Bulletin de la Société belge de Géologie Bulletin van de Belgische Vereniging voor Geologie	T. 94 V. 94	fasc. 3 deel 3	pp. 209-221 blz.209-221	Bruxelles 1985 Brussel 1985

LINEAMENTS AND EXTENSIONAL TECTONICS : EXAMPLES FROM SHABA (ZAIRE) AND NE ZAMBIA

by J. DEHANDSCHUTTER and J. LAVREAU (*)

ABSTRACT - Fracture and lineament analysis on Landsat imagery of the Shaba-Northern Zambia region reveals a remarkable persistancy of trends over both cratonic areas and mobile belts. Two axes of Phanerozoic rifting (NE and NNW) position along the short diagonals of rhombs limited by ENE and SE lineaments. NE rifting occurs where ENE lineaments are regionaliy predominant whereas NNW rifting occurs in regions SE lineaments are most abundant. All four directions are again recognized in the trends of lineaments which are likely to have been significant in all geodynamic cycles since the Kibaran.

Outstanding features are uplifted areas of folded Precambrian sedimentary series with conspicious S-shaped rhombic pattern. The largest rhomb is situated at the southern tip of the Kibara belt in Shaba (the Nzilo S-structure). Several smaller representatives are found at the Northern termination of the Irumide belt of Zambia (the Mafingi Hills, the Chimbwe syncline).

The S-structures are interpreted as sedimentary basins developing between overstepping oblique-slip faults during sinistral slip. They are of the pull-apart basin type.

The geometry of the tectonic element in the Phanerozoic, Panafrican and Kibarian is interpreted in term of extensional and oblique-slip tectonics. Compressive episodes are also recognized in the Kibarian and the Panafrican.

1. INTRODUCTION.

1.1. PHOTO-INTERPRETATION.

Fracture and lineament analysis was done on enlarged black-and-white Landsat scenes. The analysed images cover a region of some 400 000 sq. km. extending between 10 and 12 deg. S and between the river Lualaba (25 E) and lake Malawi (34 E).

Lineaments are traced in accordance with the definition given by DENNIS (1967) who follows HOBBS' early statement (HOBBS, 1911) that lineaments are "rectilinear or gently curved alignments of topographic features on a regional scale, generally judged to reflect crustal structures". Structural and morphological elements are combined into lineaments of composite nature.

A neat and straight segment is picked out and traced. The interpreter then looks for any significant cross-cutting linear structure at both ends of the traced segment, thus looking for a possible causative relationship between each pair of lines. This routine analysis is repeated under different viewing angles. Aligned segments are subjectively interconnected in accordance with the former definition. Tightly disposed parallel lines are replaced by one main lineament. In areas of horizontal cover rocks and alluvia, straight river segments, abrupt tonal changes and contrasting tonal corridors are treated in the same way as lineaments recognized in dissected terrains with hard rock lithology. The physical meaning of a class of lineament directions is taken for granted if an identical or

(*) Koninklijk Museum voor Midden-Afrika, Tervuren (België).

or paralled set of lineaments is detected by another observer. No systematic multitemporal analysis has been carried out, but scenes taken at different times of the year have been used in the course of the work. These precautions should allow for a sufficient degree of confidence in the physical reality of the recognized lineament classes.

A special care is given to geologically highly significant areas, e. g. fold closures, rift terminations and the like. A straight but interpreted line connecting several geological features is considered to be a lineament and traced.

Lineament schemes and available geological maps are then combined and the results interpreted. The photo-interpretation of selected areas may be repeated in the light of the ongoing interpretation. This non-automatic approach emphasizes all geologically significant structural directions. In most cases it discerns at once between bedding and tectonic feature and it eliminates most of the agricultural and similar elements. The final result of the survey is a reinterpretation of the available geological map on a scale of 1 to 3 000 00 (fig. 2).

1. 2. DEFINITION OF STRUCTURAL ELEMENTS.

The question how features diagnostic for particular geodynamic settings can be recognized by remote sensing has been treated elsewhere (DEHANDSCHUTTER and LAVREAU, 1985).

2. RESULTS OF PHOTO-INTERPRETATION.

2. 1. FRACTURE AND LINEAMENTS ANALYSIS.

The frequency distribution of some representative parts selected from the lineament map is given in fig. 1. Most remarkable is an ubiquitous and systematic combination of ENE and SE lineaments intersecting under an angle of 60 deg. Next in importance comes a NNW-NE conjugate system which is subordinate to the former in frequency and length and whose correlation with geology is less conspicious.

2. 2. CORRELATION WITH GEOLOGY.

The observed lineaments are compared with the information displayed on the maps of Zambia and Zaire respectively at the scale of 1/1 000 000 and 1/2 000 000 (THIEME and JOHNSON, 1981, LEPERSONNE, 1974).

2. 2. 1. PHANEROZOIC TERRAINS.

The lineaments are most strongly expressed in recent tectonic features related to rifting and downwarped swamp areas.

The Lake Upemba rift zone in Zaire, Lake Mweru and Mweru Wantipa on the border and Lake Bangweulu in Zambia are all bordered by non-indented straight NE trending lineaments. Drainages and other lineaments in the swamps of the Kalungu and Chambeshi rivers (Luwala swamps, Bwela flats) in Zambia and the lowlands bordering the Lufira river (border zone) to the west, have distinct NE orientations too. This NE lineation is also found in the Luangwa-Karroo rift where it gives exactly the direction of the long axis of the graben.

Lineaments of the NNW group often occur in cunjunction with the NE set. The southern tip of Lake Mweru and the segment of River Luapula south of the lake are controlled by rift faults of the NNW group which also come through at the southern end of Lake Bangweulu. Several NNW lineaments out northeastern Zambia projecting the main strike of the Lake Tanganyka rift to the south.

In Zaire, the ENE set closes the Upemba rift at both extremities; representatives of this lineament class border the Lufira river lowlands on one side and they close the Lake Mweru rift to the north. The headwaters of the Lubule river are drained through an ENE-directed graben.

In Zambia, lineaments of this class cut off the Luangwa rift to the north while forming the base for the NE directed Chambeshi and Kalungu swamps. Most evident is the control of this lineament class upon the strike of the Karroo rift boundary faults along the Luangwa river. A major lineament zone runs ENE from Kapiri Mposhi at the Zaire-Zambia interlocking region, to the Machinje Hills at the Malawi border. The structure divides the Karroo rift into parts of different geometry. This group of "dislocation zones" was recognized by DE SWARDT et al. (1965) who also linked the origin of the Karroo rift to the presence of the linear structures (fig. 8) situated either inside the dislocation zone (Luano rift) or at an angle to them (Lukusashi and Luangwa rifts). Parts of Lake Mweru Wantipa are probably downfaulted along ENE striking faults. It should finally be observed that the long axis of grabens are directed NE in areas where the density of the ENE lineaments is highest (Upemba, Mweru and Mweru Wantipa).

The NW-SE set of lineaments has a strong influence on Phanerozoic rifting processes as well. In Shaba, the Kafila, Lofoi, Longwhishi and Lufukwe valleys are in part downfaulted grabens. The triangular Lufira lowland abuts against the Panafrican along a line extending to the NW from the Kafila half-graben. The southern end of Mweru rift is linked to the northern termination of the Upemba rift by a NW-SE linear zone which is probably a structure of the family which also limits Lake Bangweulu to the north. Finally, the Luangwa rift is closed to the north by a wide zone of NW-SE lineaments belonging to the classic Ubendian belt.

The long axis of the grabens have NNW azimuths in areas where the density of SE-NW lineaments is highest (Lufila, Malawi). Except in areas of typical NNW rifting, lineaments of this azimuthal class are less abundant and general than those of the NE class which are related to the ENE lineament group.

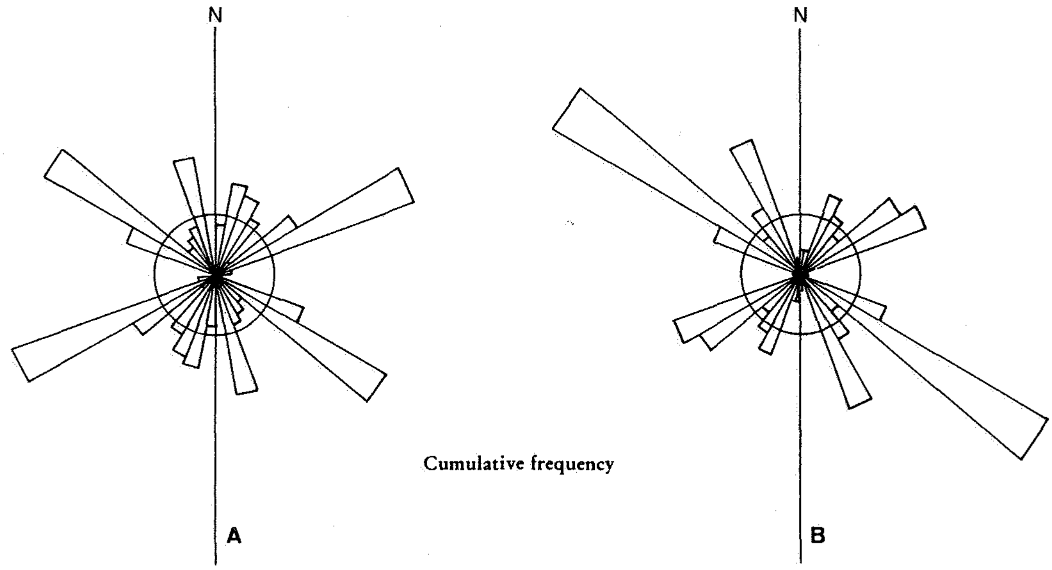


Figure 1

- Frequency distribution of lineaments in selected areas
  - A : 138 observations from Nzilo-Lufira-Mweru area; ENE and SE groups are dominant. NE and NNW groups are secondary;
  - B : 140 observations from part of the Kundelungu Plateau, note prominence of the SE and NNW sets.

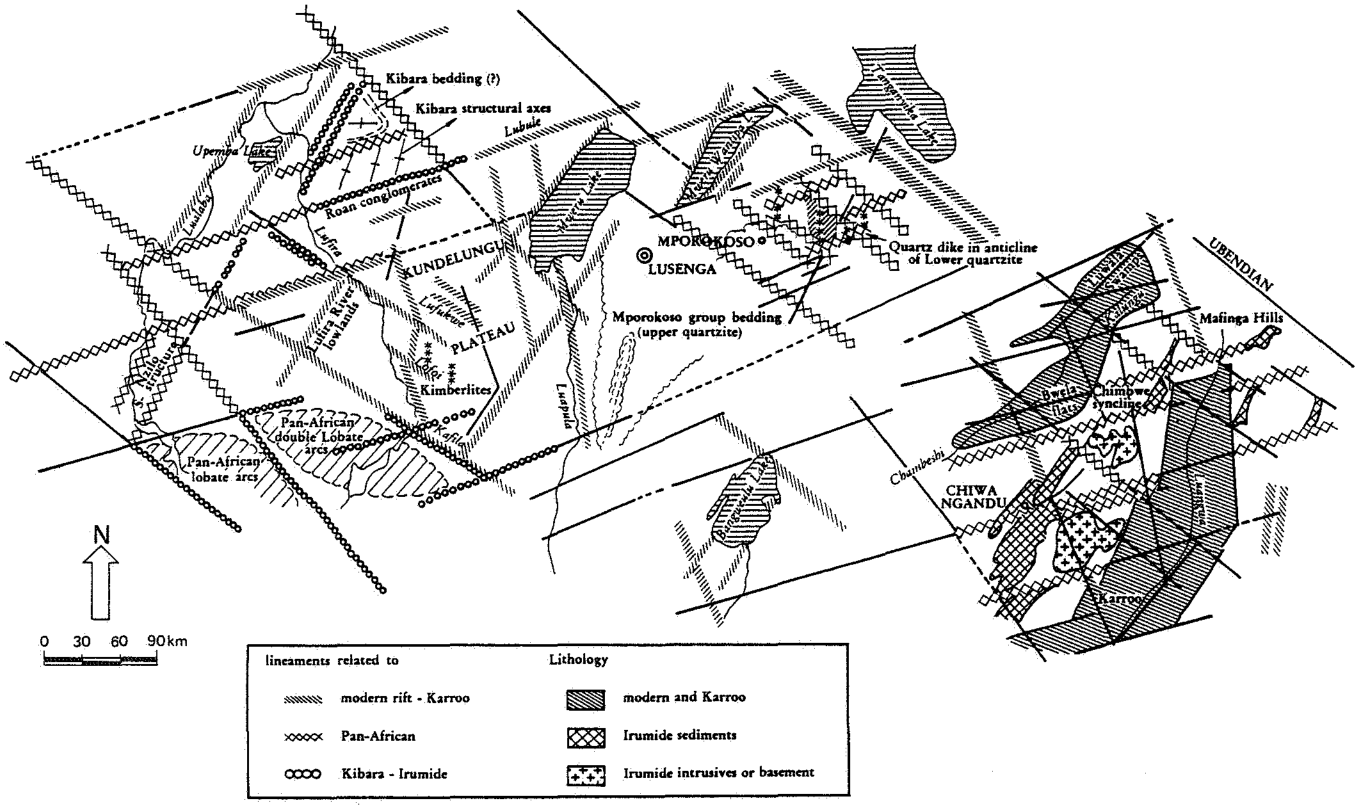


Figure 2

- Synoptic map of lineaments and structural elements; note that several lineaments are related to various geodynamic cycles.

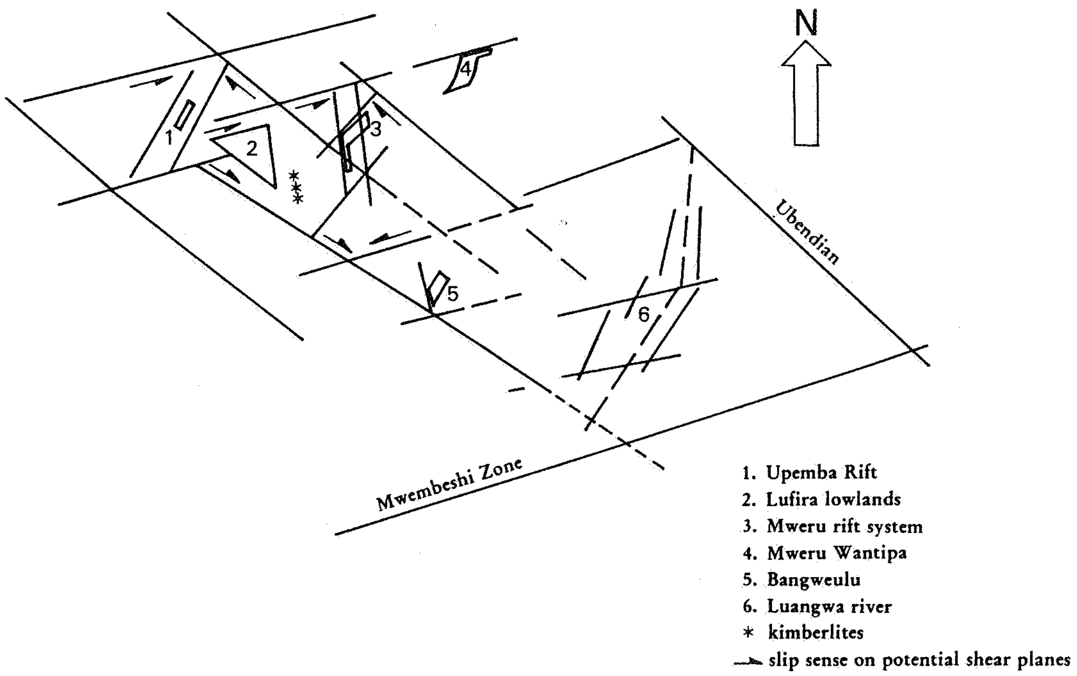


Figure 3 - Phanerozoic crustal blocks and diagonal rift faults between perennial vertical discontinuities.

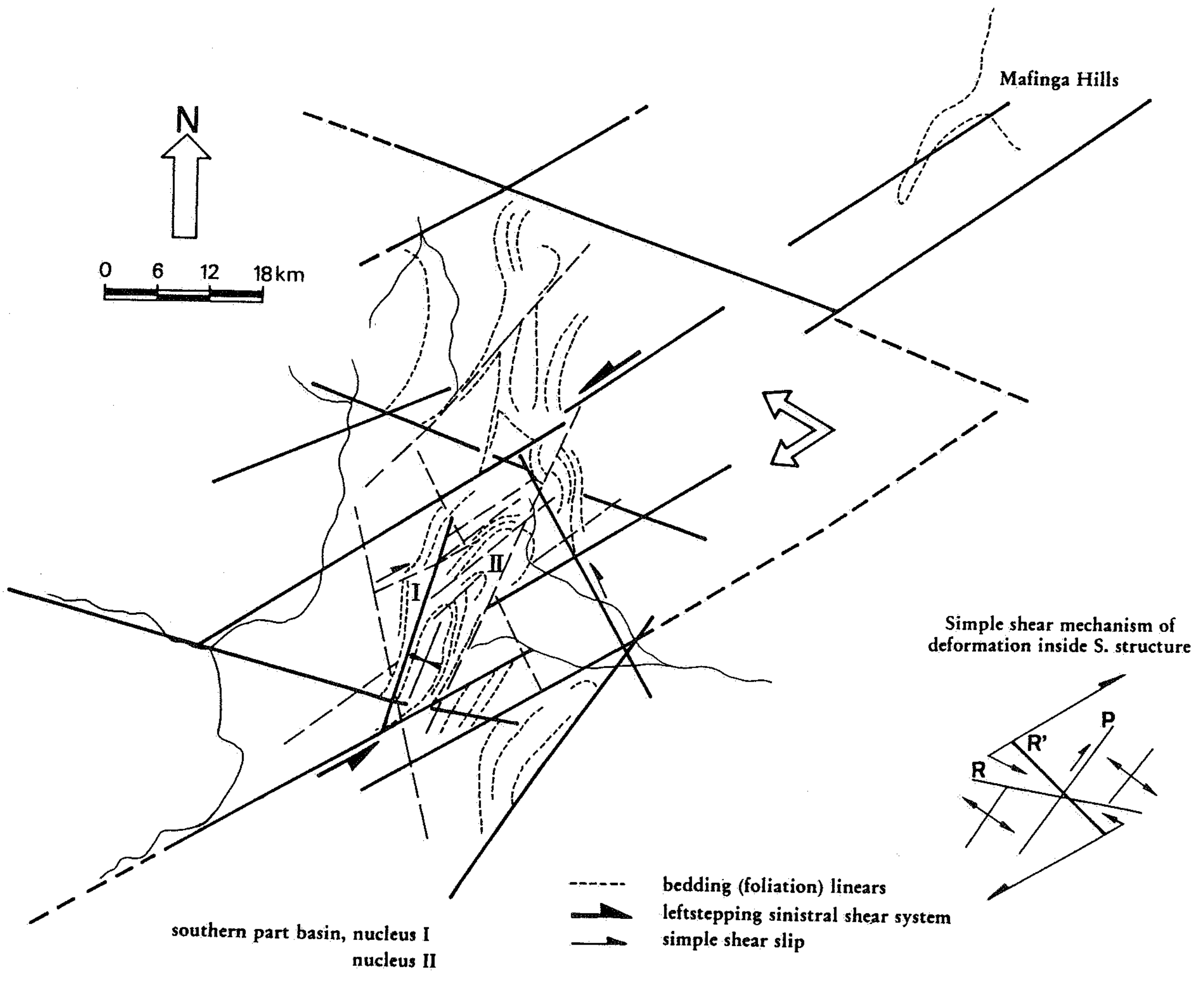


Figure 4 - Photogeological interpretation of the Chimbwe-syncline S-structure.

Attention is drawn on the geometry of Lake Mweru Wantipa (fig. 2). The long axis of this rhomb strikes NE, a direction comparable to that of the other lakes. The march is situated within a rhombic block delineated by ENE and SE lineaments. One of the diagonals of the rhomb is followed by the long axis of the swamp. The lake gets a clear sigmoid shape by extending the SW and NE corners along ENE lineaments. The elongation of the lake suggests downfaulting along these lineaments. A similar pattern is seen in the geometry of the Chambeshi and Kalungu swamps which open along ENE lineaments giving them the shape of a sigmoidal rhomb.

Taking the Luangwa rift of Karroo age as an example (fig. 3), it is obvious that the northern and southern terminations are both taken in the wide angle formed by intercrossing ENE and SE lineaments. To the south, DE SWARDT et al. (op. cit.) mapped the ENE striking Mwembeshi zone. Some minor NW-SE zones hare here interpreted to extend northwards into the Lufilian arc. To the north, the Ubendian belt and a series of ENE lineaments come together and form the intersection which closes the rift. The rift occupies one of the diagonals of a rhomb with ENE and SE directed sides. The same configuration holds for the other Phanerozoic rifts. An interpretation of their mutual relationship is shown in fig. 3.

All four of the sets of lineaments take part in normal faulting, the NE and NNW directions being however predilection direction for the rifting. The ENE and SE lineaments show normal faulting in the Lufira-Kundelungu Plateau and Mweru Wantipa areas, but their directions are mostly appropriate slip lines for shear stresses. This point will be developed later.

The diagonal grabens of the most recent rifts (Upemba, Mweru, Mweru Wantipa, Bangweulu) have straight and non-indented boudary faults. The Karroo rift and the river Lufira half-graben are indented.

Finally, it could be worth noting that the kimberlites in the Lofoi region appear to lie within NS trenfing linear zones of tension running from one wide angle of a smaller secondary rhomb to another.

2. 2. 2. PANAFRICAN.

There exists a strong correlation of the combined ENE-SE sets of lineaments with Panafrican thrust (?) folding. In Shaba, rocks composing the Lufilian arc appear compartimented in rhombs limited by lineaments of the mentioned conjugated sets. The compartiments are doubly convex and centred around an ovale core (fig. 2). The image of the double arcs is interpreted as a thrust system of double vergence emanating from the core of the arc. The fact that the conjugated lineament sets limit individual systems of double arcs (of opposite thrust sense ?) cannot be fortuitous. The lineaments neatly cut the arcs and are thus either younger than the thrust tectogenesis or they individualise separate basins and are consequently linked in one or other way to the subsidence.

Isolated Panafrican folds in the otherwise flat-lying Kundelungu (in this area) are situated in modern rifts of SE (Lufukwe river) and ENE (Lubule river) strike. The distribution and the strike of the sediments of the Petit and the Grand Conglomérat correlates with the passage of major ENE lineaments which seem to have got the function of basin boundaries at the time of sedimentation.

Folds to the east of Upemba-rift in Panafrican-mapped sediments strike NE and take position inside lineament-defined rhombs in a position similar to that in modern rifts.

2. 2. 3. KIBARA and IRUMIDES.

2.2.3.1. THE MPOROKOSO GROUP.

Undeformed early Kibaran sediments (the Upper Quartzitic Member of the map of Zambia, op. cit.) are slightly dipping away from ENE and SE lineaments. These structures have manifestly been boundary faults during basin subsidence. The current outcrop pattern and bedding attitudes still show that the basin geometry was that of adjacent rhombic blocks subsiding relatively to each other and separated by ENE and SE faults. According to UNRUG (1984), the sedimentary facies shows a strong variability and a continental origin.

Conspicious morphological features are long NS-directed quartz dykes. The absence of regional compression rules out a compressive stress regime-related origin. The dykes have the same relationship to the confining ENE and SE lineaments as the NE and NNW Phanerozoic rifts do and they are thus considered as tensional features.

The dykes are made up of short segments, some tens of km long, running diagonally across small rhombs. Taken as a whole, the short segments conform to a long line of quartz dykes each of which is contained in one rhomb of regional dimension. Apparently every single rhomb now containing a dyke experienced a tensional stress regime whilst other blocks did not. The quartz dykes seem to be constricted to the lowermost facies of the Mporokoso Group; they do not cut through the Upper Quartzitic Member that covers most of the basin.

2.2.3.2. THE IRUMIDES.

S-shaped structures typically appear in the region where the northern Irumides (NE Zambia) are truncated by the Ubendian belt.

The Chimbwe and Mafingi Hill synclines.

The Chimbwe structure is located in a corner formed between major ENE and SE lineaments (fig. 4). If the characteristic shape were indeed a consequence of strain, the sigmoid curvature would impose a right-lateral slip sense along

along the ENE lineaments and a left-lateral one on the SE lineaments.

A second possibility is considering the Chimbwe syncline and environing structures as a Precambrian equivalent of the more recent triangular Lufira lowlands to the west of the Kundelungu Plateau. Both areas are then considered as downwarped divergent corners in the small angle of a block system limited by ENE and SE structures. The sigmoid shape is then merely the consequence of the transform of motion from one slip line towards another. Note that the sense of slip under these conditions is opposite to the one derived if the hypothesis of a deformational S-shape was followed, i.e. left-lateral along the ENE lineament and right-lateral along the SE lines.

This alternative is favoured here. The Chimbwe syncline and neighbouring structures are considered as small basins belonging to the class of the pull-aparts. The southern half, composed of the syncline proper and some related surrounding structures, is formed and deformed by left lateral slip along ENE lineaments and the northern half by right-lateral slip along SE lineaments. In the northern half, the geometry is less evident than in the south. The southern half consists of two nuclei separated by NE faults. The nucleus closest to the corner developed more completely than the first one. The synsedimentary deformation operated according to the rules established for simple shear, which agrees with the observations made on the images.

A second example of this type of structure is seen in the Mafingi Hills (fig. 2). The geometry of the fold suggests a pull-apart synsedimentary origin for the structure. The difference with the Chimbwe syncline lies in the relative position of the corner in which the Mafingi pull-apart was situated : small angle for the Chimbwe and wide angle, bewteen ENE and SE (Ubendian) lineaments, for the Mafingi Hills structure.

The Chiwa Ngandu area.

Prominent eye-catching lineaments appear here at the first glance (fig. 2). They systematically curve the foliation and fold hinges which, in the area between lineaments, strike NE parallelly to the modern rift directions. SE lineaments leaving, on the one hand, less evident marks on the outcrop pattern of the Irumide rocks, do, on the other, have a real control on the contacts of igneous complexes.

The geometry of the folds in this area reminds indeed of the fundamental shape recognized a.o. in Lake Mweru Wantipa. The style of folding suggests that the Irumide sediments underlying the area represent a more envolved stage, i. e. having taken place under deeper and more ductile conditions, of the same processes which govern the development of the more recent rift lakes. This consideration has geodynamic consequences which are discussed while dealing with the model and explained in fig. 6. The NE directed fold hinges and foliation (?) would correspond to the Precambrian main compressive horizontal stress at the time of subsidence and sedimentation. The sense of shearing along the ENE systems during the same period would have been left-lateral then, and the strong curvature would, maybe in part, be synsedimentary. A reversal of slip after the deposition of the sediments caused by changing geodynamic situations would reinforce the sigmoid character by deformational drag due to right-lateral slip.

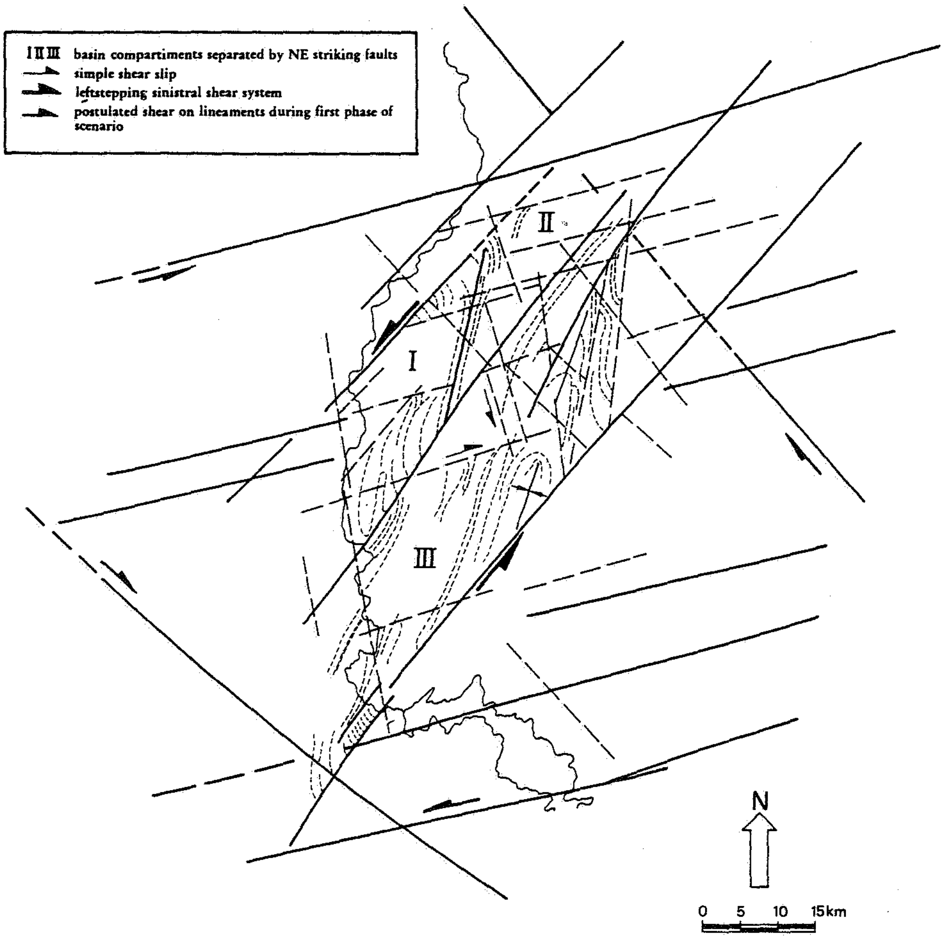
2.2.3.3. THE KIBARA BELT IN SOUTHERN SHABA.

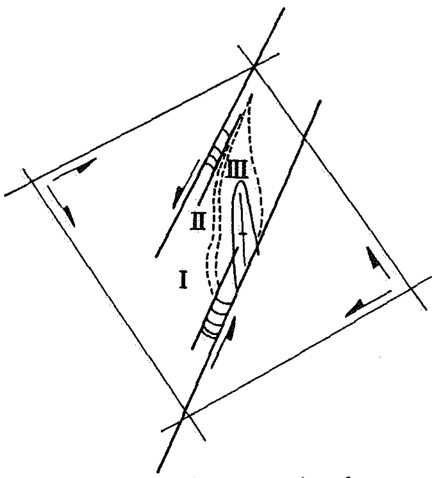
The belt takes its widest development on the northwestern side of a major ENE lineament zone passing south of the Upemba rift and north of Lake Mweru (fig. 2). Foliation and fold axes are always oblique to lineaments of the ENE family; this suggests that the lineaments play an active role in the deformational history of the Kibaran. Bedding turns occasionally to a strike parallel to the ENE direction and swings farther on towards parallelism with the NW-SE trend, thus resulting in E-W fold axes which are at odds with the regional NE-SE axial plane direction. This particular style might well be described as a superposition of folding phases. Alternatively it cannot be excluded that the divergent axial strike and plunge reflects the basin geometry at the time of deposition. This geometry should then have been controlled by the coeval operation of ENE and SE directed structures in the way shown by the undeformed Mporokoso Group. NE is a typical Phanerozoic rifting direction. To the south of the Upemba rift, a parallel lineament becomes a line of intense Precambrian shearing. Strong indications for strike-slip activity at the time of deposition and basin development come from the southern tip of the Kibara fold belt in Zaïre : the Nzilo S-structure.

The Nzilo S-structure.

To the northwest of Kolwezi (Shaba, Zaïre), a large (about 200 sq. km) S-shaped structure sandwiched between NE striking lineaments clearly marked by strong vertical shearing effects which run sub-parallaly to the bedding attitude, springs out from an otherwise structureless environment (fig. 5). The NE faults are placed en échelon above the diagonal between the two wide angles of a rhom formed by prominent ENE and SE lineaments (fig. 2). The S-structure is composed of two outstanding nuclei, the one much larger than the other and situated at the base of the structure. A third one, less obvious, is situated between the former. The nuclei are separated by NE striking lineaments. The nucleus at the base shows a soutward plunging syncline with a fold closure at its northern end and a cross-faulted and sheared contact at its southern end. The western limb of the syncline is probably folded; it is wider than the eastern one.

There are two fundamental ways for interpreting this structure. One might consider the arcuate lobate outlook of the three nuclei as the surface expression





Schematical representation of principal structural elements

Simple shear mechanism of deformation inside S. structure

Figure 5 - Photogeological interpretation of the Nzilo S-structure.

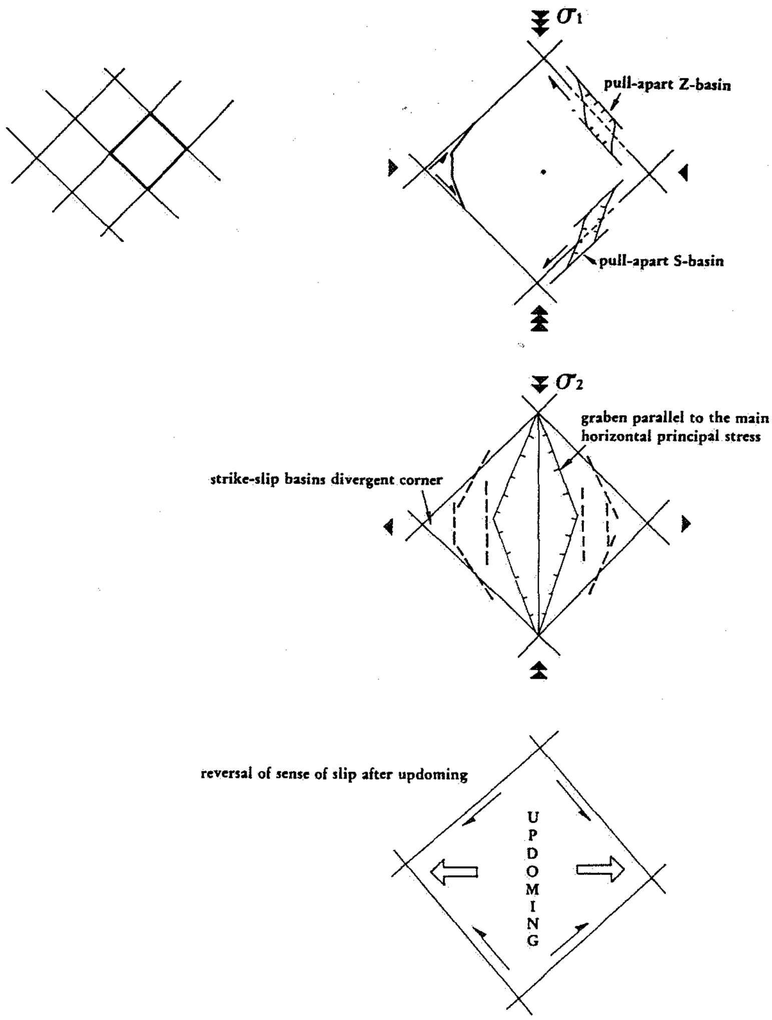


Figure 6 - Possible relationship between extensional (rifts) and oblique-slip (transtensional pull-apart basins) tectonics, followed by updoming and reversal of slip.

of three thrust sheets, transported from the east to the west, the NE faults as frontal ramps and the east limb of the syncline as backthrusted bed sequence. In order to explain the vertical drag in a narrow shear zone particulary well exposed at the southern end of the structure, one must invoke a changing dynamic situation passing from pure compression (E-W thrusting) to strike-slip at the high angle to the thrust transport (NE-SW sinistral slip).

Another explanation links the shearing effects to basin formation and synsedimentary processes in a rhombic pull-apart basin continuously forming and deforming in an area of left-stepover between sinistral oblique-slip faults. The deformation of the beds already deposited proceeds while the depocentre moves northwards. The fold and fault pattern agrees with the scheme of an E-W directed secondary pure shear compression emanating from a couple which stretches the area of overlap between the tips of two faults with NE azimuth on which a left-lateral shear is applied.

The second scheme is tentatively preferred.

The position of the S-shaped and the NE faults en échelon on the diagonal of a block limited by ENE and SE lineaments incites to develop the basin history into a twofold scenario. The subsidence of a block delineated by lineaments the azimuth of which is compatible with the direction of slip lines for a given stress direction, is eventually completed by the creation of a diagonal graben. A slight rotation of the azimuth of the regional slip vector or an increase in the differential stress would then transfer the shearing stress from the ENE and SE lineaments to the NE faults which were previously normal faults during the subsidence stage. The pull-apart basin is thus created during the second phase of the scenario.

2. 3. REMARKS CONCERNING THE LINEAMENTS.

The observations stress the importance of the role of three classes of lineaments, i.e. NE, ENE and SE, in the geodynamic evolution during Phanerozoic, Panafrican and Kibaran times. Representatives of all three classes, together with the additional NNW direction active only during the Phanerozoic, occur all over the investigated region hereby creating a dense checquered pattern of structural elements (fig. 2). It is not possible to assign a lower age limit to a particular azimuthal class or to tie a class to a single geodynamic event, all appearing indeed in each of the periods. ENE and SE lineaments are most conspicious in the Lufilian arc of Shaba, but they are certainly not constricted to the Panafrican because individual lineaments related to that event can be traced westwards across the Kibarian belt where they play a clear role in the deformational history of these terrains. Although the relationship of the same lineaments to the subsidence of blocks and hence their role in the sedimentary history remains, unlike the deformational history, conjectural in this area west of the Lufilian arc, this relationship remains very plausible in the other parts of the Kibara and the trumides.

Subjective and maybe conjectural too is the tracing of continuous lines interconnecting shorter but aligned showings of linear features. Families of ENE lineaments will generally be weighted in the same way by every analyst while the set will not be traced as long lines by all observers in all areas.

3. GEODYNAMIC MODEL.

Examples of the combined effect that four directional classes of lineaments can have together have been recognized in all dynamic cycles since Kibaran times. Geodynamic models which do not account for this geographical and chronological persistency of trends must have shortcomings (see DEHANDSCHUTTER and LAVREAU, op. cit.).

Perennial crustal discontinuities and crustal blocks.

The lineaments are considered as the surficial expression of deep and relatively narrow fundamental zones of "perennial" discontinuities (in the sense of MC.CONNEL, 1972), the rheology of which is different of that of the surrounding rock masses. The major lineaments must be of lithospheric importance (they control kimberlite emplacement). The nonductile layer of the lithosphere is segmented in blocks limited by intersecting discontinuities. The discontinuities constitute a regional frame of reference with respect to this part of the lithosphere. The fact that lineaments are deep and perennial and that younger events are linked in one way or another to the same lineaments as older events do, implies that the tectonic transport of rock units of Precambrian age cannot have been far reaching and that lithospheric separation by intervening oceans cannot have had the dimensional characteristics of the current plate-tectonic processes.

Stress distribution.

The ENE and SE sets of lineament are fundamental and perennial. The consequences of the presence of such discontinuities on the distribution of a stress system inside a block are twofold. On the one hand, if the lineamental material is more competent than the block, stresses will be partly deviated from their original trajectories and guided inside the lineaments where they will a.o. facilitate downfaulting. On the other, the discontinuities channel most shear stresses and the compressive stress will be transmitted throughout the block, all horizontal stresses with originally different trajectories being pinned down in one and the same resultant direction tying opposite angles of a block. The mutual relationship and orientation of the discontinuities are most favourable for longitudinal (E-W) trajectories that will easily reactivate both ENE and SE sets. N-S operating systems must be stronger in order to achieve the same. In the latter case, it is likely that only one of the branches, the one most parallel to the main compressive stress, will be reactivated. In the area under study, it can be predicted that the current main horizontal compressive stress would be roughly NNE, deflected to the NE and the NNW by residual stresses (FRIEDMAN, 1972) on respectively ENE and SE lineaments, and by the effects of stresses deviated inside the lineaments. The slip sense on the ENE structures is left-lateral oblique-slip, while it is right-lateral oblique-slip on the SE lineaments.

The sense of slip during the extensional episode of the Kibaran cycle along the perennial lineaments in both the Kibara and the Irumide belts can be deduced from the S-shaped structures if the latter are interpreted as rhombic pull-apart basins. The situation in the Kibara would be an analogue of the modern one : left-lateral oblique-slip on the ENE lineaments and right-lateral on the SE lineaments.

Extensional tectonics.

The fundamental construction of a basic block is depicted in fig. 6. All possible relationships the structural elements detected in the studied region can have with intersecting lineaments are illustrated in fig. 7. The geometry of the Phanerozoic elements is striking. Each rift is contained inside a quadrangular block limited by ENE and SE lineaments. Any shear stress system induced by horizontal compression will easily be transmitted through the favourable configuration of ENE and SE discontinuities. The grabens occupy the short diagonals connecting the obtuse angles of the rhombic segments. It is considered that the grabens are parallel to the direction of maximum horizontal compressive stress. The sense of slip on the discontinuities surrounding a block is sinistral on the ENE and dextral on the SE lineaments. The graben axis, generally directed NE-SW, can have a NNW direction as well. NE-SW rifts occur in regions with high densities of ENE lineaments, NNW rifts in region of predominant SE lineaments. It seems therefore logical to explain the deviation of the general strike of the rift axis in the way followed while discussing the stress distribution, namely by considering the influence of residual strain inside the ENE and SE discontinuities on the regional tensional stress system combined with the effects of stresses deviated along the lineaments.

Triangular strike-slip basins will form the divergent corners of a block, whereas oblique-slip pull-apart basins will form inside the boundary

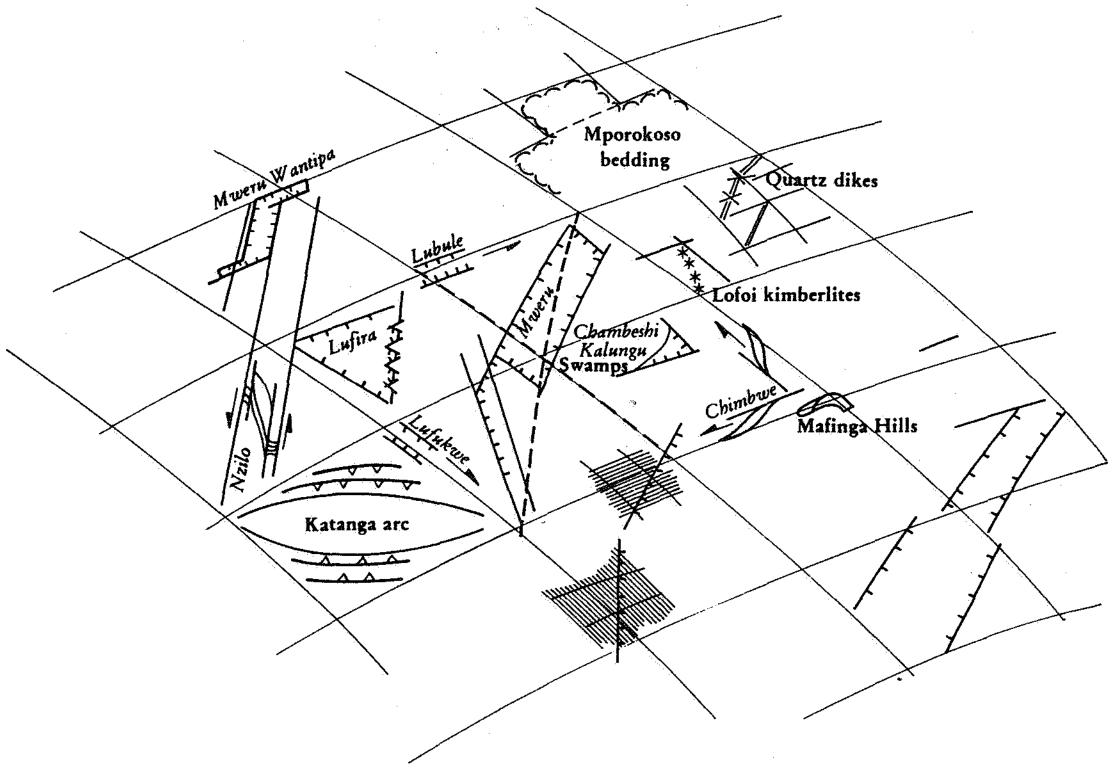


Figure 7 - Geometrical relationship of structural elements (all geological ages, no geographical significance) with ENE-SE lineaments.

lineaments. The differential stress is highest around the complex lineament (-fault) intersections. Rock failure preferentially concentrates in that area. The eastern corner of the rhombic block containing the Mweru rift system is downfaulted (Lufira lowlands). In the stress system of this block, the inferred sense of slip on the corner lineaments is divergent causing the crust to sag over there and to rise below the Kundelungu plateau.

The ENE and SE sets of lineaments are usually related to shear movements but they do occasionally occur, as illustrated here, as loci for vertical normal faulting. This faulting in lineaments is also observed in the NE and SW elongation of Lake Mweru Wantipa. It is thought that part of the total stress volume is deviated inside the lineament.

The recognition of extensional tectonics limited to crustal blocks separated by ENE and SE lineaments goes far back into the Precambrian. Two NNW aligned kimberlite occurrences of Mesozoic age in the Lofoi area (Shaba) are each taken inside one block between ENE and SE lineaments. The strike of the alignment is the one expected in this area where SE lineaments indeed predominate. The Precambrian (?) quartz dykes striking N-S in the Mporokose area (NE Zambia) are found in the same situation : they are confined to one limited crustal block.

The undeformed beds of the Mporokose Group show how intracontinental extensional phases might have proceeded. The internal part of the block functions in two ways : it either subsides in its entirety or it opens by updoming. The latter results from a combination of stress field emanating from the different sources. One system is horizontal and probably related to plate motion, another system acts in a vertical way and is probably linked to mantle convection. It is proposed that the horizontal, relatively uniform inside a block, deviatoric stress in the crust differs between segments. This statement is an extension of the conclusions of ZOBACK and ZOBACK (1980) who stated that provinces of intraplate stresses different from each other are well established in the USA. Doming takes place in the blocks where upward directed forces win over the horizontal ones. Doming and subsidence in adjoining blocks correspond by up- and downward ductile flow.

In the Mporokoso area, volcanic activity (UNRUG, op. cit.) preceded doming. The long axis of the dome lodges the central dyke, the direction of which corresponds with the azimuth of the maximum horizontal stress. Doming is strongly suggested by the morphology of the block containing the dyke situated closest to the Mporokoso town towards the east. The Lower Quartzite pierces through the Lower Shale in an anticlinal manner. One block might have been subsiding before movement was halted and reversed into doming and subsequent rifting or dyke emplacement. Rifting can go along with oblique-slip as suggested by the scenario depicting the origin of the Nzilo S-structure. Alternatively, a block might start subsiding by thermal contraction following doming. Adjoined subsiding blocks create a basin which collects coarse continental sediments unless the sinking blocks are situated on a continental shelve. The continental sediments in the young basin sink to sea level (ANDERSEN and UNRUG, 1982) and deeper to depths of ductile deformation. The depth of subsidence defines the degree of metamorphism and magmatic activity on the floor of the block. Different blocks may thus show varying metamorphic levels depending on the depth of their subsidence.

The stress distribution during the Kibara was possibly an analogue of the modern one. Admitting this it is only a small step to consider the NE Kibaran directions as some analogue of the modern rift directions. This fact was already discussed while dealing with structures in the Chiwa Ngandu area. NE axes would reflect basins formed under the influence of sinistral shear on the ENE lineaments whereas NNW axes remind of basins formed under the predominance of dextral slip on SE perennial structures. Note that the slip on lineaments creating pull-apart basins either inside lineament zones or in the triangular area containing the divergent sharp angle between intersecting lineaments is here interpreted to occur concomitantly with the formation of depositional basins which start as distinct rifts joining the obtuse angle of the crustal blocks on which borders the slip is transferred. The latter is possible if one accepts discontinuous areal distribution of stress. The pull-aparts and the rifts gradually develop into a mature basin composed of adjoining subsided blocks. Intervening blocks must not necessarily show signs of pull-apart or rift formation.

The lineaments are at 60 deg. of each other. A bissecting main principal stress oriented E-W will easily reactivate the discontinuities. Allowance made for the double convex arcs in the Lufilian arc, extension phenomena of latudinal strike or shear movements caused by E-W compression are not delected in the studied area.

Horizontal and vertical stress systems.

Dykes an other tectonic elements testifying of former tensional stress regimes are generally used for determining the direction of maximum horizontal compressive stress (NAKAMURA and UYEDA, 1980). Various sources can be envisaged for the origin of this stress field. It is likely that the compressive stresses are the result of the decay of stronger stresses emanating from subducting plates. Youg plates (20 Ma and younger, VLAAR, 1983) can only be driven underneath a continent forcedly. No back-arc forms. The flat subduction of young plates would cause considerable deviatoric stresses that are transmitted deeply into the continent. A compressive stress originally parallel to the direction of convergence (NAKAMURA and UYEDA, op. cit.) may change direction for several reasons. Without accounting with such stress and without reckoning with subsequent block rotations, the apparent stress directions during the deposition of the Kibaran sediments may nevertheless be estimated as close to N-S. A plate subducting from the north or from the south could account for them. Unlike stress coming from collisional settings, the stress difference in a system imposed by the subduction of a young slab may not be large enough for forming new shear planes. Rifting and initiating shear movements on pre-existing planes in appropriate situation, notwithstanding how deep in the continent, would be perfectly possible.

Moreover, the existence of Phanerozoic rifting on the continent proves that boundary forces not related to subduction processes, as the case must be for modern Africa, are sufficiently strong for bringing the crust to the point of rifting Such forces would include ridge push (BOTT and KUSZNIR, 1984) and asthenospheric drag resistance to absolute plate motion (ZOBACK and ZOBACK, op. cit.). The latter gives directions of maximum directions parallel to the vector of absolute plate motion. Since the Mesozoic, African plate motion has been roughly NE if the Walvis Ridge were the hot spot trace of Tristan da Cunha as it is generally believed. This direction of absolute motion agress well with the azimuth of all rifts in the studied area.

Magmatic activity correlates positively with periods of slow plate motion (BRIDEN and GASS, 1974). Orogenies seem to correspond to periods of rapid motion (ULRICH and VAN DER VOO, 1981). The velocity of the African plate slowed down to a virtual still-stand about 1900 Ma ago, then increased dramatically betwee 1300 and 1100 Ma (ibidem). Extensional tectonics, updoming, magmatic activity, mushroom structures (HALLER, 1956) and local thrusting agree well with many observations.

A slowly moving plate is divided into blocks separated by deep and perennial ENE and SE directed discontinuities. It is postulated that, at some distant boundary, the continent converges with a young oceanic plate in a meridional direction. The stress axis coming from this convergence is oriented in the same direction (NAKAMURA and UYEDA, op. cit.) and is transmitted with decreasing strength into the studied area. Here it is deviated towards the NW when crossing NW-SE discontinuities and then again to the NE when crossing NW-SE discontinuities and then again to the NE where it intercepts ENE structures. The strength of the horizontal compressive stress system decayes with distance from the source (ibidem). Vertical forces applied on the plate bottom by ascending convection cells developing under a quasi-stationary plate (ENGLAND and HOUSEMAN, 1984) may now overcome the shielding effect offered by the horizontal stress system. The crustal blocks presenting least resistance against the vertical forces are uplifted. The blocks concerned are mainly those which are weakened by the vertical discontinuities in which shear stress would have the tendency of opening the crust. The uplift causes a decline of the confining pressure. In a region of low, naught or tensile confining pressure, extensional features (rifts across the crustal block, pull-aparts and mosaics of downfaulted-uplifted blocks inside the discontinuity zone) will develop. The orientation of the extensional features is determined by the system of deep and perennial structures. They can be reactivated at any occasion. The principal horizontal stress axis would be either meridional, joining the obtuse angles between limits, or latitudinal, joining the sharp angles. The latter might have been the setting during the Panafrican.

Compressional tectonics.

The plate velocity increased around 1400 Ma ago (ULRICH and VAN DER VOO, op. cit.). Changes in plate velocities often correspond to changes in the kinematic system. We postulate a plate rotation or a motion changing from a meridional to a latitudinal direction. The lithosphere-asthenosphere interface was highly irregular after a prolonged period during which secondary convection cells have been working out. The change in motion and the increase in velocity destroy the plumes with which the lithosphere was kept anchored. The plumes were pressed up and intruded the segments under which they had docked. A pushing mushroom structure as the one presented by HALLER (1956, in BADGLEY, 1964) thrusts the sediments in one or two directions. The mushroom is limited to its own block. The pushing sedimentary cover puts a renewed shear stress system on the upper parts of the perennial discontinuities. The resulting stress acts in a sense perpendicular to the one active in the extension phase of a cycle (fig. 6). A rapid survey of drag on folialtion trends in rocks mapped as Kibaran reveals a component of horizontal pure shear symmetrical around a latitudinal axis. The ENE lineaments are dextral faults, the slip on the SE set is sinistral. The double thrust vergence of the sedimentary cover of a rising magmatic mushroom would explain some of the double lobate arcs on the images.

After a waning phase of the compressional episode, the fundamental discontinuities will rework in a vertical direction and reappear as lineaments at the surface.

4. CONCLUSIONS.

The method used - remote sensing - has some inherent bias and severe shortcomings. This means that the formulated suggestions must be substantiated by observations of sedimentological and structural nature. The geometric characteristics and the mutual relationship between several structural elements are nevertheless strong indications for the proposed geodynamical model.

The existence of two persistent sets of lineaments (ENE and SE) in the Phanerozoic cannot be denied if one agrees with the notion of "lineament" as a valid geological concept. The relationship of the lineaments of the same trends in the regional deformation history during the Panafrican and the Kibaran is evident as well.

The relationship between the lineaments and the formation of sedimentary basins must be investigated, though the shape of the Nzilo S-structure and the Chimbwe syncline strongly suggest they do.

The stable configuration of ENE lineaments-Ne rifts and SE lineaments-NNW rifts is a second important result of this survey. It merits ground investigations in Precambrian studies.

The concept of a segmented crust is popular amid geologists trained in remote sensing. The idea meets somewhere the concept of slip-line fields in collisional tectonic as developed by TAPPONNIER and MOLNAR since 1976. It offers an extension to the theory of the latter in non-collisional regions where pre-existing structures have the same function as their homologue faults parallel to slip-lines in collisional settings.

The seismic and geomagnetic date of the area might also substantiate the concept of a crustal mosaic, as systematic in situ stress measurements might do as well by showing differences in the homogeneous stress situation from the one block to the other.

5. REFERENCES.

ANDERSEN, L. S. and UNRUG, R. (1983) - Geodynamic evolution of the Bangweulu block, northern Zambia. Unpublished. *Int. Conf. on the Proterozoic, Lukasa, 1983,* 37 pp.

BADGLEY, P. C. (1965) - Structural and tectonic principles. *Harper & Row Publ., New York,* 510 pp.

BOTT, M. H. P. and KUSNIR, N. J. (1984) - The origin of tectonic stress in the lithosphere. *Tectonophysics,* 105, 1/13.

BRIDEN, J. C. and GASS, I. G. (1974) - Plate movements and continental magmatism. *Nature,* 248, 650.

DEHANDSCHUTTER, J. and LAVREAU, J. (1985) - Integration of lineament study in stress analysis and basement tectonics. *Mus. roy. Afr. centr., Tervuren (Belgium), Dép. Geol. et Min., Rapp. ann. 1983-1984,* in the press.

DENNIS, J. G., ed. (1967) - International tectonic dictionary. *Am. Ass. Pter. Geol. Mem.,* 7, 195 pp.

DE SWARDT, A. M. J., GARRARD, P. and SIMPSON, J. G. (1965) - Major zones of transcurrent dislocation and superposition of orogenic belts in part of Central Africa. *Geol. Soc. Am. Bull.* 76, 89/102.

FRIEDMAN, M. (1972) - Residual elastic strain in rocks. *Tectonophysics,* 15, 297/30.

HALLER, J. (1956) - Probleme der Tiefentektonik. Bauformern im Migmatitstockwerk der ostgrondlandischen Kaledoniden. *Geol. Rundschau,* 45, 159/167.

HOBBS, W. H. (1911) - Repeating patterns in the relief and in the structure of the land. *Geol. Soc. Am. Bull.,* 22, 123/176.

LEPERSONNE, J. (1974) - Carte géologique du Zaïre. *Dép. Géol. et Mines, Kinshasa.*

NAKAMURA, K. and UYEDA, S. (1980) - Stress gradient in arc-back arc regions and plate subduction. *J. Geophys. Res.,* 85, 6419/6428.

TAPPONNIER, P. and MOLNAR, P. (1976) - Slip-line field theory and large scale continental tectonics. *Nature*, 264, 319/324.

THIEME, J. G. and JOHNSON, R. L. (1981) - Geological map of the republic of Zambia. *Geol. Surv. Dep., Lukasa.*

ULRICH, L. and VAN DER VOO, R. (1981) - Minimum continental velocities with respect to the pole since the Archaean. *Tectonophysics*, 74, 17/27.

UNRUG, R. (1984) The mid-Proterozoic Mporokoso Group of northern Zambia : stratigraphy, sedimentation and regional position. *Precambr. Res.*, 24, 99/121.

VLAAR, N. J. (1983) - Thermal anomalies and magmatism due to lithospheric doubling and shifting. *Earth and Planet. Sci. Lett.*, 65, 322/330.

ZOBACK, M. L. and ZOBACK, M. (1980) - State of stress in the conterminous United States. *J. Geoph. Res.*, 85, 6113/6156.

Public presentation : April 3d., 1985.