ON MODEL OF PLATE BREAKUP

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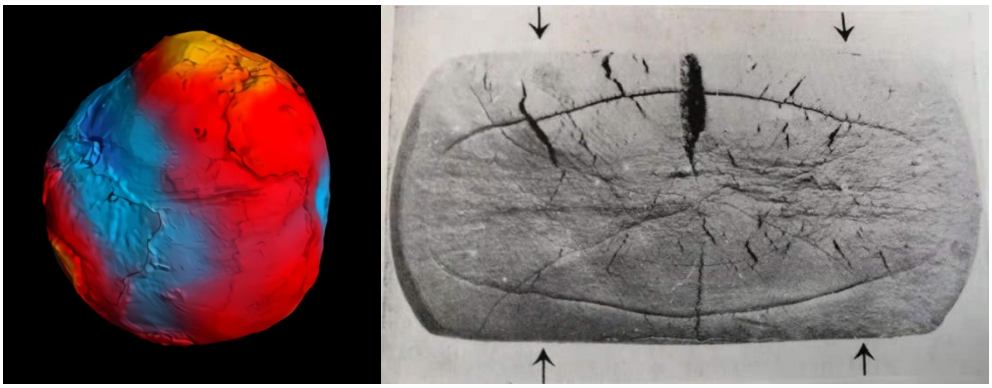
Highlights

- The author want to study the mechanism of plate breakup based on the stress field.
- The plate breakup model can explain the linear characteristics of rift valleys and oceanic ridges.
- This model is supported by experiments.

Abstract

The five-stage model of plate breakup can explain the linear characteristics of rift valleys and oceanic ridges, which other hypotheses in terms of mantle convection, hot-spots and mantle plumes cannot be explained. The course of the plate breakup is as follows: any plate has to undergo 5 stages before breaking up; the 5 stages own each tectonic system; the strikes of these 5 tectonic systems gradually deflect 15° towards the rotation axis of the Earth; and after entering the 5th stage, the plate will normally be broken up. This model is supported by experiments.

Graphical Abstract



Keywords: Plate Breakup; Model; Linear characteristics; Direction of the resultant force; 5° Deviation; Three-axis ellipsoid.

1. Introduction

Since the 1960s, many scientists have felt much interest in plate breakup and tried to explain it with mantle convection, hot-spots, etc.

However, as Armstead once said: these hypotheses can't explain the fact that the spatial arrangements of oceanic ridges and continental rifts are linear(Armstead, 1973).

To solve this problem, I propose a five-stage model of plate breakup.

2. Some premises

The synopsis of the plate breakup mode is as follows: any plate has to undergo 5 stages before breaking up; each stage owns each tectonic system; the strikes of these 5 tectonic systems gradually deflect 15° towards the rotation axis of the Earth; and after entering the 5th stage, the plate will normally be broken up.

Several premises must be clarified before discussing this model.

2.1. Internal frictional angle of lithospheric plate as a whole

Overall, the internal frictional angle of the lithospheric plate should be assumed as:

$$\varphi_{\text{- plate}} = 10° \quad (1)$$

Tectonic geologists have been used to conduct tectonic model experiments using mud materials. Most geologists believe that the simulation of large geological bodies with mud cakes conforms to the principle of similarity.

In effect, the solution of the focal mechanism can be interpreted very satisfactorily by two orthogonal perpendicular shear cracks, which is powerful evidence of $\varphi_{\text{- plate}} = 10°$.

2.2. Gradually deflecting 15°

The tectonic belts with strikes of N50°E, N35°E and N20°E in East Asia were named Old-, Mid- and Neo-Cathaysian respectively, in China(Lee,1929). The strikes were gradually deflected at 15°. Currently, longitudinal tectonic belts of the N5°E strike should be produced in East Asia, because the lithosphere is pressed in a direction near EW by the Pacific Plate's underthrusting towards the west. Oh, the 15° style emerges once more.

A clear pattern of gradually deflecting 15° is shown in Table 1(Sun, 1983).

Table 1. Five Stages in Plate Breakup on Our Earth (in shape of three-axis ellipsoid; take example by plates in East Asia)

Stage	1	2	3	4	5
Direction of principal compressive stress	N5°E - S5°W	NW - SE → EW Gradually deflecting 15°			
Corresponding tectonic system	Latitudinal	Old-Cathaysian	Mid-Cathaysian	Neo-Cathaysian	Longitudinal
Strike of main shear plane		N45°E	N30°E	N15°E	0° Shear rupture
Strike of main tectonic line	EW	N50°E	N35°E	N20°E	N5°E

Based on Tianxi Sun (1983)

Deflecting 15° has proved the inheritance and causality of Earth's tectonic movements.

The following pattern may exist: regional tectonic lines within the eastern parts of the plates in the Northern Hemisphere gradually deflect 15° counter-clockwise and the lines within the western parts gradually deflect 15° clockwise, just opposite to the Southern Hemisphere. That is, it turns toward the rotation axis of the Earth.

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2.3. Resultant force by which lithospheric plates would be subjected

When the Earth rotates, lithospheric plates are squeezed mainly by a south-north(SN) horizontal component of the resultant force of the longitudinal force and gravity(Van Bemmelen, 1975). Considering the fact that the shape of our Earth is a three-axis ellipsoid similar to a pear(Combined Diagram **1-A**)(ESA, 2011), it might be assumed that the resultant force of the lithospheric plate within eastern Asia might turn deflect slightly, with a direction of N5°E-S5°W(Table **1**).

3. The five-stage model of plate breakup

In this force field, the plate breakup model for East Asia is as follows:

3.1. The 1st stage

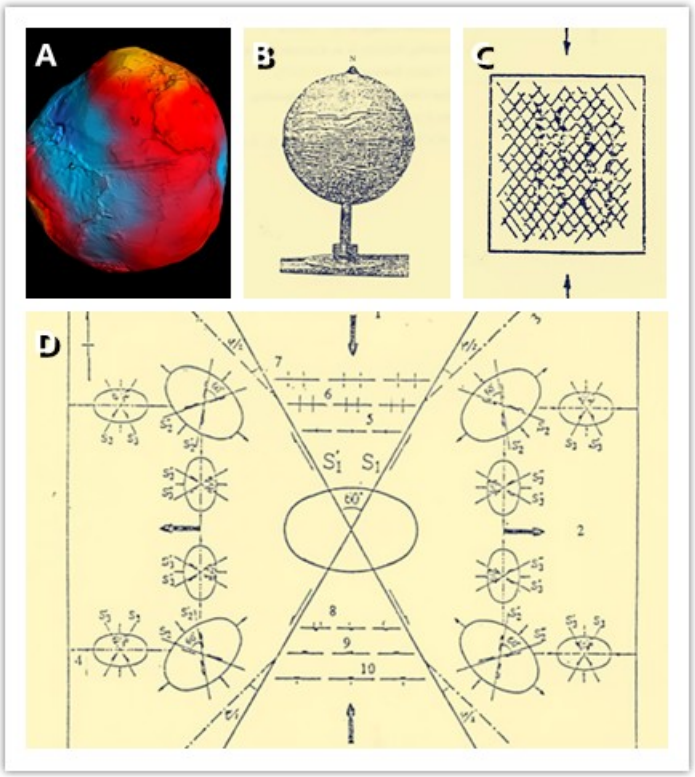
Because the plate was squeezed in the direction of N5°E-S5°W (Section 2.3), latitudinal compressed zones were first formed.

EW folds were first formed after rotating a globe that was coated evenly with mud test materials(Combined Diagram **1-B**)(Sun and Zhang, 1980).

3.2. The 2nd stage

Two sets of principal shear fracture zones then appeared within the plate; the

bisectors of their acute angles were parallel to the longitudinal force (Combined Diagram **1-C**) (Zhang and Zhong, 1977).



Combined Diagram 1

A. New GOCE Geoid of Our Earth (Image: European Space Agency, 2011)

B. Latitudinal Structures Formed by Model Experiment on Rotating Globe

C. Two Sets of Shear Planes on Mud Sample

D. Relation between Primary and Secondary Stress Fields during Tectonic Movement

where φ = internal frictional angle; S1, S1'= shear ruptures; S2, S2'= shear ruptures under the 2nd stress field;

S3, S3'= shear ruptures under the 3rd stress field

1: maximum principal stress (compressive stress) , 2: minimum principal stress (tensile stress), 3: secondary fold axis, 4: the 3rd fold axis, 5: erect rock stratum, 6: synclinal axis, 7: anticlinal axis, 8: reversed fold axis, 9: thrust fault, 10: overthrust fault.

In rock mechanics, there is a formula(China Wuhan Geology Institute, 1979) as:

$$\alpha = 45° - \varphi/2 \quad (2)$$

where α is an included angle between the shear fracture zone and the maximum principal stress axis; $\varphi_{\text{- plate}} = 10°$ (please see Equation 1).

We determined that α was 40°, so the strike of shear zones in the eastern part of the plates within East Asia in that stage should all have been N40°E, if our Earth were in the shape of a standard sphere.

However, the direction of the resultant force subjected to the lithospheric plate within eastern Asia might turn deflect slightly, becoming N5°E-S5°W(Section 2.3), that is, it might be deflected by approximately 5°. Thus, the strike of the shear zones in the eastern part of the plates within East Asia in that stage became N45°E.

Regional compressive belts can be derived from shear zones. The included angle β between the compressive belt and the shear zone is shown in Combined Diagram **1-D**.

According to a law as shown in Equation 3 (National Institute of Geology, Academia Sinica, 1972), β can be given as:

$$\beta = \varphi/2 = \varphi_{\text{- plate}}/2 = 10°/2 = 5° \quad (3)$$

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Therefore, the strike of the regional compressive belts in that stage should be N50°E, which, is the mechanical cause of Old-Cathaysian(Table 1).

Many experiments mentioned above and those by Sih (1973) testified the above expression.

3.3. The 3rd stage

N30°E new shear zones then appeared in the eastern part of the plate with a deflection angle of 15° from the N45°E old shear zones that had been formed during the 2nd stage. Therefore, the new shear zones could also derive some N35°E new regional compressive belts with an included angle of 5°(Equation 3). This was the mechanical cause of Mid-Cathaysian(Table 1).

Doerner(1948) pointed out that new sliding planes must deflect gradually toward the compressive stress axis under a single compression(Combined Diagram **2-E**).

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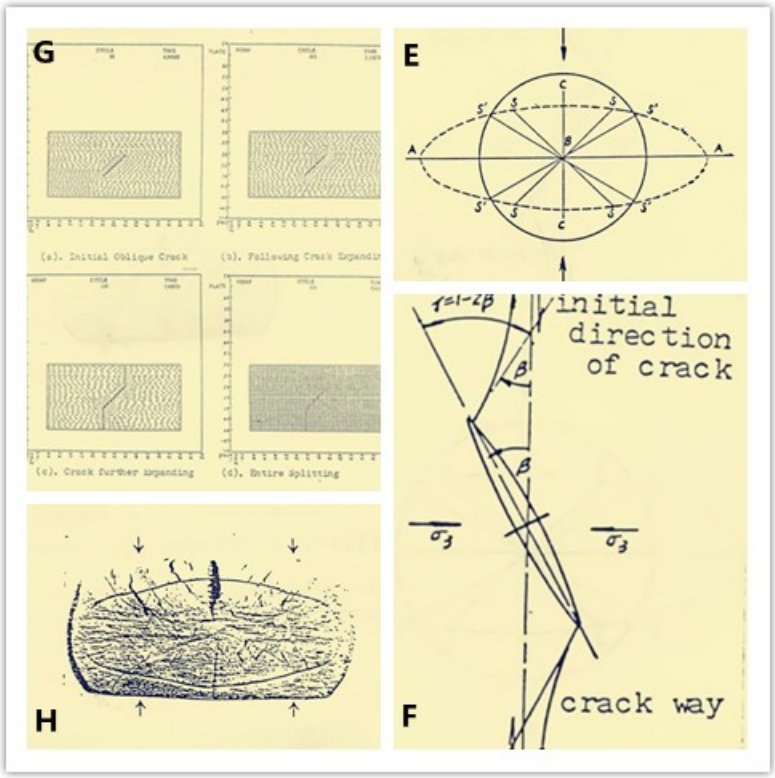

Combined Diagram 2

E. New Sliding Planes under Simple Compression (where S'S' are sliding planes of the earlier period; SS are new ones.)

F. Crack Expanding Direction from Ends of Non N - S Elliptic Crack under Compression

G. Crack Expanding Prediction with Oblique Crack under EW Tension

(a: Initial oblique crack; b: Following crack expansion; c: Crack further expanding; d: Entire splitting)

H. Splitting of Mud Cake

3.4. The 4th stage

Subsequently, N15°E newer shear zones appeared with a deflection angle of 15°

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171 from the shear zones that had been formed during the 3rd stage. These zones could
172 also derive the N20°E newer regional compressive belts with an included angle of 5°.
173 This was the mechanical cause of Neo-Cathaysian(Table 1).

174 Stagg(1978) indicated that the direction of crack expansion must be toward the
175 load under a single compression(Combined Diagram **2-F**).

176 **3.5. The 5th stage**

177 Finally, the two sets of shear zones that had formed during the 4th stage, one of
178 strike N15°E in the eastern part and the other of strike N15°W in the western part of
179 the plate, again deflected 15° towards the rotation axis of the Earth, producing an
180 extremely strong 0° (south-north strike) shear rupture, which was parallel to the
181 maximum principal stress axis, by way of the two sets of shear planes combined into
182 one shear plane, thus creating a south-north direction's whole breakup in the
183 plate(because the shear cracks during the 2nd stage to the 4th stage were produced by
184 a simple shear, thereby preventing splitting of the entire thickness of the plate).
185 Hence, the plate was entirely split, ending the entire breaking course. Of course, this
186 0° shear rupture could also derive its compressive regional belts of N5°E and N5°W
187 strikes, that is, longitudinal belts(Table 1).

188 * Sih(1977) considered that under EW tension(i.e., under SN compression), a non
189 SN oblique crack could still be split in the SN direction, based on his
190 experiments(Combined Diagram **2-G**).

* An experiment by Zhang(1985) showed an axial splitting of a mud cake under simple compression(Combined Diagram **2-H**).

Combined Diagram **2-H** seems to be an excellent epitome for the entire course of plate breakup. Why can we not look upon this result as strong evidence to supporting the model of plate breakup? Interestingly, the experiment shows that plate breakup often occurs in the middle of the plate. Bonnin, J. and Dietz, R.S. also once said that oceanic ridges often remained in the middle of two plates(Bonnin and Dietz, 1977).

There could be several phases during the plate breaking occurred:

A. 0° shear rupture (initial splitting);

B. Hot mantle arched upward along the 0° (SN) linear split, leading a linear plate breaking with a SN direction (final breakup).

C. As the movement of plates dredged up rock from the depths and brought it back down again, it could have transported both water and carbon dioxide. The recycled carbon dioxide may have generated, or at least helped sustain, a dense, carbon-rich atmosphere. This blanket of greenhouse gas could have warmed our Earth.

Strikes of oceanic ridges/rises and continental rifts on Earth are mostly SN. For example, the Atlantic Mid-Ridge, the East Africa Rift, etc.

However, the non SN strikes, perhaps because they were secondary

structures(please see Combined Diagram **1-D**) such as the oceanic ridges/rises with EW strike. Their basements are always sialic(Li, 1983).

4. Conclusions

The following hypothesis has been proposed: the splitting of plates with SN strikes was just attributed to the maximum principle stress field accumulated by rotation of the Earth.

The course of the plate breakup would be as follows: any plate has to undergo 5 stages before breaking up; the 5 stages own each tectonic system; these 5 tectonic systems gradually deflect 15°towards the rotation axis of the Earth. After entering the 5th stage, the plate will normally be broken up; that is, one plate will be split into two plates.

Theoretically, the significance of this paper might be its filling in the gaps in the field of plate tectonics. The author has considered that plate tectonics would consist of three parts: continental drift, sea floor spreading and plate breakup. That is because without sea floor spreading there would be no continental drift; and also without plate breakup there would be no sea floor spreading. Therefore, it is of great significance to research the mechanism of plate breakup.

Declaration of Conflicts of Interest

I declare no conflict of interest.

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References

Armstead, H.C.H.(Ed.), *Geothermal Energy-Review of Research and development*, UNESCO, Paris, 1973. p.18. https://doi.org/10.1016/0013-7952(73)90026-4

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246 Bonnin, J (editor); Dietz, R S (editor). Present state of plate tectonics — Special issue, *Tectonophysics*,
247 vol.38, no.1–2, pp.1–168, 1977.
248 https://www.sciencedirect.com/science/article/abs/pii/014890627890788X

249 China Wuhan Geology Institute, *Tectonic Geology*, Beijing: Geology Press, 1979, p.45 (in Chinese).
250 http://book.kongfz.com/158660/833948369/

251 Doerner, F. J., *Minerals and Tectonic Evolution of Metamorphic Rocks*, Beijing: China Industry Press,
252 1963, p.155 (in Chinese). https://xueshu.baidu.com/usercenter/paper/show?
253 paperid=bd91ad9c3b744eeb7140d379783b6d8b&site=xueshu_se

254 ESA, 2011.
255 http://www.esa.int/Our_Activities/Observing_the_Earth/GOCE/Earth_s_gravity_revealed_in_unpr
256 ecedented_detail

257 Lee, J. S., Some Characteristics of Structural Types in Eastern Asia and Their Bearing Upon the
258 Problems of Continental Movements, *Geol. Magaz.*, 1929, vol.66, no. 11, pp.501-522. DOI: 10.1017/
259 S0016756800105400
260 https://www.researchgate.net/publication/231847490_Some_Characteristic_Structural_Types_in_
261 Eastern_Asia_and_their_Bearing_upon_the_Problem_of_Continental_Movements

262 Jin, X.C., *Fundamental of Plate Tectonics* Shanghai: Shanghai Science And Technology Press, 1984, pp.
263 35-250(in Chinese). https://xueshu.baidu.com/usercenter/paper/show?
264 paperid=d8927b4b53564fb8fa8b0496abcf81f9&site=xueshu_se

265 Li, H.Y., On Formation and Movement of the Ocean, *Ocean Geol. Quater. Geol.*, 1983, no.3, pp.63-67.
266 https://en.cnki.com.cn/Article_en/CJFDTotal-HYDZ198303006.htm

National Institute of Geology, Academia Sinica, Principle and Methods of Rock Engineering Mechanics, *Acad. Sinica.*, 1972, no.1, p. 44(in Chinese). https://xueshu.baidu.com/usercenter/paper/show?paperid=a05611b8d1af816712266c0c0e5b3ea9&site=xueshu_se

Sih, G.C., *Methods of Analysis and Solution of Crack Problems*, Leyden, Noordhoff: International Press, XXII, 1973.

Sih, G.C., *Methods of Fracture (3): Plates and Shells with Cracks*. Leyden, Noordhoff: International Pub., 1977, p.302.

Stagg, K.G., *Rock Mechanics in Engineering Practice*, Beijing: Geology Press, 1978, pp.100-101(in Chinese). https://xueshu.baidu.com/usercenter/paper/show?paperid=c2ea6407a5a7d029cfa2231a05d91763&site=xueshu_se

Sun, D.Q., Zhang, G.D., *Simulated Experiments of Geologic Structures on a Rotating Globe*, **in** An Album of International Geological Exchange Theses, Beijing: Geology Press, 1980, vol. 1, p.214 (in Chinese).

Sun, Tianxi, On Plate Breakup, *Potent. Sci.*,, 1983, no.4, pp.36-37 (in Chinese). https://paper783569636.wordpress.com/34-2/?frame-nonce=6a8418a631

Van Bemmelen, R. W., *Some Basic Problems in Geonomy*, **In** Progress in Geodynamics, Proceedings of the National Symposium on Geodynamics Held in Amsterdam, Amsterdam/New York: North-Holland Pub., 1975, April 3-4. DOI：10.1007/3-540-31080-0_122.

Xu,J.W., *Xu Jiawei discourses on Tanlu Fault*, Hefei University of Technology Press, Hefei, China, 2015. ISBN：9787565023330 (in Chinese). https://baike.baidu.com/item/%E5%BE

%90%E5%98%89%E7%82%9C%E8%AE%BA%E9%83%AF%E5%BA%90%E6%96%AD%E8%A3%82%EF%BC%88%E8%AE%BA%E6%96%87%E9%80%89%E9%9B%86%EF%BC%89/56601448?fr=aladdin

Zhang, W. Y., Zhong, J. Y., Development of China Fault Tectonic Systems, *Scientia Geolgica Sinica*, 1977, no.3, p.197 (in Chinese). https://xueshu.baidu.com/usercenter/paper/show?paperid=1p0y0xy0d14w06s095650g50sr565426&site=xueshu_se

Zhang W. Y., Zhong J, Y., *Model Experiments Pictures on Tectonic Physics*, Beijing: Science Press, 1985, p.18 (in Chinese).

https://xueshu.baidu.com/usercenter/paper/show?paperid=9e8035dfc1951cd55f865e4945daafdf&site=xueshu_se