke pattern in terms of stress. Such an explanation is based on the assumption that an intimate relation exists between stress field and Dyke pattern. Anderson (1951) postulated that the formation of Dykes is due to a wedging effect of the intruding magma. According to his theory Dykes form along planes lying normal to the direction of least principal stress or in Other words along planes of greatest and intermediate principal stress.

Anderson's assumption are derived directly from the work or Griffith (1921;1924) From terminations of the tensile strength of brittle materials it was noted that the observed values of the tensile strength were one or two orders of magnitude lower than values expected from theoretical considerations (Orowan, 1949). To explain this discrepancy Griffith assumed that the tested brittle material contained numerous small cracks of random orientation. These small cracks he envisaged as small ellipsoids of large eccentricity. Stresses applied to the material cause large stress concentrations at points near the ends of the ellipsoids. The sudden and rapid propagation of the crack occurs then as follows. If the crack is given a small virtual increase in length some energy is required to break the bonds between particles in the material. There is also a small increase in strain energy of the plate. Griffith postulated that, as soon as the total work done by the external forces exceeds the sum of the increases in surface energy and strain energy of the material, the crack will spread. In this manner the observed tensile strength can be related to the length of the crack. Also the orientation of the cracks first to become unstable under various systems of applied loadings can be investigated. In general the orientation of those cracks does not coincide with that of the principal stresses in the plate. Therefore Griffith suggested that his theory could explain the inclined fractures often observed in specimens of brittle material deformed under various states of triaxial stress. In view of the basic assumption made by Griffith that the stress-strain relation satisfies Hooke's law exactly up to the moment of rupture this suggestion seems doubtful. His analysis probably can be applied to the wedging effect of a fluid under pressure, however, because little energy will be dissipated in permanent deformation. It is then assumed that the Dyke is an ellipse of large eccentricity on the walls of which a hydrostatic pressure p is exerted by the intruding magma. This leads to large but much localized tensile stresses at the tip of the crack (Griffith, 1921; 1924). The largest tensile stresses occur for a crack whose long axis is oriented in the direction of the largest principal stress. Because the Dyke will originate in this orientation it will during its growth remain along such a maximum stress trajectory. The problem therefore is to determine the maximum stress trajectories of the stress field.

The stress field in the material of the crust is obtained by superposition of two simpler fields. The first, which we shall call the local field, is caused by the fluid pressure in the central hole, and the second is a regional field which is assumed to vary little over large distances. This is the field in the crust at the moment the Dyke was injected.

The symmetry of the Dyke pattern indicates that the total-stress field must be symmetric in the same manner. The absence of Dykes west of the mountain front suggests that this mountain front acted as a more or less rigid boundary, and the divergence of Dyke from one central area indicates that the stress in this area can be described by the formulas used to compute the stress around a hole-which for convenience shall be considered circular-in an infinite plate caused by an internal pressure *p.*

The Dyke pattern derived on the assumptions that there is no regional-stress field does not resemble the Dyke pattern around the Mahadeva range. Thus the existence of a regional field at the time of Dyke injection is very probable. It seems plausible then to assume a regional stress field in which the greatest principal stress had the direction of the line of symmetry exhibited by the Pachmarhi Dyke system. This agrees with the intuitive notion that the mountain ranges west of the Pchmarhi are related to such a stress field. The superposition of this regional-stress field over the local-stress field created by the Dyke injection yields a stress pattern which is in striking agreement with, the pattern of Dykes surrounding the Pachmarhi. The Dyke pattern of the Pachmarhi is made unique by its peculiar shape (Fig.1). Whereas the other patterns described are regularly radial or are confused because of several superposed systems, the geometrical pattern of Dyke surrounding the Pachmarhi.

Local-stress field

To simplify the problem of finding the local-stress field, it is necessary to make the following assumptions:

1. The "fluid" igneous mass rose through a vertical circular hole to the surface.
2. The focal point of the curvilinear Dyke pattern is at west of Mahadeva
3. The mountain front was straight and acted as an almost rigid boundary.

Treating the problem in two dimensions reduces it to the problem of finding the stresses in a semi-infinite plate pierced near its boundary by a circular hole, in which a hydrostatic pressure is exerted. The boundary condition imposed by the mountain front is attained by assuming an "image" source, as is commonly done in potential theory. By "image" source here is meant another circular hole in which either the same or a different hydrostatic pressure is exerted, or which is placed somewhere at the other side of the mountain front. The usefulness of the concept of image sources lies in the fact that the stresses, which act along the mountain front, and which must be given to obtain a solution, are determined by superposition of the stresses caused by the real hole and its images. The stresses along the mountain front are unknown, and, therefore, it is impossible to decide where the image sources must be placed and what their respective pressures are. However, the symmetry of the Dyke pattern suggests that an "image source" can be placed at a point which is the mirror image of the real hole with respect to the mountain front. This image source, which will be assumed to be of the same magnitude as the real source, may be positive or negative. When the image is positive, *i.e.,* if the fluid within it exerts a hydrostatic pressure, there is a displacement along the front (Fig. 2A). If the source is negative, *i.e.,* the hole tends to close, the mountain front is displaced normal to itself (Fig. 2B). These displacements are relatively small.

The preference to treat the problem in this manner, rather than to solve the analogous problem for an exactly rigid boundary, has a simple reason. Although the "exact" point can be solved with the appropriate matical tools, it’s greater complexity guarantees greater accuracy, since boundary conditions along the mountain are unknown. Moreover the "exact" solution leads essentially to the same results.

For a single hole in an infinite plan the stresses at a point *P,* which result from hydrostatic pressure in the hole, are functions only of *R,* the distance from the center of the hole to the point *P.* The easiest way of solving the problem is to use Airy's stress function Φ which satisfies the equation $\nabla^2\nabla^2\Phi = 0$.From the function Φ the stress components are derived from the following equations (Timoshenk, 1934)

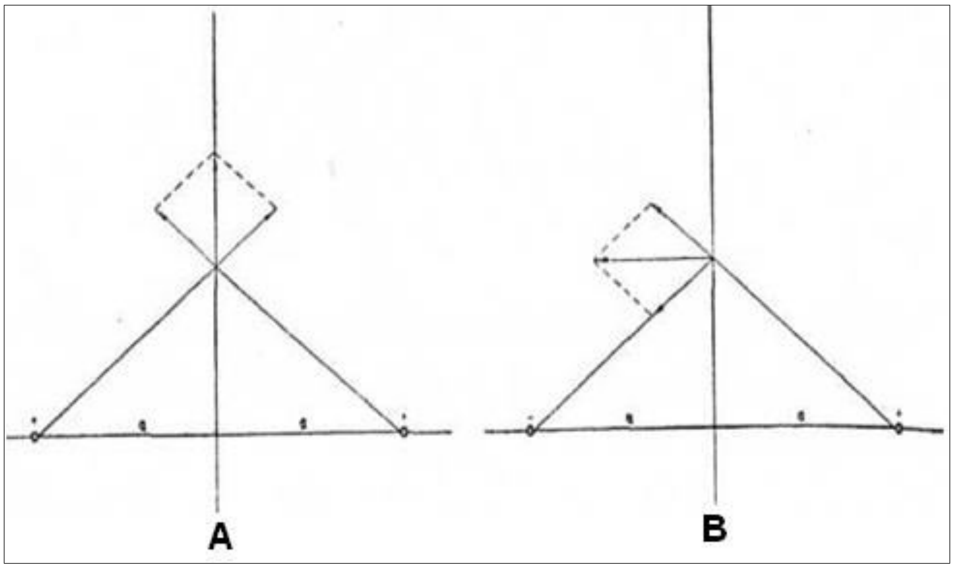

Figure. 2 – Displacements at the Mountain Front a positive image source A.For a negative image source

$$\sigma_R = \frac{1}{R}\frac{\partial\Phi}{\partial R} + \frac{1}{R}\frac{\partial^2\Phi}{\partial\theta^2},$$

$$\sigma_\theta = \frac{\partial^2\Phi}{\partial R^2},$$

$$\tau = \frac{\partial}{\partial R}\left(\frac{1}{R}\frac{\partial\Phi}{\partial\theta}\right), \tag{1}$$

Where $\sigma_R, \sigma_\theta$and τ are the normal radial normal tangential, and shear stress respectively. The stresses which act on a small element of volume are shown in Figure. 3. The stress function Φ for a hole in an infinite plane is obtained from $\nabla^2\nabla^2\Phi = 0$ with the condition that the stresses are independent of θ and vanish a infinity; then$\Phi = A$. In *R,* where A is a constant. If in two holes the same hydrostatic pressure in exerted, and the origin of the co-ordinate

System is taken halfway between the two holes (Fig. 4), the function Φ is given by

$$\Phi = A1\ In(r_1 r_2),$$

$$r_1^2 = R^2 + a^2 - 2aR\cos\theta, \tag{2}$$

$$r_2^2 = R^2 + a^2 - 2aR\cos\theta.$$

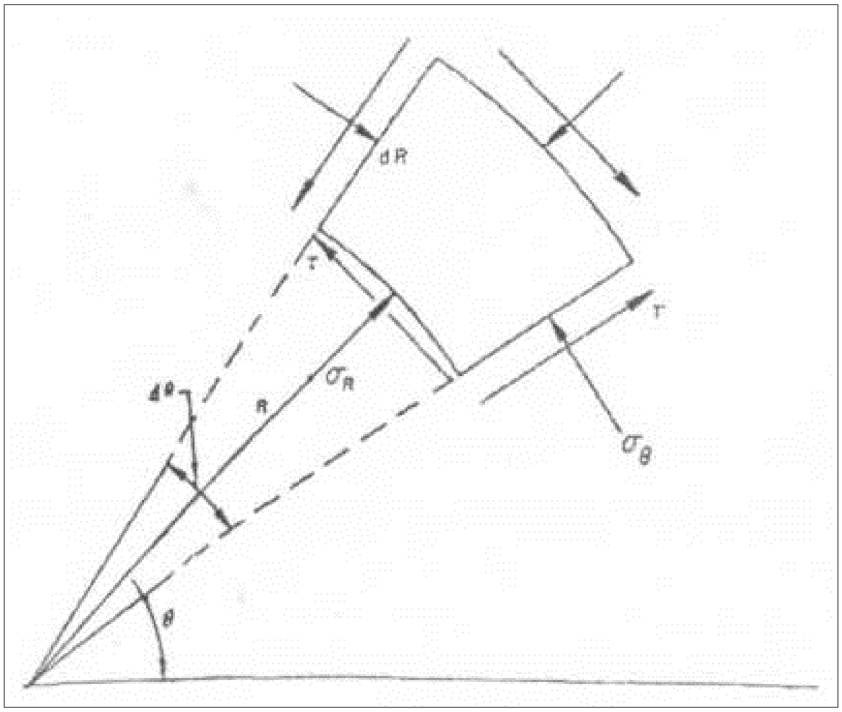

Figure. 3 – Stresses acting on a small element of Volume.

Since $\Phi = A_1$ In r satisfies $\nabla^2\Phi = 0$ and $\sigma_R + \sigma_\theta = \nabla^2\Phi$

Then,

$$\sigma_R + \sigma_\theta = 0,$$

Performing the differentiations indicated (1) the stress components in a point (R, θ) are given by

$$\sigma_R = -\sigma_\theta = \frac{A_1}{(\xi^4 - a^2R^2\cos^2\theta)^2}[\xi^6 - \xi^4 a^2 \sin^2\theta - \xi^2 a^2 R^2 \cos^2\theta - a^4 R^2 \cos^2\theta \sin^2\theta], \quad (3)$$

$$\tau = -\frac{A_1 a^2 \sin\theta\cos\theta}{(\xi^4 - a^2R^2\cos^2\theta)^2}[\xi^4 - 2\xi^2R^2 + a^2R^2\cos^2\theta],$$

where for simplification of the formulae the following substitution is made:

$$R^2 + a^2 = 2\xi^2,$$

In case $\boldsymbol{\Phi} = \mathrm{A}_2 \text{ in } (\boldsymbol{r_1}/\boldsymbol{r_2})$, which applies if the pressure in both holes is equal but opposite in sign, the stress components are given by

$$\sigma_R = -\sigma_\theta = \frac{A_2 a R\cos\theta}{(\xi^4 - a^2R^2\cos^2\theta)^2},$$

$$[\xi^4 - 2a^2\xi^2 + a^4\cos^2\theta], \quad (4)$$

$$\tau = A_2 \frac{aR\cos\theta}{(\xi^4 - a^2R^2\cos^2\theta)^2}[\xi^4 - a^4\cos^2\theta],$$

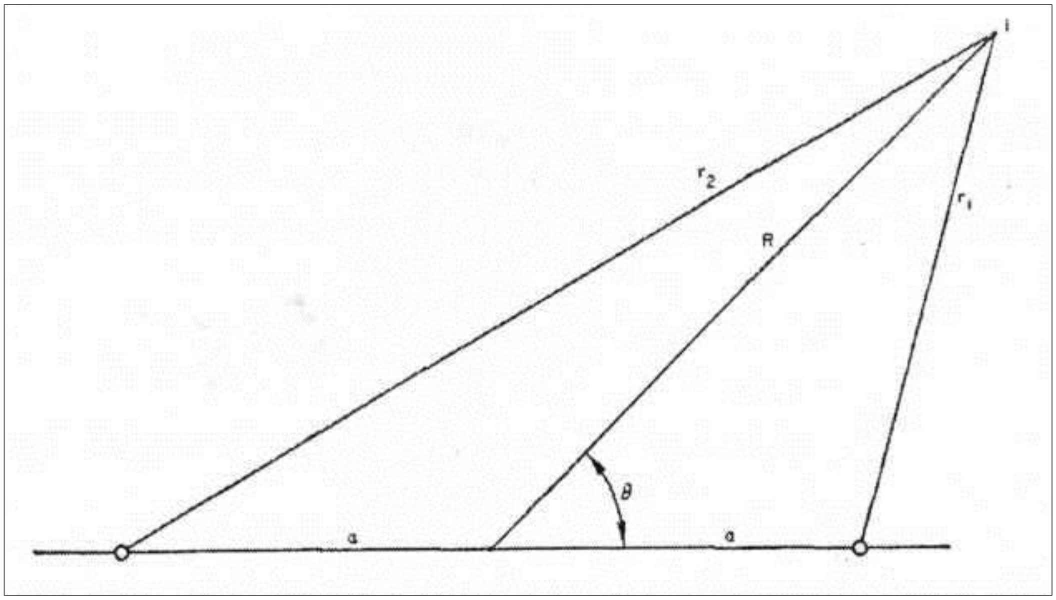

Figure. 4 – Co-ordinate Notation used in stress Analysis.

$$tan\, 2\,\alpha = \frac{2\tau}{\sigma_R - \sigma_\theta} = \frac{\tau}{\sigma_R}, \qquad (5)$$

Substituting *(3)* into *(5):*

$$\tan 2\alpha = \frac{a^2 \sin\theta \cos\theta [\xi^4 - 2\xi^2 R^2 + a^2 R^2 \cos^2\theta]}{[\xi^2 - \xi^2 a^2 \sin^2\theta - a^2 R^2 \xi^2 \cos^2\theta - a^4 R^2 \cos^2\theta \sin^2\theta]},$$

It is obvious that as R goes to infinity $\tan 2\alpha$ goes to zero. Hence, the stress trajectories at infinity are parallel to a pencil of rays through the origin, *i.e.,* these rays are asymptotic to the stress trajectories. This is quite as should be expected, for at infinity the two holes act as one.

Singular points in the stress pattern are obtained from indeterminate values of $\tan 2\alpha$ or in other words for values of R and θ which make both $\sigma_R$and τ zero. There are only four such points

$R = a$ $\qquad$ $R = a$

and

$\theta = 0, \pi$ $\qquad$ $\theta = \pm\frac{\pi}{2}$

The first two correspond with both sources and are, therefore, of little interest.

The stress pattern can now be drawn by computing values of a for different values of R and θ. In points of the circle $R = a$, the directions of the two principal stresses point toward both sources.

The resulting stress pattern is shown in Figure 6. The magnitude of the two principal stresses $\boldsymbol{\sigma}_P$ at any point is given by

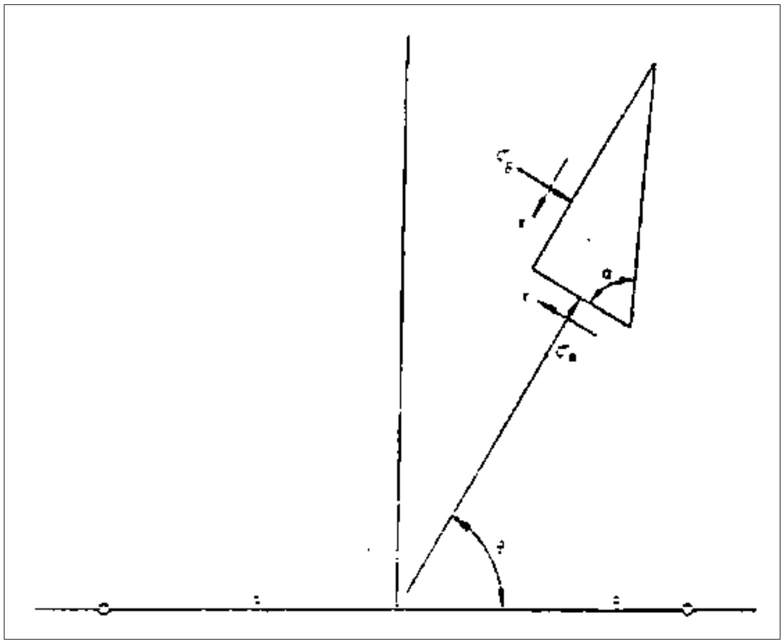

Figure.5 – Definition of the angle α.

$$\sigma_P = \pm\sqrt{\sigma_R^2 + r^2} = A_1 \frac{\sqrt{\xi^4 - a^2R^2 \sin^2\theta}}{\xi^4 - a^2R^2\cos^2\theta}, \tag{7}$$

In case of an "image" source of negative sign $\tan 2\alpha$ is given by

$$\tan 2\alpha = \frac{\tan\theta \times (\xi^4 - a^4\cos^2\theta)}{\xi^4 - 2\xi^2a^2 + a^4\cos^2\theta}, \tag{8}$$

This pattern also possesses the property mat the directions of the principal stresses in the circle $R = a$ point toward both sources. It can be shown that the point $R = 0$ is, apart from both sources, the only singular point in the stress pattern. The resulting stress pattern is shown in Figure 7. The magnitude of the principal stress is given by

$$\sigma_P = \pm\frac{A_2 aR}{\xi^4 - 2\xi^2a^2 + a^4\cos\theta}, \tag{9}$$

In both cases the value ai σp at singular points is zero, which is immediately apparent from the fact that σ_R and $\boldsymbol{\tau}$ are zero. This means that the material in these points is in an unstressed state. But it can be verified that the Displacements reach a maximal value in those points. Figures 6 and 7 show that the sign of σ_p changes along a trajectory passing through a singular point.

If the stress components of both cases multiplied by different factors are added, the stress pattern resulting from the case of two sources o different "strength," situated symmetrically with respect to the mountain front, is obtained. However, stress patterns obtained in this manner do not resemble the Dyke pattern of the Mahadeva area.

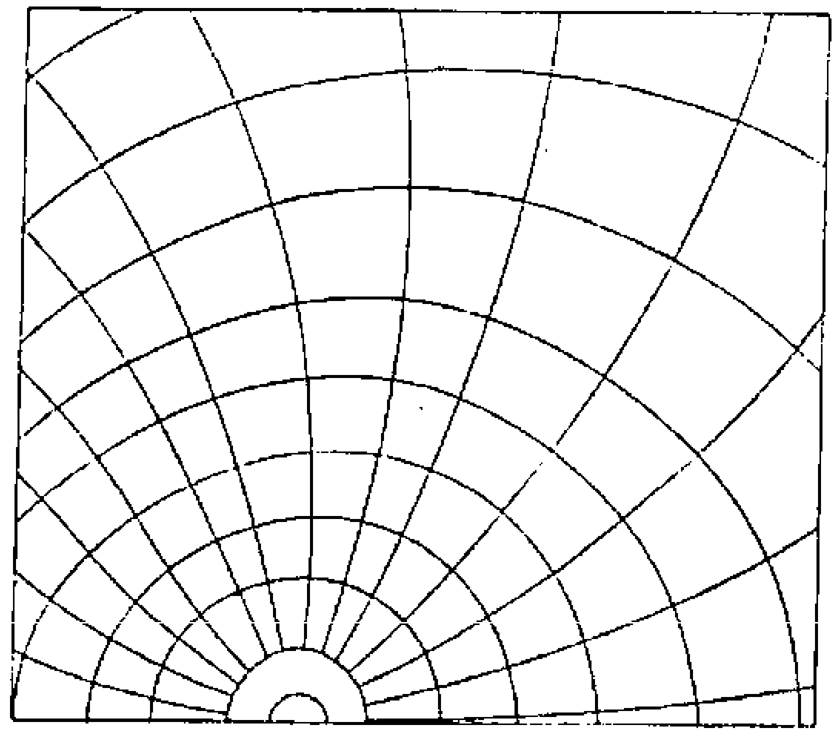

Figure. 6 – Pattern of Principal Stress Trajectories caused by Two Sources of Equal sign.

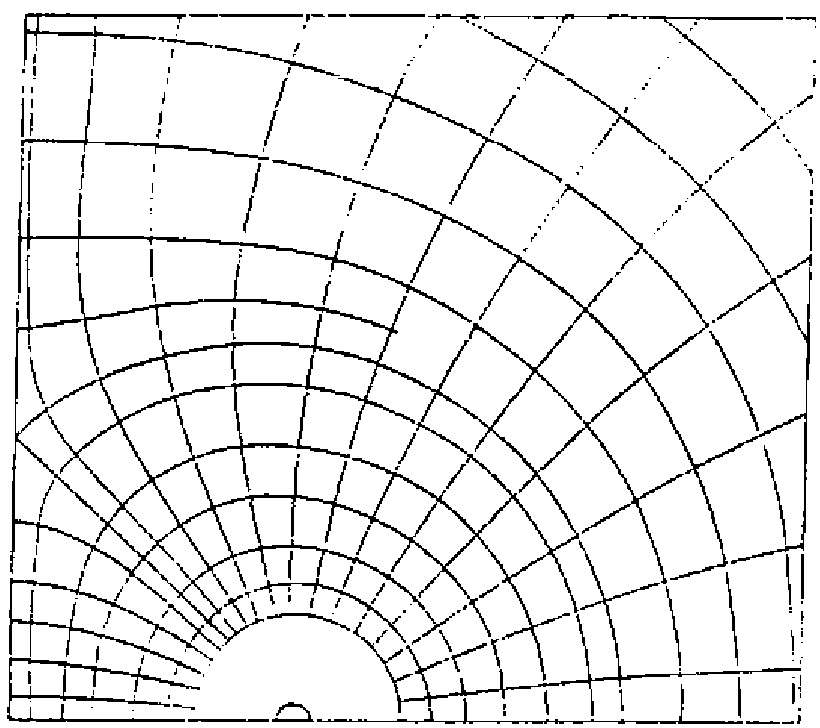

Figure. 7 – Pattern of Principal Stress Trajectories Caused by Two Sources of Opposite Sign.

Superposition of the Regional-Stress Field

As pointed out in the Introduction, the most probable reason for this discrepancy is that at the time the Dykes were injected a regional-stress field existed. The symmetry of the pattern immediately suggests that this regional-stress field existed. The symmetry of the pattern immediately suggests that this regional-stress field was also symmetrical; in particular the eastward curving of the Dykes suggests that its direction of greatest principal stress was parallel to the line of symmetry of the pattern. It is not unlikely that this pattern was related to the northward-trending mountain range west of the Mahadeva. Therefore, it is assumed that this regional-stress pattern can be described by

$$\Phi = \frac{B}{2}x^2 + \frac{C}{2}y^2,$$

where

$$\sigma_x = \frac{\partial^2\Phi}{\partial y^2} = C,$$

$$\sigma_y = \frac{\partial^2\Phi}{\partial x^2} = B,$$

$$\tau_{xy} = -\frac{\partial^2\Phi}{\partial x\partial y} = 0,$$

or expressed in polar co-ordinates:

$$\Phi = \frac{B}{2}R^2\cos^2\theta + \frac{C}{2}R^2\sin^2\theta,$$

$$\sigma_R = B\sin^2\theta + C\cos^2\theta,$$

$$\sigma_\theta = B\cos^2\theta + C\sin^2\theta\,, \tag{10}$$

$$\tau = \frac{B-C}{2}\sin 2\theta,$$

If expressions (3) and (10) are added the stress pattern caused by the two superposed stress patterns can be determined in the same manner as before. A stress pattern closely resembling the stress pattern of the Dykes radiating from the Mahadeva will result.

Computations were carried out for the positive case $C = 2B$;$B = A_1/a^2$.In the superposed system the principal stress in the *x* direction (normal to the mountain front) is twice as great as the stress in the v direction, and its magnitude is equal to the magnitude of the principal local stress in the origin in the case of two symmetric holes with equal hydrostatic pressure, as may, be seen when $R = 0$ is substituted in (7).

The stress components and $\tan 2\alpha$ are then given by

$$\sigma_R = \frac{A}{(\xi^4 - a^2R^2\cos^2\theta)^2}[\xi^6 - \xi^4 a^2 \sin^2\theta - \xi^2 a^2 R^2 \cos^2\theta - a^4 R^2 \cos^2\theta \sin^2\theta] + \frac{A}{a^2}\sin^2\theta + \frac{2A}{a^2}\cos^2\theta,$$

$$\sigma_\theta = \frac{-A}{(\xi^4 - a^2R^2\cos^2\theta)^2}[\xi^6 - \xi^4 a^2 \sin^2\theta - \xi^2 a^2 R^2 \cos^2\theta - a^4 R^2 \cos^2\theta \sin^2\theta] + \frac{A}{a^2}\cos^2\theta + \frac{2A}{a^2}\sin^2\theta,$$

$$\tau = -\frac{Aa^2\cos\theta\sin\theta}{(\xi^6 - a^2R^2\cos^2\theta)}[\xi^4 + a^2R^2\cos^2\theta - 2\xi^2R^2] - \frac{A}{2a^2}\sin 2\theta,$$

$$\tan 2\alpha = \frac{-2a^4\cos\theta\sin\theta[\xi^4 + a^2R^2\cos^2\theta - 2\xi^2R^2] - \sin 2\theta[\xi^4 - a^2R^2\cos^2\theta]^2}{2a^2[\xi^4 + \xi^4 a^2\sin^2\theta - \xi^2a^2R^2\cos^2\theta - a^4R^2\cos^2\theta\sin^2\theta] - \sin 2\theta[\xi^4 - a^2R^2\cos^2\theta]^2},$$

As R approaches infinity $\tan 2\alpha = \tan 2\theta$ or the stress trajectories coincide at infinity with the stress trajectories of the superposed system. The resulting stress pattern is shown in Figure 8. In all of its important aspects, this pattern resembles that of the Dykes radiating from the Dhupgarh .Mahadeva and Chauragarh ranges.

If the holes have opposite signs, expressions for the stresses are obtained in the same manner as above by addition of (4) and (10). For $\tan 2\alpha$ we obtain

$$\tan 2\alpha = \frac{2a^3R\sin\theta[\xi^4 - a^4\cos^2\theta] - \sin 2\theta[\xi^4 - a^2R^2\cos^2\theta]^2}{2a^3R\cos\theta[\xi^4 - 2a^2\xi^2 + a^4\cos^2\theta] + \cos 2\theta[\xi^4 - a^2R^2\cos^2\theta]^2},$$

The corresponding stress pattern is shown in Figure 9. Figures 8 and 9 show a remarkable resemblance. That the difference between the patterns is greatest near the mountain front is not surprising, as the boundary conditions along that front are different, whereas at infinity they are the same. The question of which case provides the best fit to the Mahadeva Dyke system is not very important. As already pointed out, the boundary conditions along the mountain front are uncertain, and, therefore, neither of the two cases will be quite correct. The map shows that most or the westward trending Dykes end at an acute angle to the mountain front, which is slightly bent inward. This may indicate that the assumption of an image of opposite sign is the better one. It is important to note that if the ratio of the constants A_1, A_2, B, C is changed a better fit between computed and observed pattern may be obtained. So a large value of B with respect to A_1, A_2 and C gives a stress pattern in which the stress trajectories diverging from the Mahadeva and asymptotic to eastward trending trajectories of the regional stress system are compressed into a narrow band. If the value of B is decreased, this band can be broadened. If the values of A_1 and A_2 are increased and B and C are kept constant, the influence of the local stress system is emphasized. Therefore, if the right ratios of A_1, A_2, B, and C are selected, it is possible to obtain a better fit between computed and observed pattern than is shown in Figures 6,7, 8, and 9.

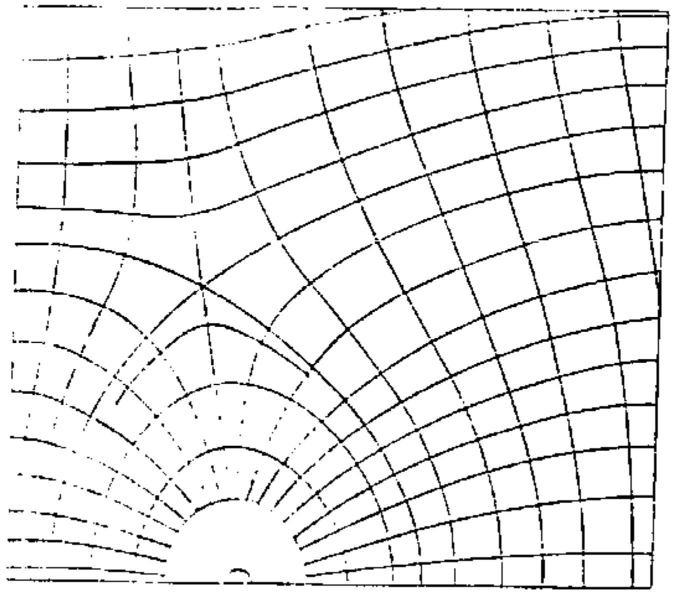

Figure.8 – Pattern of Principal stress Trajectories Caused by Two Source of Equal Sign and Superposed Regional Stress System

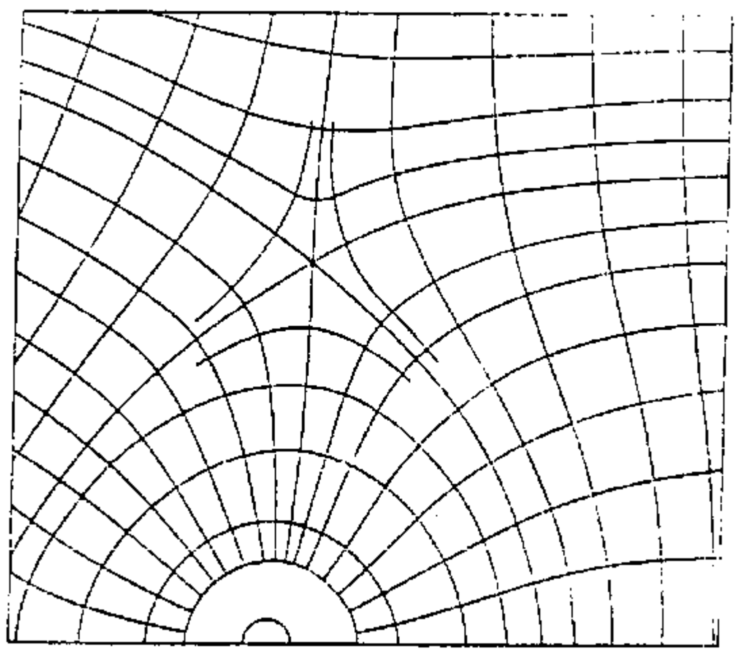

Figure. 9 – Pattern of Principal stress Trajectories caused by two sources of opposite sign and Superposed Regional-stress System Displacements.

Of much interest are the Dykes which are normal to the mountain front and do not originate in the center of Mahadeva. Some of these Dykes are crossed by, and some cross, Dykes converging to the Mahadeva .Thus not all Dykes are formed contemporaneously. It seems probable, however, that both are the result of the same igneous mechanism.

Inspection of the other Dyke systems mentioned in the Introduction shows that most are regularly radial. This indicates that, in these cases, the boundary condition imposed by the mountain front was absent.

The order of magnitude of the elastic displacements is easily found if no regional stress is present. If U_R is the radial displacement, E Young's modulus, and v Poisson's ratio we have:

$$\frac{\partial U_R}{\partial_R} = -\frac{1}{E}(\sigma_R - v\sigma_\theta) = \frac{1+v}{E}\frac{\partial^2 \Phi}{\partial R^2},$$

or

$$U_R = \frac{1+v}{E}\frac{\partial \Phi}{\partial R} + f(\theta), \tag{11}$$

or

$$U_R = \frac{2(1+v)}{E} A_1 R \left\{\frac{R^2 + a^2 - 2a^2 \cos^2\theta}{(R^2+a^2)^2 - 4a^2R^2\cos^2\theta}\right\} - f(\theta),$$

Quantity $\boldsymbol{U_R}$ must be zero, for $R = 0$, hence $f(\theta) \equiv 0$. The value of $\boldsymbol{U_R}$ along the mountain front is obtained if $\theta = \pi/2$ is substituted in (11):

$$U_R = \frac{2(1+v)}{E} \cdot \frac{A_1 R}{a^2 + R^2},$$

which reaches its greatest absolute value if $R = \boldsymbol{a}$. Therefore:

$$U_R(max) = \frac{A_1}{2\mu a},$$

Where μ is the coefficient of rigidity for surface rocks. To obtain an estimate of this maximal displacement, probable values of the quantities involved must be substituted. The value of μ for rocks under surface conditions is about$3.5\ X\ 10^{11} dynes/cm^2$. Hence if A/a^2 represents a stress of about $10^9 dynes/cm^2$, which is undoubtedly high, and as *a,* the distance from Mahadeva to the mountain range is about $1.4X10^6 cm$, A is approximately $2X10^{21} dynes$. Thus the magnitude of U_R is found to be

$$\frac{2\times 10^{21}}{7\times 10^{11}\times 1.4\times 10^6} = 2\times 10^3\ cm,$$

However, it is not very likely that *A* had this very great order of magnitude. Stresses of the order of 10^5 dynes/cm^2 are more likely to produce over thrusting and rupturing. Even if the value of μ was taken too large, then still the fact that the value of *A* is rather high makes the value of $2X10^3\ cm$ a likely one. However, when an additional stress is present, all the displacements are different. The displacements caused by the superposed stress system alone are given by

$$U = \frac{1}{E}(2 - v)Bx,$$

$$U = \frac{1}{E}(1 - 2v)By,$$

(A surface element in the origin of the co-ordinate system is considered fixed.) These displacements are greater with increase in distance from the origin. Therefore, the total displacements far from the sources are due only to the superposed stress field. To what extent the elastic shortening of the area is compensated by the dilation caused by the injected matter of the Dykes is a matter of conjecture. The data, on which such a calculation must be based, are too inaccurately known.

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