Wrench-faults in the Pachmarhi

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Abstract-Extending the work of E. M. Anderson, M. K. Hubbert, and W. Hafner on faulting, the author develop the Hypothesis that anticlinal folds, thrust faults, and wrench faults can be generated as a result of movement on a large wrench fault such as the Pachmarhi of this concept leads to the conclusion that

for any given tectonic area, at least eight directions of wrench faulting and four directions of anticlinal folding and/or thrusting should accommodate the structural elements of that region; these directions should have a more or less symmetrical disposition relative to the direction of the primary compressive stress. The angles α, β and γ are defined to describe the geometry of such a *wrench-fault tectonic system* relatively completely. The authors' interpretations of tectonics in various areas indicate that wrench-fault tectonic systems do exist and are aligned systematically over large portions of the earth's crust as indicated by Hobbs, Vening Meinesz, Sonder, and others. Eight principal wrench directions are defined in terms of major elements of the earth's crust such as the Patalkot fault of Structural elements aligned in these eight directions constitute major features of the *regmatic shear pattern* of Sonder. The authors conclude that the shear pattern may have resulted from stresses which are oriented essentially meridionally ana have been acting in nearly the same direction throughout much of crustal history. It is concluded that major wrench faults, which penetrate the entire outer crust of the earth and result in wholesale segmentation of the outer crust into polygonal blocks, constitute a fundamental type of yielding in the crust. Possible origins of the stresses involved, formation of geosynclines, island arcs, volcanism, and crustal evolution are discussed in terms of these ideas. Some possible objections and weak points in the argument are pointed out, and suggestions for further study are included New concepts of fault dynamics, evolved through re-evaluation of published data on crustal strain, mechanics of faulting, and field observations, are presented. The purpose of this paper is to develop an over-all hypothesis, based on these concepts, of the stress and strain mechanisms in the Pachmarhi.

Definition of Wrench Fault

The term wrench fault is adopted from Kennedy (1946) and Anderson (1951) to describe ruptures in the earth's crust in which the dominant relative motion of one bloc to the other is horizontal and the fault plane essentially vertical. The term is translates from the German "blatt", originally used by Suess (1885), and is synonymous with strike slip fault and transcurrent fault. The author favor using wrench in deference to Anderson and Kennedy's pioneer work. Wrench fault is interchangeable with lateral fault where that expression means actual rather than apparent, horizontal movement. Right lateral and left, lateral refer to the apparent relative movement-of the two blocks viewed in plan; right lateral; indicates clockwise and left lateral indicates counterclockwise separation, as described by Hill (1947). The author extends the use of right lateral and left lateral by adding wrench so that actual horizontal slips are implied.

Wrench-Fault Tectonics

The writers propose that large-scale wrench faults may be a dominant type of failure in the earth's crust. Large areas, probably continental in dimensions, appear to have been subjected to rather uniform stresses for extended periods. Possible orientations and origins of these regional stresses and strains are discussed. The application of these concepts to the interpretation of local and regional tectonics is considered, and many geotectonic hypotheses are re-examined in the light of wrench-fault tectonics.

Theory

Stress Ellipsoid and the Angle β

A brief review of Anderson's (1951) work provides a basis for understanding fault mechanics. Fundamental to his exposition is the expression of stresses in terms of a set of three mutually perpendicular axes. In a homogeneous isotropic material under compression, the maximum compressive stress can be represented as acting in a given direction (Fig.1, Y). The minimum-stress direction (Fig.1, X) is then at right angles to the maximum-stress direction, and the third rectangular axis must coincide with the direction of an intermediate stress These stress axes are of unequal length and described an ellipsoid which long has been termed the stress ellipsoid.

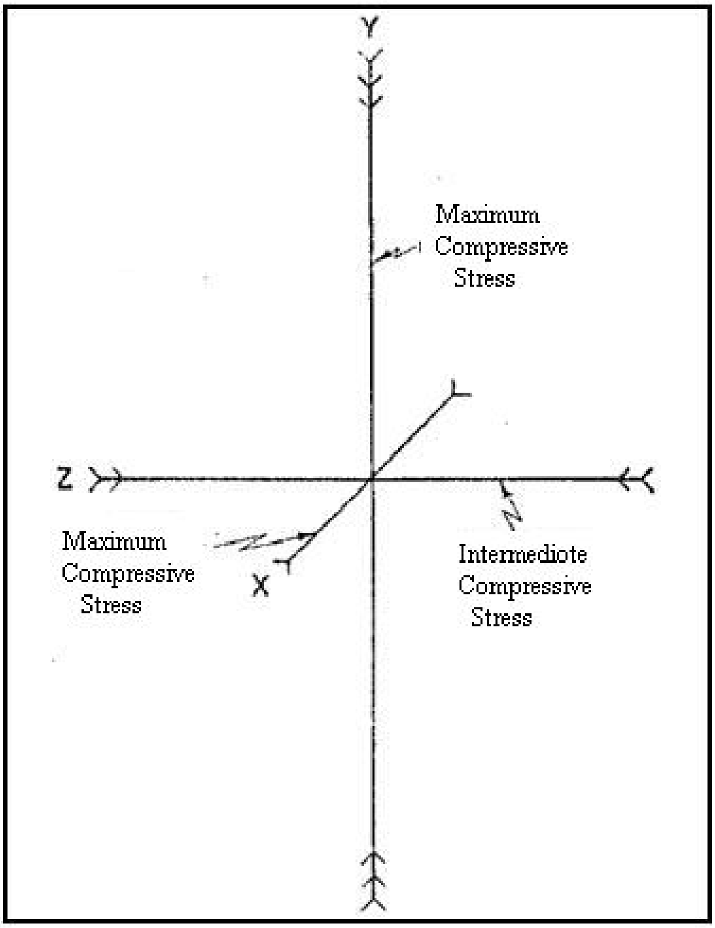


Figure.1 - Axes Of the Stress Ellipsoid

If a material of sufficient rigidity to react elastically rather than plastically is stressed .beyond its strength, it will rupture. In situations such as those described above, the planes of maximum shearing stress are parallel to the intermediate stress axis and lie at angles of 45° on either side of the maximum compressive stress. The planes of actual shear do not coincide with the planes of maximum shearing stress but lie closer to the axis of maximum compressional stress and form an angle with it which is here called β, the angle of shear (Fig. 2).The factors which contribute to the deviation in direction between actual strain and theoretical strain are included in the "angle of internal friction" which is one of the controlling parameters for the value of the angle β.

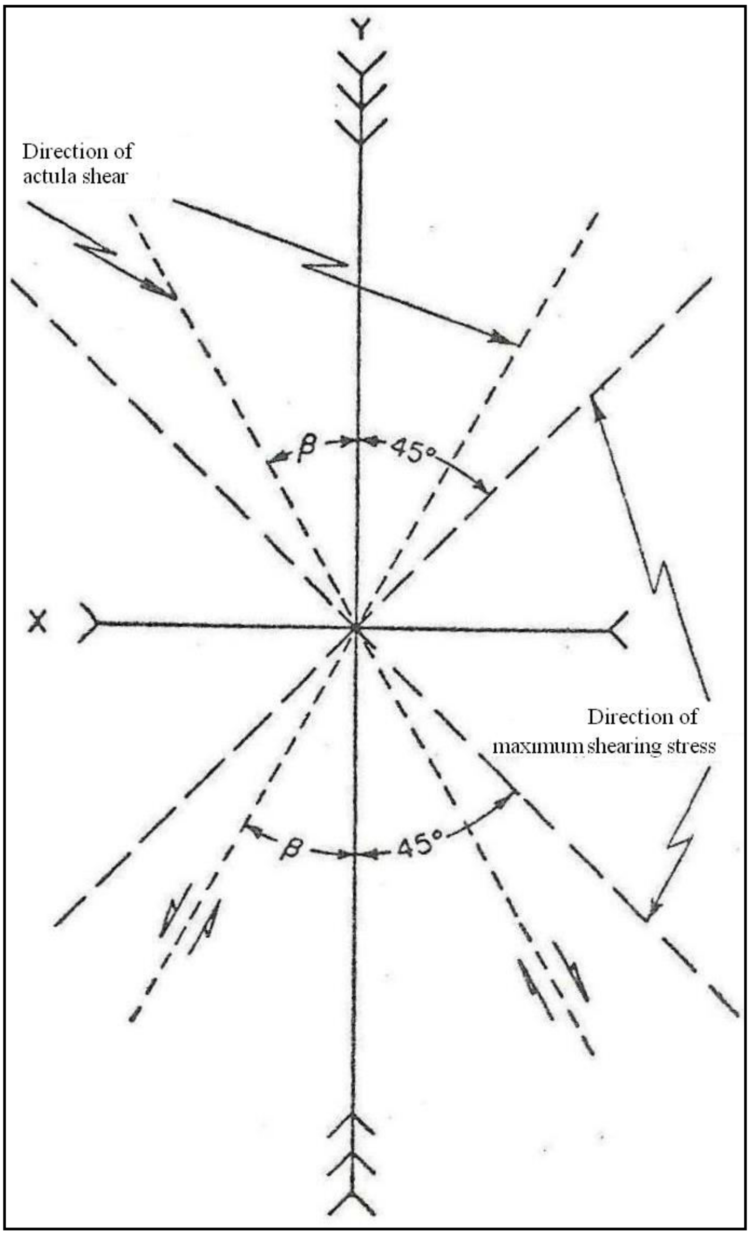


Figure.2 - Sheas Directions in Homogeneous Media

X=Direction of minimum stress
Y= Direction of minimum stress

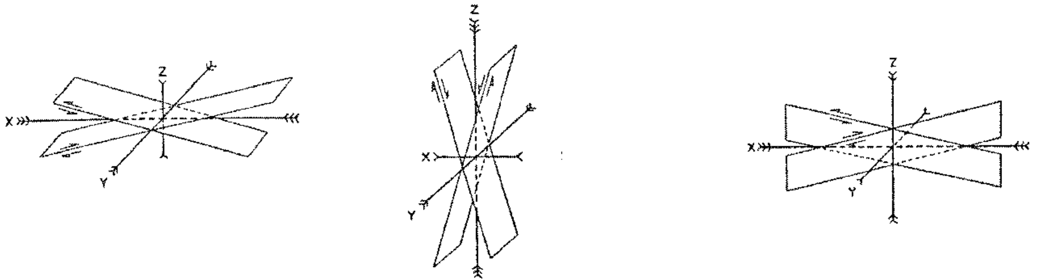
Hubbert (1951) indicates that, although the value of β may vary among different materials, a good average for rocks is approximately 31°. He wrote, "For rocks, this would correspond to normal faults with hades, or reverse faults with dips, of 31° ± 2°." Hubbert's data were for normal and thrust faults; however, the value of 31° should be applicable to wrench faulting also because of the similarity of the dynamics. Billings (1954) stated, ". . . the angle between the compressive force and the shear fractures is about 30°". although the possibility of considerable variation in the value of this angle is recognized, 30° is used throughout this paper as the average value.

Orientation of Stress Ellipsoid

The orientation of the stress ellipsoid is variable and generally must result from a complex interplay of varying stresses which are differently oriented; however, field observations of the dips of fault surfaces, which are planes of actual tear in the crust of the earth, show three frequency maxima near 90°, 60°, and 30°. For example, I cites Pachmarhi as stating that of some separate faults examined, 79 per cent were normal and 21 percent were reverse; dip frequency distribution curves plotted for these two groups showed well-defined peaks at 63° and 22° respectively. I can say that of the numerous faults of the Mahadeva uplift in central Pachmarhi that the greater number are vertical.

Such observations can be accommodated in most cases by assuming that the stress ellipsoid is oriented with respect to the surface of the earth so that two of its axes lie very nearly in a horizontal plane; the other axis is then essentially vertical. The majority of faults must have resulted from the interplay of stresses oriented approximately horizontally (lateral Compression) and approximately vertically (gravitational and other forces). Here I define that in reality beneath the Pachmarhi in its topography one principal direction of stress is, in general, nearly vertical, and two are nearly horizontal. The air-earth interface is a surface of zero shear; hence, it must be normal to one of the principal stress directions.

The orientation of the two axes of the stress ellipsoid in the horizontal plane determines the strike of the associated shear planes.



STRESS X > STRESS Y > STRESS Z
THRUST FAULTS

STRESS Z > STRESS Y > STRESS X
NORMAL FAULTS

STRESS X > STRESS Z > STRESS Y
WRENCH FAULTS

Figure.3 - Theoretical Fault Orientations

Normal, Thrust, and Wrench Faults

This restriction on the orientation of the stress ellipsoid reduces to three the possible stress orientations, which should correspond to the three dip maxima observed. In Fig. 3 the classification of shears in the crust of the earth into normal, thrust, and wrench faults is a apparent. The direction of movement on each shear plane is relatively the same in each case. (Low-angle fault surfaces formed in connection with gravitational sliding are not considered shears.)

The maximum compression stress for both thrust and wrench faults is oriented in the horizontal plane; for normal faults it is vertical. In an area under tangential compression, the stresses can be relieved along either thrust-or wrench-fault surfaces, depending only on the orientation of the minimum stress. Since the minimum-stress direction in thrust faults is vertical, thrust faulting in most cases should be a shallow phenomenon that exists only at depths where the weight of overburden is relatively small.

Normal faults require that the maximum stress be vertical, which means that the horizontal stresses are smaller than the vertical stresses. This requirement obviates the syngeneic development of normal faults with wrench or thrust faults except where normal faults are a secondary effect due to local deformation. Thus in an area of compression phenomena, normal faults can result only if the vertical stresses exceed the horizontal compressional stresses; this situation usually obtains in areas of local positive uplift, as in domes (Fig.4) and igneous intrusive masses (Fig.5).Gravity faults at the crests of anticlines and over domes are examples of normal faults that result from decreased horizontal stress and consequent increased vertical stress. Dynamically, normal faults are identical with the other two types, except in the orientation of the stresses; all three are shears, and the term normal fault as used here should not be considered a result of crustal tension.

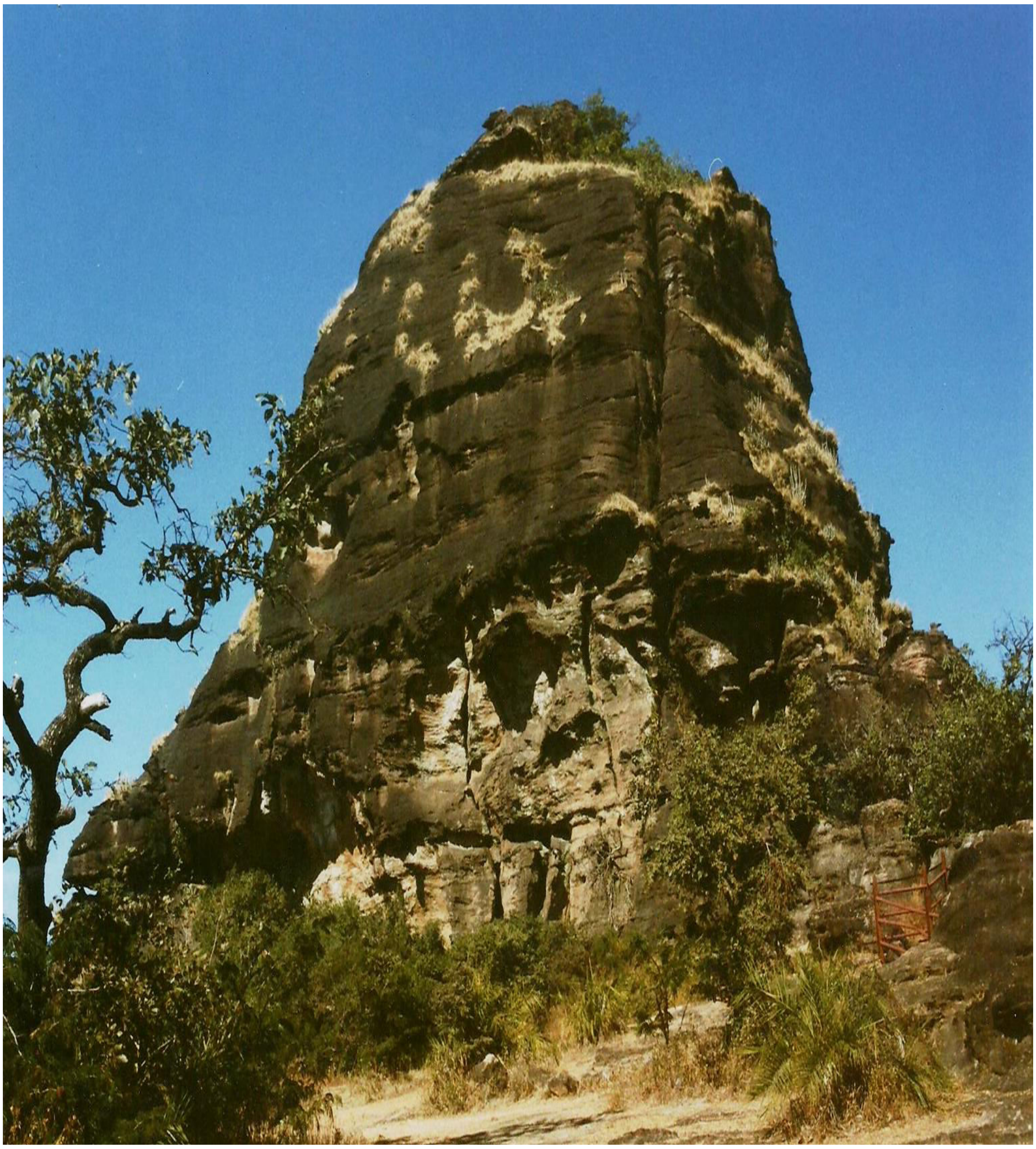


Figure.4 - The Dhupgarh, an area of compression phenomena, normal faults can result only if the vertical stresses exceed the horizontal compressional stresses; this situation usually obtains in areas of local positive uplift, as in domes.

Figure.5 - Vertical stresses exceed the horizontal compressional stresses; this situation usually obtains in areas of local positive uplift, as in domes and igneous intrusive masses

All gradations within these three classes of faults can exist because of varying stress orientations; however, the three categories should be valid for the great majority of faults.

Second-Order Effects and the Angle – γ

McKinstry (1953) developed a thesis of secondary strain features and discussed several known fault systems in terms of second-order shears. My opinion about Pachmarhi is that ,if movement is in progress on a main fault or 'master shear', stresses in the rock adjoining, it will have such orientation as to cause failure on a new pair of mutually complementary planes, one of which will make an acute angle with the master shear." McKinstry considered that inertial and frictional forces involved during movement on a shear plane resulted in a local reorientation of the compressional stresses. This mechanism can probably account for some second-order shears; however, as McKinstry points out, the available forces decrease rapidly and the system is not regenerative. A mechanism, which is regenerative and seems more likely to explain the large-scale second-order features contemplated here was developed by Anderson (1951), based on computation by Inglis (1913). Body forces developed by movement along a fault could also yield local stress reorientation, which might result in second-order features. The idea of elastic rebound is promulgated by me to explain the movement on the Pachmarhi fault. A further possible mechanism for generating reoriented stresses adjacent to wrench-fault blocks may be found in the change of shape which must ensue when fault blocks are subjected to continued compression.

One or a combination of the mechanisms mentioned above results in locally reoriented compressional forces which generate new strain directions called second-order shears (Fig. 6).The principal-stress direction is indicated by the vector AB, which is equal in magnitude to the compressive force. The vector CD is of a second order resulting from one or a combination of the mechanisms suggested above and creates second-order strain directions as indicated. Strains resulting from the stresses associated with the direction CD can be second-order right and left lateral wrenches disposed on either side of CD at the angle β, or a second-order anticline or thrust fault ,or both oriented at right angles to CD as shown by the line DE. Such second-order anticlines, called drag folds, are normal to the direction CD and form an acute angle γ with the first-order, or parent, shear Fig.6.shows a means of determining the strikes of the various second-order features in terms of the direction of the primary principal stress, if values for β and γ are available.

The value of the critical angle γ has not been determined satisfactorily; generally it varies between $5°$ and $30°$ with an average value of 15°. However, in some instances γ is apparently $0°$, and the drag folds, in this situation called compression ridges, are parallel to the parent wrench fault. Inglis's diagram as reproduced in Anderson (1951) provides some basis for deducing values for γ. Second-order shears of the same type can also be developed by movement on a first-order left lateral fault with corresponding orientations in mirror image to those in (Fig.6) Thus, third-order shears can be developed secondary to each of the second-order shear fractures. For a single primary stress orientation there can arise two first-order shear directions, four second-order shear directions, eight third-order shear directions, and 16 fourth-order shear directions.

Second-order shears and drag folds are manifestations of stress reorientation in one fault block or a block between two parallel faults and need have no counterpart in adjacent blocks; they should terminate at the master fault. Parallel second-order strains can exist in adjacent blocks but cannot be continuous across the primary faults.

The Angle α

The azimuth of the primary principal-stress direction (that is, the maximum-stress axis of the stress ellipsoid) which gives rise to first-order shears is defined as the angle a (In the case of stress orientations resulting in normal faults, the maximum-stress axis is essentially vertical and has no azimuth.) Observed structural relations indicate that this stress direction in most instances throughout geologic time has been oriented approximately meridionally and that the value for the angle a varies from $340°$ to $20°$; (Fig.7) the orientation of the primary principal stress is discussed below.

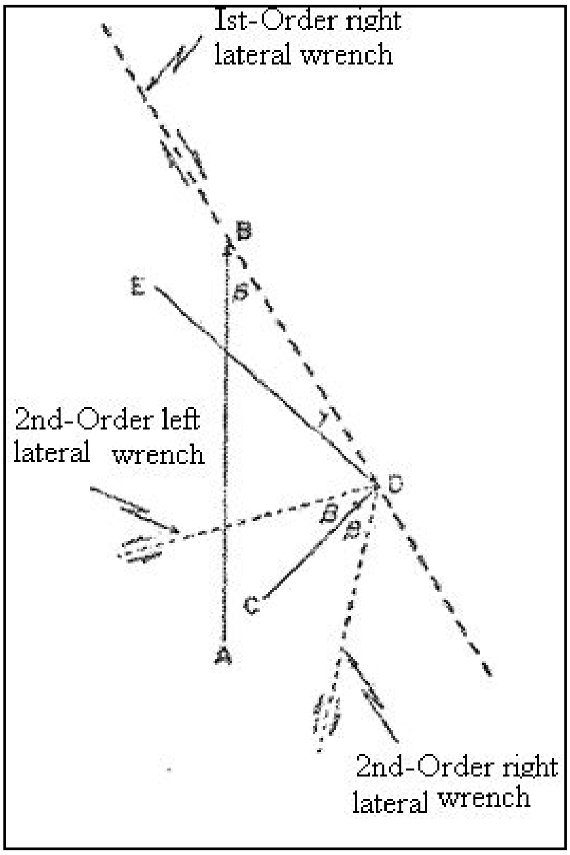


Figure.6 - Second-Order Wrench Faults

Figure.7 - The Chauragarh throughout geologic time has been oriented approximately meridionally and that the value for the angle *a* varies from 340° to 20°

Wrench-Fault Tectonics

If reasonably accurate values can be assigned to the three critical angles $\alpha, \beta$and γ a complete tectonic system can be developed in accordance with the principles presented above. If."the values $0^\circ, 30^\circ,$and 15° are assigned to $\alpha, \beta\ and\ \gamma$ respectively, the tectonic directions that result are shown in Table 1.

Table 1.—Theoretical Wrench- and Thrust-Fault Directions

Right or left lateral wrench			**Anticlines and/or thrusts**
RL	N.30° W.	First order	E.-W.
LL	N.30° E.		
RL	N.15° E.	Second order	N.45° E.
RL	N.75° W.		
LL	N.15° W.		N.45° W.
LL	N.75° E.		
RL	N.30° W.	Third order	N.-S.
RL	N.30° W.		
RL	N.60° E.		E.-W.
RL	N.60° E.		
LL	N.30° E.		N.-S.
LL	N.30° E.		
LL	N.60° W.		E.-W.
LL	N.60°W.		

The shear and anticlinal directions are duplicated in the third order, making it impossible to distinguish fourth-order and lower directions from first-, second-, or third-order directions. Thus, an infinity of shear directions does not arise the system is resolved into eight major -wrench directions and four major anticlinal thrust-fault directions.(Arolu. F,2010 Fig.8) illustrates a hypothetical wrench-fault system showing first-, second-, and third-order wrench faults with their corresponding drag folds. It is assumed that the right lateral wrench fractured first and is dominant; however, the left lateral could equally well be the primary fracture. An entire geometric system of strain can be developed from a single primary compressive stress orientation. Of course a somewhat different system would result in the event γ varied considerably from 15°.

Compression

The values used in (Fig.8) are hypothetical and the directions indicated should not be considered rigorously. Deviations from the ideal system can result from the following:

1. The indicated system resulted from consideration of essentially constant horizontal stresses in one direction,whereas, Hafner (1951) showed that variable stresses acting in two horizontal and one vertical direction must be considered in the general case. Although these are valid and important considerations, in most instances the result would be to impress relatively minor curvatures on the idealized surfaces. However, any orientation of the stress ellipsoid is possible.

2. Crustal materials exhibit a wide range of inhomogeneity and anisotropy

3. In consequence of the above, the orientation of the stress ellipsoid with respect to the vertical, and the values of *a, 8,* and *y* probably vary horizontally and vertically.

4. Non elastic deformation exists in crustal materials where stresses are continuous over Long periods. As Anderson (1951) points out, non elastic behavior must contribute extensively to deviations from the ideal theoretical plain vertical-shear surfaces.

5. A further complicating possibility is that since normal and thrust faults are also shears the same analysis, must be valid. Thus (Fig.6) and (Fig.8) can be regarded as vertical sections of normal or thrust faults, and the ensuing second-and third-order strains can be expected to occur in association with these types of faults also.

6. In strongly orogenic areas, subsequent deformation can alter original dips and strikes of fault surfaces.

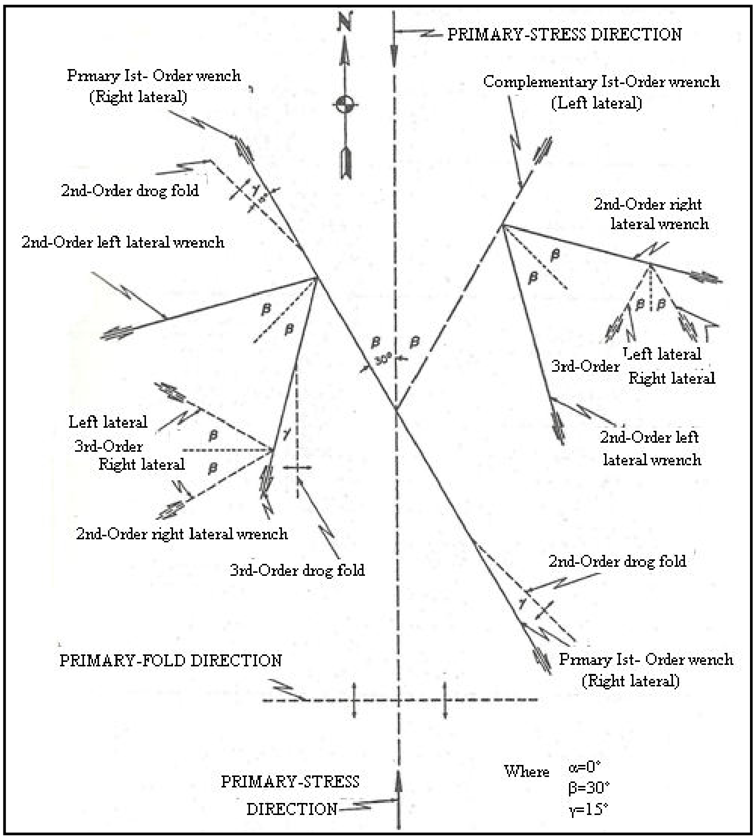


Figure.8 - Plan of   Wrench System under North-South Simple

Field observations

Recognition of Wrench Faults

Criteria for recognition of faults have been admirably discussed by Billings (1954); the following extends his material with particular reference to wrench faults. Wrench faults of Pachmarhi are characterized by steeply dipping fault planes on which there have been appreciable strike-slip components of movement (Fig.9). Theoretically wrench-fault planes should be vertical; actually, any fault plane whose dip is steeper than 70° should be examined to see whether or not it might be of the wrench type and wrench faults with much gentler dips have been described in the literature. Photographs and toposheets are of great assistance in identifying possible wrench faults by means of their straight traces (Fig.10). Cotton (1950) gave a lucid presentation of tectonic aspects of faulting, much of which pertains to wrench faults. Variations in apparent vertical displacement along strike suggest wrench faults, as do fault planes which vary in dip from high-angle normal to high, angle reverse. Fig.11 Scissors faults, which show reversal of apparent dip-slip displacement along strike, might also be of the wrench type (Fig.11)

Figure.9 - the wrench faults of the Pachmarhi are characterized by steeply dipping fault planes on which there have been appreciable strike-slip components of movement.

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Figure.10- Wrench faults by means of their straight traces

Figure.11- Scissors faults, which show reversal of apparent dip-slip displacement along strike, might also be of the wrench type

Evidence of Strike-slip components of movement along fault planes is most frequently seen in slickensides, stream offsets, Fig.12 and offsets in structures and outcrop patterns. Modern movement along faults of this type in some places provides direct evidence of horizontal movement in association with tectonic. It is the writers' belief that major wrenches need not have strike-slip movement of the order of magnitude indicated for the south eastern fault line scarpment. The quantitative relations existing between primary and lower-order wrenches and drag folds are not known; large-scale drag folds might develop in association with wrenches of relatively small strike-slip displacement

Figure.12- Strike-slip components of movement along fault planes is most frequently seen in stream Offsets

The orientation of folds and thrusts furnishes a clue which can be used to delineate wrench faults, in as much as the wrench to which any given anticlinal fold (Fig.13) or thrust fault is secondary should make an acute angle *y* with the axis of the anticline or with the strike of the thrust-fault plane drag folds should be asymmetric or overturned on the flank closest to the parent wrench. The apex of the angle *y* should be opposed to the direction of lateral movement of the block. Structures which terminate abruptly with no apparent cause might be limited by wrench faults.

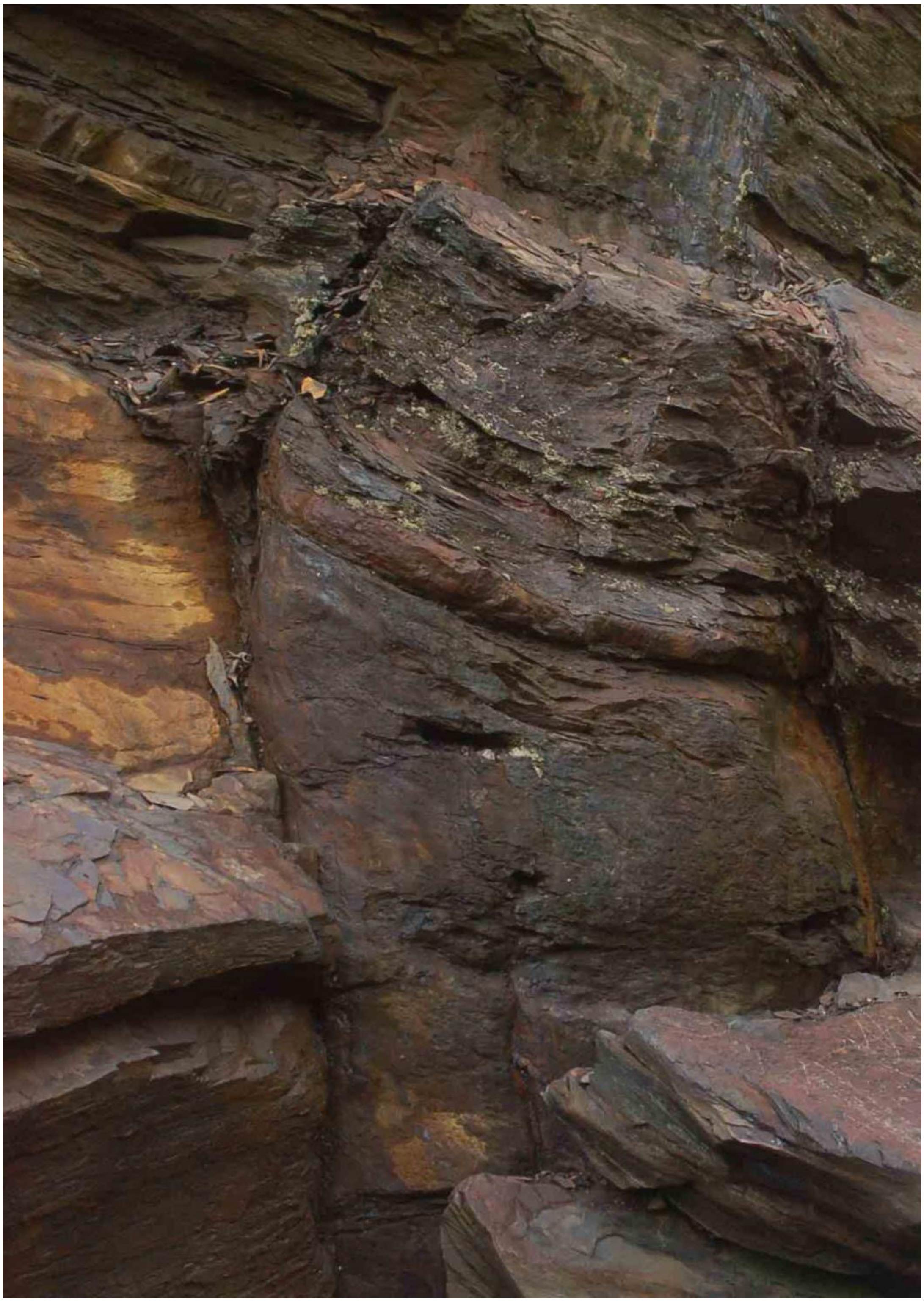

Figure.13- The orientation of folds and thrusts furnishes a clue which can be used to delineate wrench faults, in as much as the wrench to which any given anticlinal fold

As emphasized by Anderson (1951), I consider wrench-fault zones of Pachmarhi are characterized by the development of fault breccia along the individual faults. The writers believe that the large primary wrenches extend through the outer crust and thus are very deep and fundamental flaws in the crust (Fig.14) The result of movement along these deep faults can be expressed in the over-lying sedimentary veneer more commonly by a complex zone of wrench faults and generally complicated structure than by an individual fault trace .

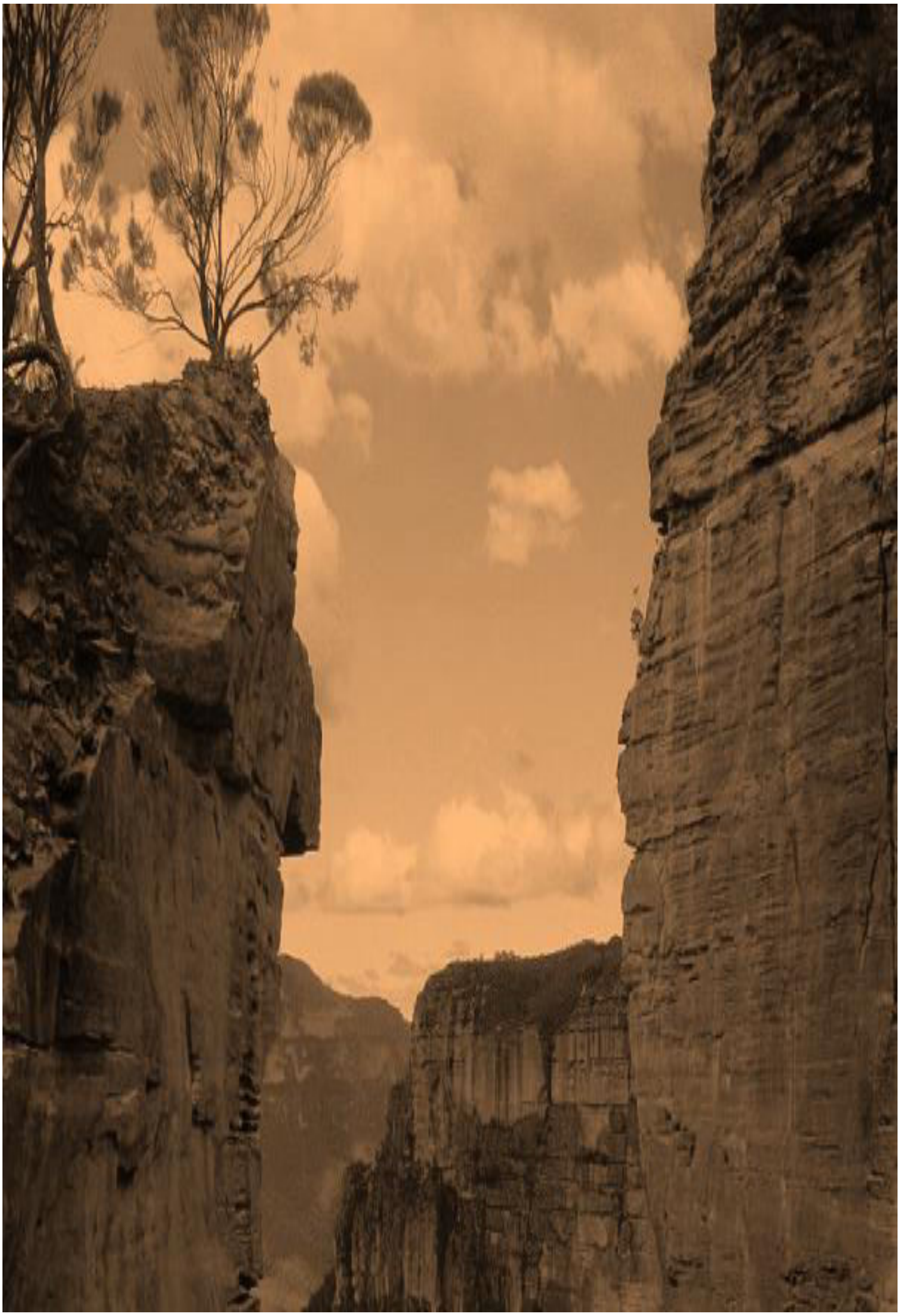

Figure.14- The large primary wrenches extend through the outer crust and thus are very deep and fundamental flaws in the crust.

Some deep-seated wrenches appear to be indicated at the surface only by systems of small en echelon faults or anticlines. Situations of this nature as described by Picard(1954) as disharmonic faulting, where I observed the Tamia and Patalkot rift system are rarely dishormonic faults. A further example is the well-known zone of en echelon faulting in south-central Pachmarhi which appears to lie in extension of the Dhupgarh Mahadeva Chauragarh lineament, here considered to be a lateral wrench-fault zone. On a large wrench fault, such as the Belkandhar, the zone of faulting can be several meter wide; in this zone, individual surfaces of movement anastomose in a complicated fashion resulting in a crush zone with many fault splits whose surface traces form a braided pattern, and in the development of a fault breccia throughout.

There are many difficulties inherent in the recognition of the wrench fault in the Dhupgarh Mahadeva and Chauragarh. The last increment of movement in many cases has been essentially vertical, so that the fault simulates a high-angle normal fault or high-angle thrust fault. Many wrench-fault zones are covered by secondary thrust sheets which are considered to have been built up from adjacent drag folds and moved across the parent wrench.

Dating of Wrench Faults

Exact dating of wrench-fault movements is a difficult problem arising from the continuous activity of many of these faults through geologic time. In general, geologists determine the youngest formation offset by a fault or the oldest rock unit unaffected by a fault, and approximate a time of rupture. This method is applicable to wrench faults only to the extent of dating the last increment of faulting. Many individual pulsations can be dated by local unconformities or buttressing of individual stratigraphic units on growing drag folds. Where stratigraphic data are available on both sides of a wrench, a progressively increasing offset of older and older units can be demonstrated by measuring fades separation; following Hill and.Dibblee (1953), I have successfully applied this principle to the Nagduari fault. In some cases, an approximate date of fault inception can be determined by correlating offset portions of pre-existing deformation of known age.

Field evidence from the major wrenches studied, suggests that "the determination of fault inception is not clear-cut but is a function of the readable geologic history. For example, the Patalkot fault is said to have originated in the pre-Tertiary, probably Jurassic, only because the oldest rocks that contribute understandable data are probably late Jurassic and point to the presence of an ancestral Patalkot (Fig.15.) This inference suggests that some of the major wrenches are as old as the rigid crust of the earth. On the other hand, as compression and deformation have continued through geological history, new fractures have formed in response to the increasingly complex stress distribution in the earth's crust

Patalkot Examples

A discussion of field examples of wrench faulting should start with the Patalkot. An early record of strike-slip movement on faults is to be found in the discussion by Crookshank (1936) (Fig.16) is an outline of Patalkot on which the principal fractures have been traced, showing the Patalkot as the dominant, feature. The Patalkot fault extends from Tamia, in a general southeast direction, with its characteristic strike of 75-85° The Patalkot, a stress orientation explaining their interpretation of the dynamics: the authors believe that: (1) the Patalkot is a steep fault zone of variable width consisting of one or several nearly parallel faults; (2) its inception was quite likely pre-Tertiary, and it is now active; (3) it has probably been characterized by right-lateral displacements throughout its history; (4) it marks such an important contact that rarely can it be crossed, except in recent alluvium, without passing into significantly different rocks; and (5) its cumulative displacement of some rock units is at least tens of kilometer, and older rocks may have been displaced .

Figure.15- Field evidence from the major wrenches studied suggests that "the determination of fault inception is not clear-cut but is a function of the readable geologic history of the Pachmarhi

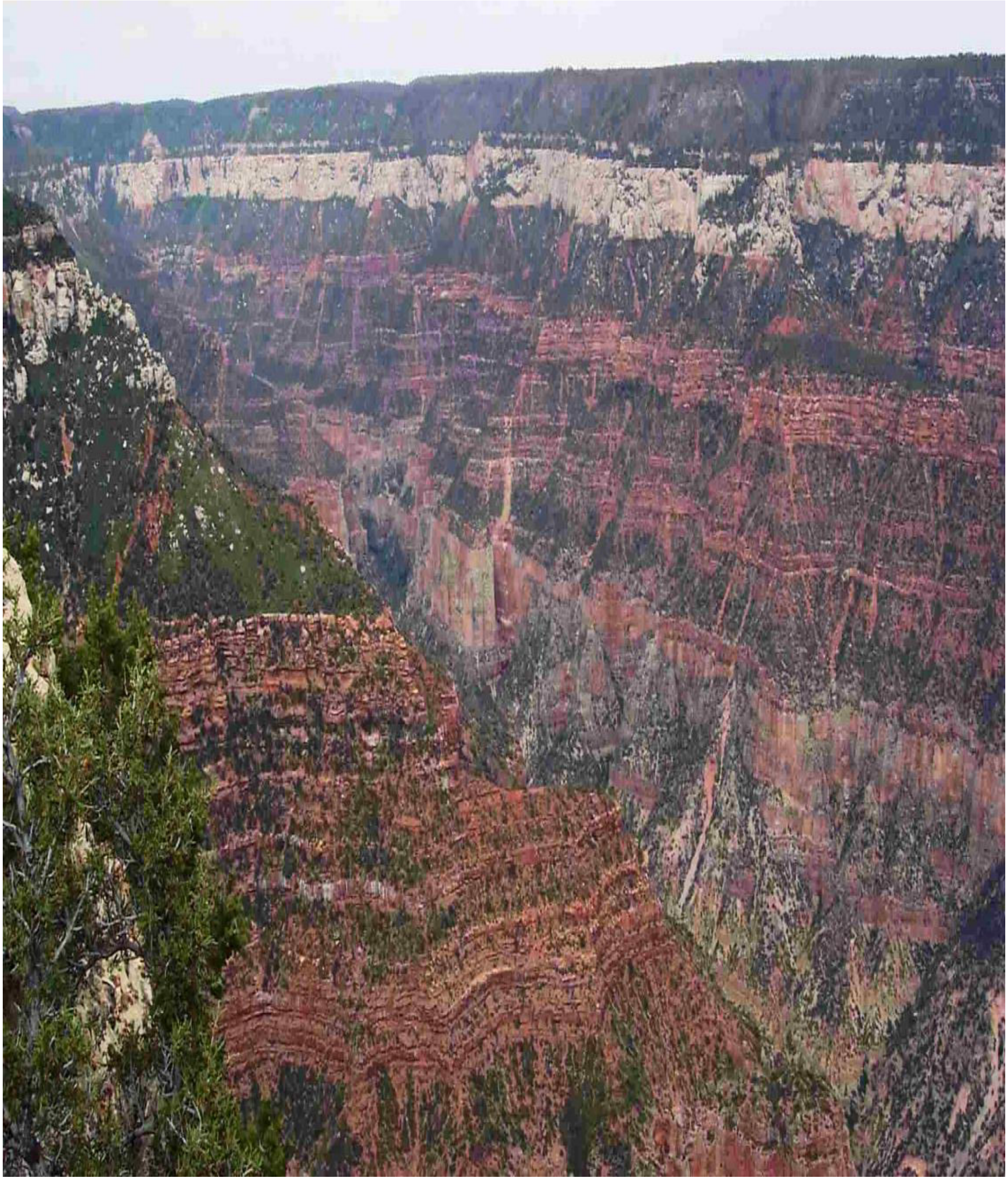

Figure.16- An outline of Patalkot on which the principal fractures have been traced, showing the Patalkot as the dominant, feature. The Patalkot fault extends from Tamia, in a general southeast direction, with its characteristic strike of 75-85°

It is most important to understand the mechanism of the section, but is equally important to define the mechanics responsible for the great extent of the fault where it is nearly a straight line. Major part of the fault requires a nearly north-south direction for the principal-stress axis, or possibly a little east of north, to give right lateral movement. The drag-fold orientations illustrated in (Fig.17) and many other drag folds on the west side of the fault are clear evidence of right lateral movement. Uniform stress orientation over a wide area must exist to develop such a lengthy and uniform rupture in the crust.

Figure.17- The drag-fold orientations drag folds on the west side of the fault are clear evidence of right lateral movement.

The authors believe that the Patalkot fault represents one of the major primary fractures of the earth's crust, responding directly to stresses of fundamental importance in crustal mechanics.

A number of faults essentially parallel to the Patalkot are also shown in (Fig.18) probably represent the first-order wrench direction associated with the Patalkot or possibly a part of a major rift-fault system of which the Patalkot is the most pronounced fracture.

Figure.18- The first-order wrench direction associated with the Pachmarhi, or possibly a part of a major rift-fault system of which the Pachmarhi is the most pronounced fracture.

Central and south Pachmarhi Examples

Since Gilbert's (1874; 1875; 1928) description of the fault-block theory of origin for structure, many geologists have been bound to a concept of tension faulting. Other workers have long recognized the compressional aspects of the rock deformation. Many complex thrust zones, in some cases involving upper Tertiary rocks, have been described, and some have been observed by me in the areas of extreme compressional deformation in central and south eastern parts of Pachmarhi. Normal faults are' recognized as subordinate features. In several cases in the literature a stratigraphic unit changes character abruptly between two exposures, suggesting facies off sets (Fig.19). Topographic lineaments appear to have tectonic origins, indicating that a grand fracture pattern is controlling a large area and structural complexities which indicate that it is a large wrench-type shear zone with right lateral movement. This is certainly a major right lateral wrench-fault. Several major faults have been described along the eastern and southeastern side of the Pachmarhi.

Figure.19- Topographic lineaments appear to have tectonic origins, indicating that a grand fracture pattern is controlling a large area and structural complexities which indicate that it is a large wrench-type shear zone with right lateral movement

The existence of the regmatic shear pattern in the area is a strong evidence of a rigid crust reacting elastically to tectonic forces (Fig.20). The strength of this force must be considerable. The regmatic dissection runs across are well, showing everywhere the existence of a strong, rigid, and splittable body.

The major tectonic features of Pachmarhi hills and Dhupgarh Mahadeva,Chauragarh are generally supposed to be younger than the deformed rocks which they transgress. During the last two or three decades observations began to accumulate which prove that several, if not all, of the main fractures or fracture zones are old and have been active practically during

Figure.20- The existence of the regmatic shear pattern in the Pachmarhi, is a strong evidence of a rigid crust reacting elastically to tectonic forces. The strength of this force

all the tectogenetic periods of the Earth's history. This indicates that the Pachmarhi was divided into polygonal fields or blocks of considerable depth or thickness during an early stage of its history (Nilsen T. H. And Mclaughlin R. J. 2010). (Fig.21) The structural relation along the part of Rock Knob formaton an inlier in the ,south eastern,south Pachmarhi ,suggest wrench faulting of Tectonic Catagory .In the opinion of Hendric K.S.(1947).This type of inlier dips at the surface are very nearly 90^0

In the following, the author will speak of 'basement blocks' which are separated by eofractures or geo-sutures.

Geotectonics

Reginatic Shear Patter

Hobbs (1911), in a paper describing the uniformity of fractures, joints, and other lineaments throughout the world, wrote:the practically uniform pattern and the like orientation within each of the orderly fracture fields, point clearly to a community of origin in stress conditions throughout an area of continental dimensions.

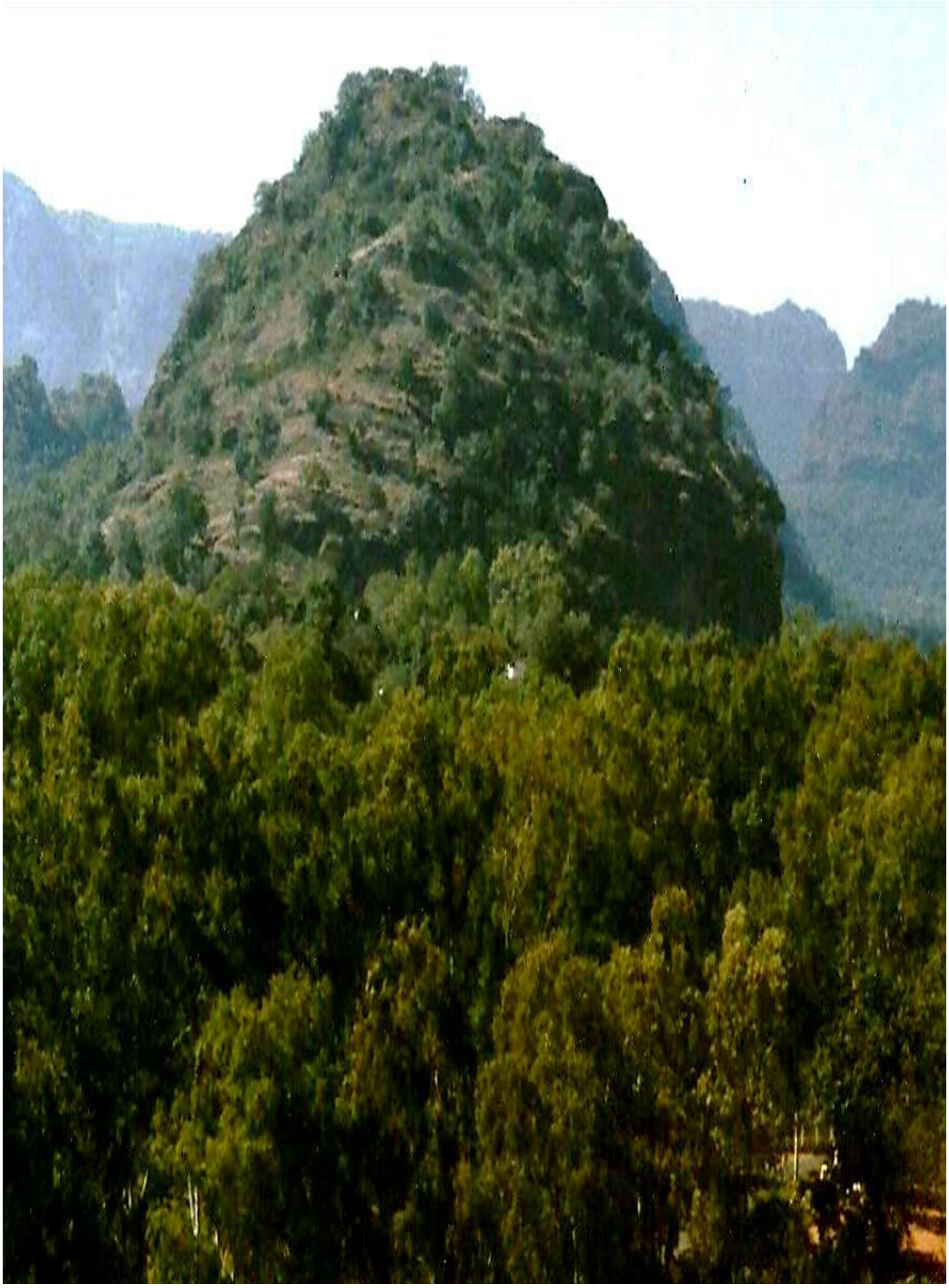

Figure.21- The major tectonic features of Pachmarhi hills are generally supposed to be younger than the deformed rocks which they transgress.

This recognition within the fracture complex of the Pachmarhi an unique and relatively simple fracture pattern, common to at least a large portion of the surface, obscured though it may be in local districts through the superimposition of more or less disorderly fracture complexes, must be regarded as of the most fundamental and far reaching importance. It points inevitably to the conclusion that more or less uniform conditions of stress and strain have been common to probably the Pachmarhis entire structure (Fig.22)

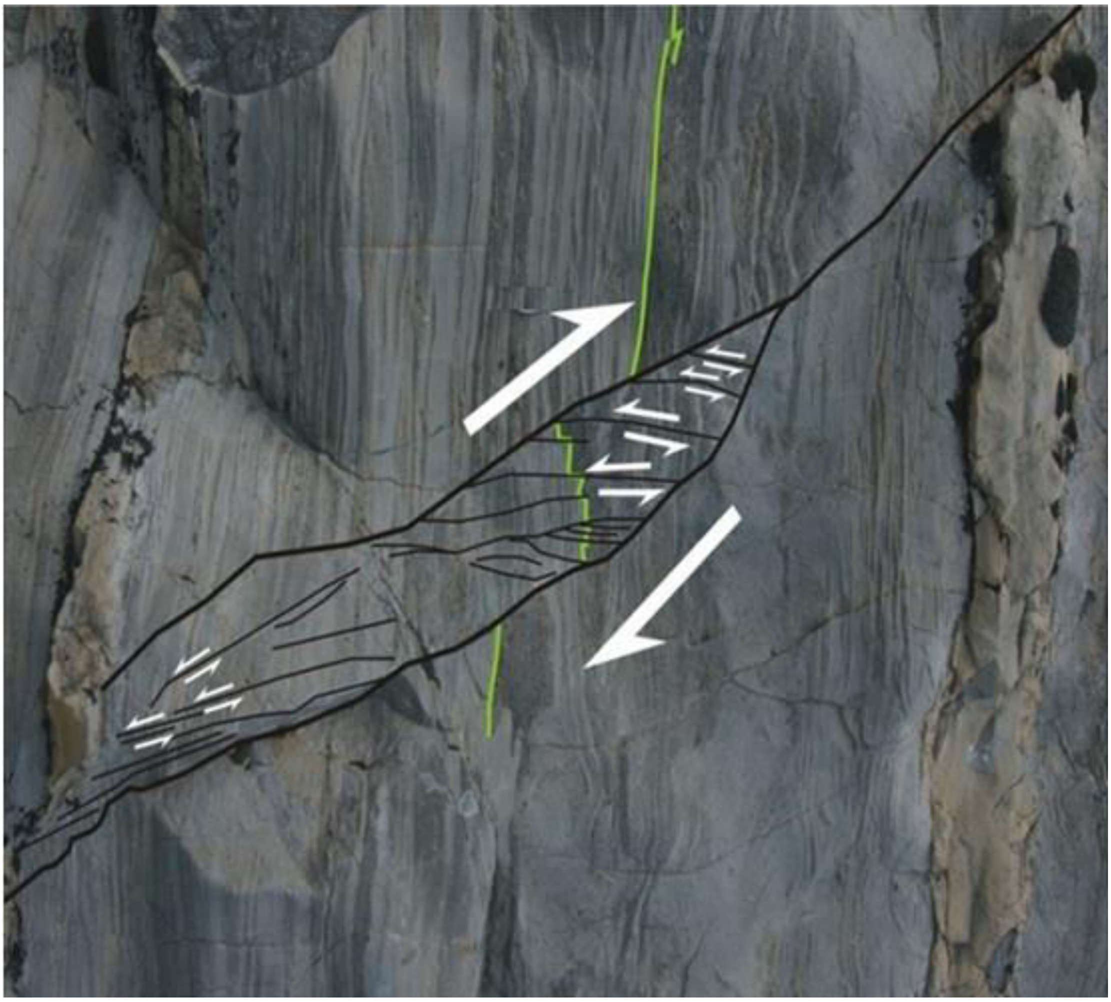

Figure.22- It points inevitably to the conclusion that more or less uniform conditions of strain have been common to probably in the Pachmarhis entire structure.

The ultimate brittle rocks at and near the surface, without superincumbent load of other rocks, have broken into a complicated mosaic of fault blocks by lateral slip movements in a zone under compression, producing elongated-domical or elliptical areas of uplifted ridges, the longer dimensions or axes of which are nearly parallel to the direction of lateral slippage.(Christie-Blick N.And Biddle K.T.J 2010)Therefore, they may be a consequence of thrust or shear and differ from the commonly accepted thrust planes in that the fracturing is more nearly vertical than horizontal and the direction is more nearly parallel than at right angle to the direction of shear or thrust (Fig.23). Considerable rotatory or torsional effect, it would seem, would be a necessary consequence and would shatter such zones into an assemblage of angular-outlined blocks.

The investigations of the Tawa,Denwa, Sonbhadra Nagduari,Bainganga,and Dudhi river revealed a complex system of shear-fault zones and joint systems in the unconsolidated sediments of this area. I regard the entire segment of wrenchfault, part of a regional shear zone. The tectonics of this area seems to be that the longitudinal motion is fundamental, and that everything else is incidental and resultant. The stresses which yielded such a uniform shear pattern result from forces which are commonplace. This shear pattern is termed as the regmatic joint or shear pattern.

The existence of the regmatic shear pattern is a strong evidence of a rigid crust reacting elastically to tectonic forces. The strength of this force must be considerable. If this were not so, the coordination of the regmatic pattern would be impossible.

Figure: 23. The consequence of thrust or shear and differ from the commonly accepted thrust planes in that the fracturing is more nearly vertical than horizontal and the direction is more nearly parallel than at right angle to the direction of shear or thrust.

The major tectonic features are generally supposed to be younger than the deformed rocks which they transgress. During the last two or three decades observations began to accumulate which prove that several, if not all, of the main fractures or fracture zones in the Satpura are old and have been active practically during all the tectogenetic periods . This indicates that the Satpura was divided into polygonal fields or blocks of considerable depth or thickness during an early stage. In the following, the author will speak of 'basement blocks' which are separated by 'geofractures' or 'geosutures'. Pre-Jurassic record has been destroyed by metamorphism so that no date other than pre-Jurassic can be assigned to the origin of this fault. The writer believes that the boundary fault which he postulates in the heart of the Pachmarhi had its inception in Triassic time. It must be realized that many of the shear planes must have been maintained throughout great parts, or perhaps the whole, of the crustal history; in all cases where forces have since worked on the crust, the chances must have been great of differential movements of the separate crustal blocks and, therefore, of new shearing along these planes. If the crust had been covered by more recent sediments, these layers must have had insufficient strength for resisting the movements, and so the shear planes must have penetrated these layers also. It may, therefore, be expected that a continuous rejuvenation of the Net has taken place at the surface. Doubtless this must have been one of the main causes of the volcanicity of the alkaline type.

Possible Origin of the Regmatic Shear Pattern

Apparently the Pachmarhi major wrench faults have moved more or less continuously since their inception; in most cases they are traceable to back as far as the geologic record goes. For example, in the Tawa and Sonbhadra fault been inferred to have been moving in Jurassic time; the There are large wrench faults which can be shown to have been active in, for example, Precambrian and Paleozoic time, on which there is no evidence of later movement. Apparently boundary faults can "heal" or lock so that no further movement occurs, and the stresses are then accommodated along other fractures. It should be emphasized that the period of geologic observations covers only a few scores of years, and it is possible that recent movements on faults believed to have been inactive since, for example, Mahadeva time may have occurred. As an illustration, the Chandkia Golandoh fault, believed to be associated with a major wrench-fault zone, had its main structural growth in late Gondwana time.

The writers believe that the origin of the regmatic joint pattern goes back to the period when the Pachmarhi structure was very young, when the crust first evolved enough to support compression. Several different types of forces are considered to have been responsible for the genesis of the regmatic shear pattern. Subcrustal convection currents have been suggested to explain various phenomena associated with the deformation of the crust (Fig.24). *(See* Gutenberg, 1951; Hafner, 1951; Scheidegger, 1953; Vening Meinesz,, 1954.) If subcrustal convection currents exist, they must exert a considerable drag on the base of the crust. Their orientation would perhaps be symmetrical in some fashion with the axis of rotation of the earth so that subcrustal convection currents could result in forces acting in an essentially meridional direction. Another source of compressional stress in the Pachmarhis sructure is attributable to the diurnal rotation of the earth itself, possibly in association with "Polfluchtkraft". *(See* Gutenberg *et al,* 1951.) Secular compression should result in consequence of cooling and contraction, as emphasized by Lees (1953), Landes (1952), and Jeffreys (1952). Possibly each of these three types of forces has had and does have large north-south components; other forces of a similar nature may be involved. These forces, which have been acting essentially continuously and in the same sense throughout geologic time, are, in the opinion of the authors, responsible

Major Boundary Fault

The existence of a shear pattern comprised predominantly of major wrench faults results in.' a definite segmentation of the crust. Important components of horizontal movement on these faults, as has been demonstrated for the Dhupgarh,Mahadeva, Chauragarh, Richhkhoh, Nishangarh, Brijlaldeo ,Belkandhar Guuadeo, PhasiPahar, Gerudeo, Guttideo and the Tawa fault, imply the existence of a surface of horizontal movement at some depth below the surface. This surface could be at Barrell's asthenosphere, or Davison's "level of no strain", or the base of the solid crust, or a zone of plastic flow. Gutenberg *et al.* (1951) give 30 to 100 km as the probable depth to the "base of the outer crust". The authors believe that the major vertical faults extend to this surface, wherever and whatever it may be, so that the solid compression-transmitting portion of the outer shell of the earth at least is divided into blocks. These blocks, bounded by major linear elements of the regmatic shear pattern, tend to be polygonal.

Figure: 24. Different types of forces are considered to have been responsible for the genesis of the regmatic shear pattern. Subcrustal convection currents have been suggested to explain various phenomena associated with the deformation of the crust.

Such dimensions correspond roughly to those of areas over which isostatic adjustment is estimated to be relatively complete. The Pachmarhi has diagonal dimensions of roughly

115 kilometer. This shape and size are perhaps typical of mega blocks bounded by two primary right lateral and two primary left lateral wrench zones.

One result of such segmentation of the crust would be that blocks or groups of blocks separated by major boundary faults could have decidedly different geological histories, as borne out in many regional geological studies.

As movement continues along the boundary faults any block could be freed from compressive forces, and thus it would be possible to have an unstressed block or blocks surrounded by stressed blocks; the unstressed block or blocks could then respond to whatever other forces to which it was subjected (Fig.25). (For example, gravitational forces, sedimentary loading or unloading acting on its surface, or hydrostatic stresses acting on its base) and could then move vertically in response to such forces. Such a stress release could explain sostatic adjustment and "equilibrium" and the continued downwarping of particular crustal areas which results in what most geologists call geosynclines; it could also explain the abundant field evidence that there has been late vertical movement on vertical faults.

The development of sedimentary suites displaying most of the characteristics of geosynclinal accumulations is readily visualized. Given a major boundary fault between two independent crustal blocks, minor vertical components of movement associated with the dominant strike-slip movement of the fault could be evidenced by minor tilting of these blocks so that the emergent part of one ' block could be apposed to the lowest part of the adjacent block. A strongly asymmetric basin would thus be formed which could accumulate sediments from two directions. Thus the finegrained sediments accumulating from the north and south in the diagram could be contaminated by coarse debris eroded from the scarp of the boundary fault; this could result in mixing graywackes and conglomerates into the fine-grained clastic from the north-and south, yielding bimodal sediment. Major boundary faults are considered principal avenues for movement of subterranean material upward in the crust so that volcanic and/or siliceous components could easily be added to the already complicated sediment. A further consequence of a crust thus segmented would be that, although individual blocks or groups of blocks could show great Strength, larger groups of blocks which include several major boundary faults would have very little strength insofar as vertical movements are concerned. Perhaps in this manner a second paradox which has plagued geologists for many years could be resolved.

Ver Wiebe (1936) and Weeks (1952) pointed but that most geosynclines or large basins are asymmetric and bounded on the steep flank by what Ver Wiebe termed geosynclinal bound-faults. The authors believe that the Satpura geosynclinal boundary faults are in most cases wrench faults and constitute important elements of the regmatic joint pattern.

In a segmented crust, the surface areas of the individual blocks must decrease with continued compression; in the writers' view this contraction takes place around the edges of the major blocks in the vicinity of the boundary faults where folding and thrusting is concentrated. Continued distortion of individual blocks must result in a change of shape, so that the directions of the major wrenches might vary slightly as compression continues; this is actually an increase in the angle β from the theoretical value of 31°. The magnitude of this effect is not known as elevation difference resulting in widespread shallow water over large portions of the Satpura blocks represents a closer approach to equilibrium conditions.

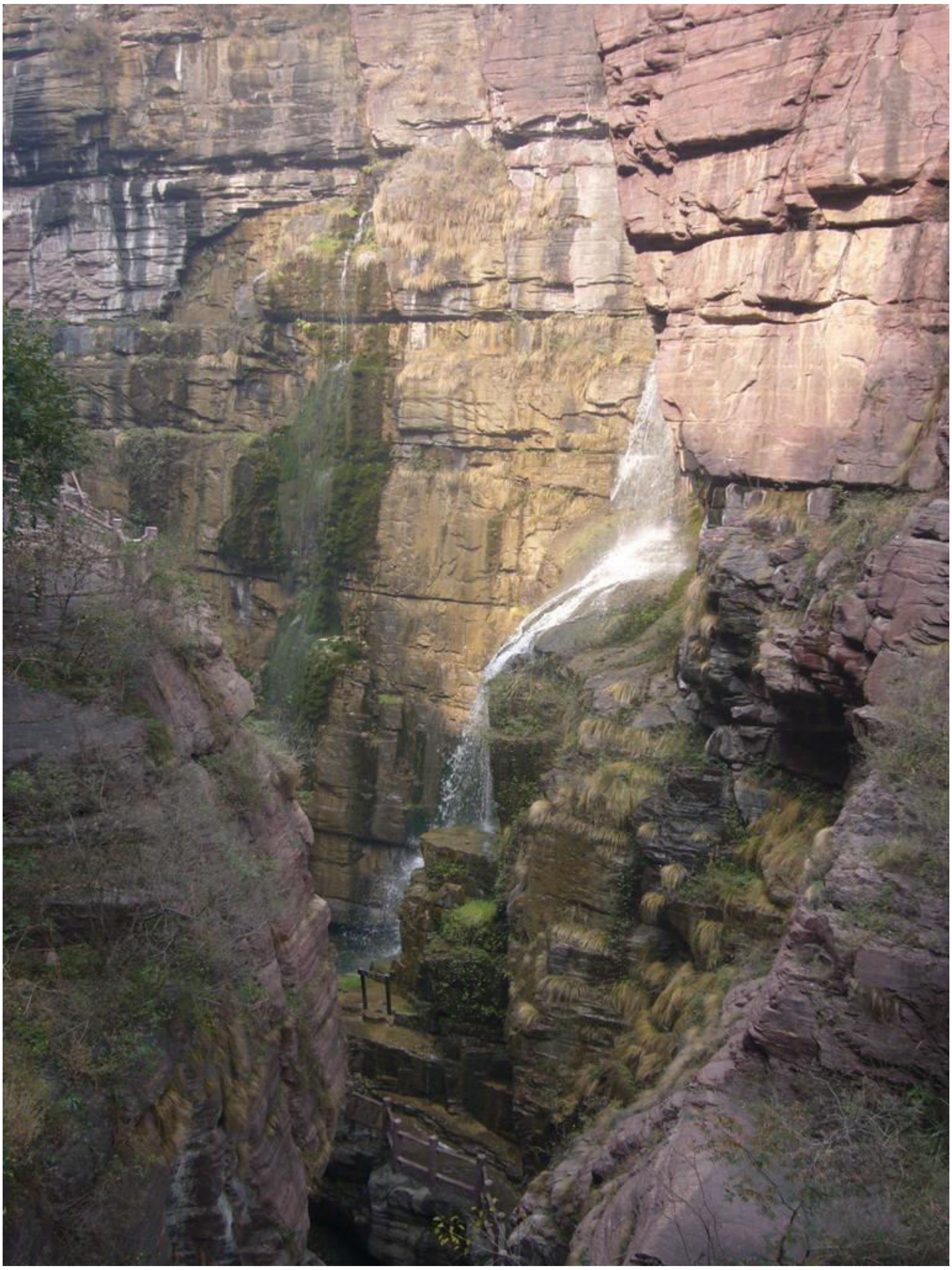

Figure.25 - As movement continues along the boundary faults any block could be freed from compressive forces, and thus it would be possible to have an unstressed block or blocks surrounded by stressed blocks; the unstressed block or blocks could then respond to whatever other forces to which it was subjected

Conclusion

The main concepts and conclusions presented in this paper are:

1. Wrench faulting is much more prevalent than ordinarily supposed.
2. There exists a regmatic shear pattern common to the entire structure

3. The major elements of this shear pattern are extremely large wrench faults which extend through the outer crust. Movement on these wrench faults has been dominantly horizontal and has resulted in wholesale segmentation of the structure.
4. Second-order features developed as a consequence of movement on these large geofractures constitute a major portion of the large- and small-scale compressive phenomena of the Pachmarhi
5. The major elements of the regmatic shear pattern tend to be aligned in eight directions. These eight directions possibly resulted from primary compressional stresses whose orientation did not vary more than a few degrees from north-south, although this orientation is not unique.

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