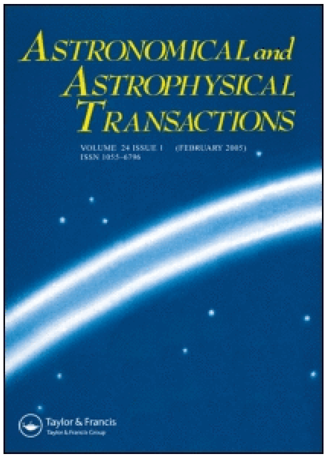

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

Geometric regularities of the lithosphere plate structure

Yu. V. Barkin [a]
[a] Sternberg Astronomical Institute, Moscow, Russia

Online Publication Date: 01 June 2000
To cite this Article: Barkin, Yu. V. (2000) 'Geometric regularities of the lithosphere plate structure', Astronomical & Astrophysical Transactions, 18:6, 751 - 762
To link to this article: DOI: 10.1080/10556790008208170
URL: http://dx.doi.org/10.1080/10556790008208170

Astronomical and Astrophysical Transactions, 2000, Vol. 18, pp. 751–762
Reprints available directly from the publisher
Photocopying permitted by license only

GEOMETRIC REGULARITIES OF THE LITHOSPHERE PLATE STRUCTURE

Yu. V. BARKIN

Sternberg Astronomical Institute, Moscow, Russia

(Received November 5, 1998)

It is shown that the positions of the centres of the main and medium plates display an elegant order and allow us to bring into consideration the special lithosphere reference system (LRS). The following notions are introduced: the lithosphere equator, north and south poles of the lithosphere, etc. The plane of the lithosphere equator is inclined at the angle of 26°7 to the Earth's equator plane and has longitude of the ascending node 3.4° W in the Greenwich (Earth's) reference system (ERS). In the new reference system (LRS), the boundaries of the plates are situated in the zone of latitudes ±70°. The lithosphere belt of the plates is clearly distinguished: the plates are arranged along the equator of the lithosphere . A new phenomenon of pairing of the triple junctions of the plates has been discovered.

KEY WORDS Plate positions, regularities, triple junctions, lithosphere reference system

1 MAIN GEOMETRIC REGULARITIES

The lithosphere is a set of a comparatively small number of the main and medium plates (see Table 1) with a definite density structure, which is different for continental and ocean areas, and with different thicknesses (or powers). Geological, paleomagnetic data (Zonenshain and Kuzmin, 1993), and in the last few years, high-precision satellite data (Smith *et al.*, 1990) attest that in a first approximation the plates execute slow spherical motions as rigid bodies.

In this paper, we will restrict ourselves to a geometrical analysis of the plate positions (their centres, boundaries, etc.), that is we will study only their geometrical properties and peculiarities. Here we adopt the map of the plate boundaries which was used in an interpretation of the GPS data in GFZ-Potsdam (1993–1995).

Let us introduce into consideration the epicentres of the mass centres of the plates (for brevity, we will call them centres of plates). We determine the positions of the centres of mass of the plates and their masses by approximate calculation, using the trapezium method, of the corresponding volume integrals for simple models of the plates.

For this purpose, every plate (from a list of 14 main and medium plates) with its contours, corresponding to the present geologic epoch, was represented as a definite

Table 1. Masses and spherical coordinates of the centres of mass of the plates.

N	*Plates*	m_σ	$r_{C\sigma}$	$\varphi_{C\sigma}$	$\lambda_{C\sigma}$
1	Eurasian (EA)	4.360	0.816	49°3	87°6
2	African (AF)	3.441	0.866	8°3	14°3
3	Pacific (PA)	2.959	0.765	1°8	201°6
4	North-American (NoA)	2.380	0.865	58°8	267°7
5	South-American (SoA)	2.176	0.902	−18°6	306°7
6	Australian (AU)	2.097	0.883	−28°1	125°7
7	Antarctic (AN)	2.065	0.888	−85°1	62°8
8	Indian (IN)	0.447	0.964	18°8	77°2
9	Nasca (NA)	0.415	0.964	−21°0	267°8
10	Arabian (AR)	0.376	0.980	21°8	46°2
11	Philippines (PH)	0.137	0.985	19°1	134°4
12	Caribbean (CA)	0.122	0.993	14°0	289°7
13	Cocos (CO)	0.101	0.993	7°8	267°7
14	Juan de Fuca (JF)	0.019	0.999	45°0	232°7

system of trapezium cells with a given power and averaged density structure. An effective power of 47 km was accepted for ocean areas of the plates and 117 km for continental areas (for an averaged value of density). The powers accepted are in good agreement with modern ideas about the lithosphere structure and with the corresponding parameters of the well-known PREM Earth model (Dziewonski and Anderson, 1981), which was obtained on the basis of numerous seismological observations. Thus, in accordance with Artushkov (1979), the power of the lithosphere for platform areas is 110 ± 20 km and the power of the subducting lithosphere is 50–70 km. On the other hand, the polar moment of inertia of the lithosphere for our plate model is practically equal to that for the PREM model (Dziewonski and Anderson, 1981). Moreover, an analysis shows that the suggested plate model possesses an original property of stability with respect to integral characteristics of the plates. For example, the positions of the plate centres of mass change insignificantly (by a few degrees in latitude and longitude) for significant variations of the powers of the ocean and continental areas of the plates.

Our plate model, based on the above properties, was used as the basic model for which the plate masses (m_σ) and spherical coordinates of the centres of mass ($r_{C\sigma}, \varphi_{C\sigma}, \lambda_{C\sigma}$) in the geographic reference system (ERS) were determined (Table 1). The values of the coordinates $\varphi_{C\sigma}$ and $\lambda_{C\sigma}$ (geographic latitude and longitude of the plate centres) are given in degrees. The values of m_σ are given in units of $10^{-3} m_\oplus$ (where $m_\oplus$ is the Earth's mass); $r_{C\sigma}$ are given in Earth radii R. The positions of the plate centres, which are epicentres of the mass centres of the plates, are shown by circles on the standard projection of the Earth's surface (Fig. 1).

The main result of this work is the discovery of an ordering in the positions of the major, medium, small and some microplates. The ordering emphasizes the asymmetry of the lithosphere and indicates gravitational and other interactions

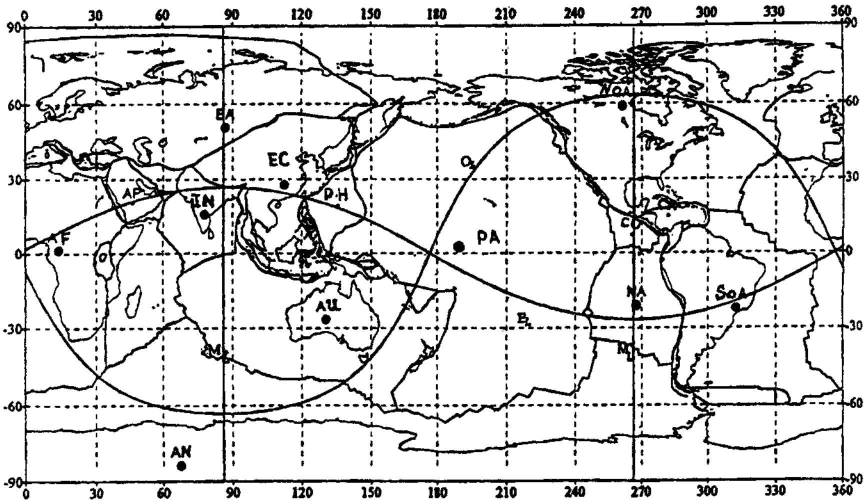

Figure 1 Main great circles of the lithosphere reference system and positions of the plate cenres.

of the dynamical asymmetry of the Earth's envelopes and on their slow relative motions.

Here I change the usual presentation of the results. First I introduce an inclined lithosphere reference system, formed by the intersections of the mutually orthogonal planes of the three great circles and then I use this reference system for the description of the observed regularities in the plate centre positions, the plate boundaries, in the triple junction positions, etc.

I emphasize that the new Cartesian reference system $Ox_{\mathrm{L}}y_{\mathrm{L}}z_{\mathrm{L}}$, called the lithosphere reference system (LRS), has been introduced as a result of an analysis of the positions of the plate centres and also of the kinematic and dynamic details of the plate motion (Barkin, 1994, 1996). The intersections of the coordinate planes $Ox_{\mathrm{L}}y_{\mathrm{L}}$, $0x_{\mathrm{L}}z_{\mathrm{L}}$ and $Oy_{\mathrm{L}}z_{\mathrm{L}}$ with the Earth's spherical surface are great circles E_{L}, O_{L} and M_{L}, where E_{L} is the lithosphere equator, and O_{L} and M_{L} are zero and 90° meridians of the LRS, respectively. The plane of the lithosphere equator (great circle E_{L}) is inclined to the plane of the Earth's equator at an angle of 26°7, and the longitude of its ascending node is 3°4 W (in the ERS). The Ox_{L} axis is placed in the equatorial plane of the Earth and directed along the line of intersection of the equatorial planes of the Earth and lithosphere toward the west coast of Africa. The great circle M_{L} is meridian 86°6 E in the ERS and meridian 90° E in the LRS. The polar axis Oz_{L}, is directed to Godson Bay, and its pole has geographical coordinates 93°4 W, 63°3 N. The opposite pole of the axis Oz_{L} (southern) has coordinates 86°6 E, 63°6 S.

Application of the LRS gives a good illustration not only the geometric properties of the plate positions, which are studied below, but many other details and regularities of the structure and motion of the plates, and of the structure and evolution of all physical fields of the Earth. The boundaries of the continents and the

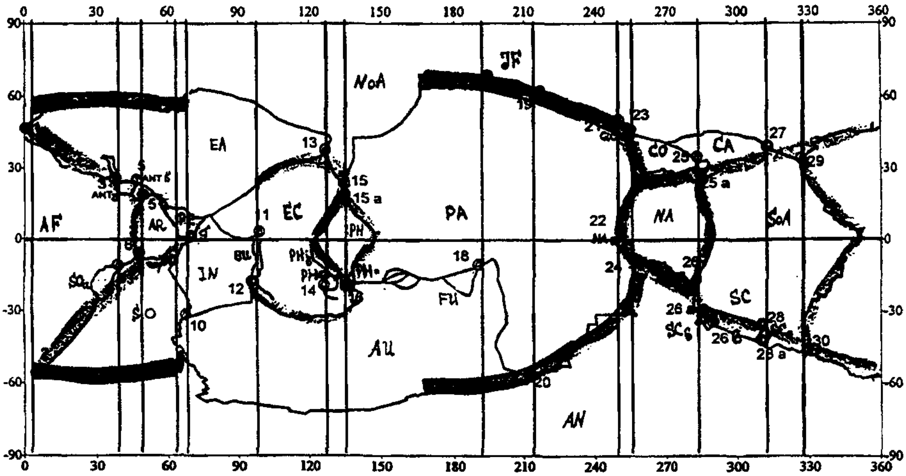

Figure 2 Positions of the plate boundaries and plate centres in Mercator's projection in the LRS; the lithosphere belt of plates.

lithosphere plates and also the positions of their centres of mass are displayed on Fig. 2 in standard projection in the LRS.

A remark: in the tables, text and figures of this paper we use abbreviated notation. The main plates are described in Table 1. In addition to the plates from Table 1, we will also consider the East-Chinese plate (EC), and some microplates, which will be regarded as 'satellites' of the corresponding main and medium plates. The notation of the latter plates is given in Section 4, in the description of the triple junctions. For some other small and microplates, the abbreviations are given below.

As a result of a simple geometric analysis, very important regularities of the lithosphere structure were established.

The essence of these is that the centres of virtually all main and medium plates are situated on the Earth's surface along three great circles: E_L, O_L, M_L.

In more detail, these regularities are formulated as follows.

1. The centres of the African, Arabian, East-Chinese (EC), Philippines, Pacific, Nasca and South-American plates are located near the lithosphere equator E_L (along great circle E_L on the Earth's sphere); the plane of the circle is inclined at an angle of 26°7 to the Earth's equatorial plane and has a longitude of the ascending node 3°4 W. We call this circle the equator of the lithosphere: it lies in the Cx_Ly_L plane of the LRS.

   A remark: the centres of the small Marianna plate (MA) and the Easter (ER) microplate are also located close to the lithosphere equator.

   The plates mentioned above (AF, AR, EC, PH, PA, NA, SoA) form the lithosphere equatorial belt of plates.

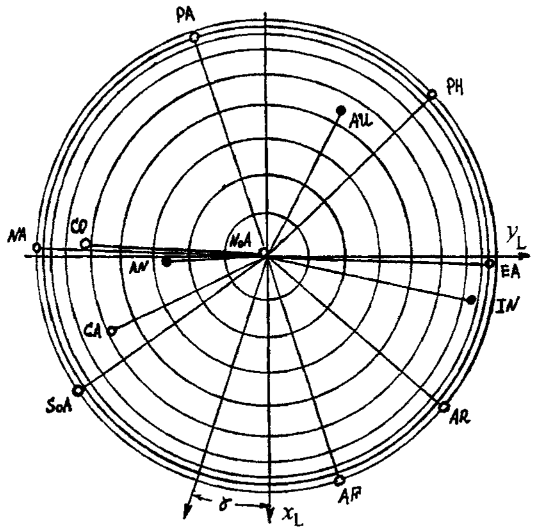

Figure 3 Positions of the epicentres of mass centres of the plates in the equatorial projection (on the lithosphere equator plane) Shadowed circles denotes poles, situated in the southern hemisphere of the LRS, and open circles are poles, situated in northern hemisphere of the LRS.

2. The centres of the Nasca, Cocos, Carribean, Antarctic, North-American, Eurasian and Indian plates are located near the great circle M_L on the Earth's sphere; the plane of this circle is orthogonal to the planes of the equators of the Earth and the lithosphere. The great circle M_L coincides with the meridian 93°4 W of the ERS and with meridian 90° W of the LRS.

3. Centres of the North American, Pacific and African plates and of the small Juan de Fuca plate and the Fudji basin (FU) are located in the vicinity of the great circle O_L which is the zero meridian of the LRS.

Thus, only the centre of the Australian plate has a somewhat isolated position with respect to the great circles E_L, O_L, M_L. This fact reflects a feature of the evolution and fast motion of the Australian plate in the last 43 my. All the other plates demonstrate an elegant order in the positions of their centres, boundaries, junctions, etc. On the other hand, regularities (1)–(3) define a special lithosphere reference system (LRS). We will show in future papers that the LRS has a very important geodynamic meaning.

Now let us note some features in the plate positions along the great circles. These features also testify to the ordering of the lithosphere structure.

1a. The centres of the plates of the lithosphere belt are located in three sectors, spanned by arcs O_{EA} O_{AF}, O_{PA} O_{PH}, O_{SoA} O_{CO}. Opposite to them, arcs O_{CO} O_{PA}, O_{AF} O_{SoA}, O_{PH} O_{EA} have an equal span of sectors where the centres of any plates are absent (sectors of avoidance) (see Fig. 3). The longitudes of the plates centres in the LRS are related by the following approximate equalities:

$$\lambda_{\mathrm{EA}}-\lambda_{\mathrm{AF}}=\lambda_{\mathrm{NA}}-\lambda_{\mathrm{PA}},\quad \lambda_{\mathrm{AF}}-\lambda_{\mathrm{SoA}}=\lambda_{\mathrm{EA}}-\lambda_{\mathrm{AF}},\quad \lambda_{\mathrm{SoA}}-\lambda_{\mathrm{PA}}=\lambda_{\mathrm{PA}}-\lambda_{\mathrm{EA}}.$$

1b. The centres of the Pacific and African, Philippines and South-American pairs of plates of the lithosphere belt, are located diametrically opposite on the lithosphere equator.

1c. The centres of the South-American and African, Nasca and Arabian, Pacific and Philippines pairs of plates are arranged symmetrically with respect to the major axis of the Earth's ellipsoid of inertia. For the longitudes of these centres in the LRS, the following approximate relationships are fulfilled:

$$\lambda_{\mathrm{AF}}+\gamma=\lambda_{\mathrm{SoA}}-\gamma,\quad \lambda_{\mathrm{AR}}+\gamma=\lambda_{\mathrm{NA}}-\gamma,\quad \lambda_{\mathrm{PH}}+\gamma=\lambda_{\mathrm{PA}}-\gamma.$$

where $\gamma = 14.5°$ is the angle formed by the major equatorial axis of the ellipsoid of inertia of the Earth with the plane of the Greenwich meridian.

2a. The centres of the following pairs of plates: Nasca and Eurasian, Arabian and North-American, Pacific and African, Philippines and South-American are located on the same meridian in the LRS and for their longitudes the following approximate equalities are fulfilled:

$$\lambda_{\mathrm{NA}}-\lambda_{\mathrm{EA}}=\pi,\qquad \lambda_{\mathrm{CO}}-\lambda_{\mathrm{EA}}=\pi,\qquad \lambda_{\mathrm{AN}}-\lambda_{\mathrm{EA}}=\pi,$$
$$\lambda_{\mathrm{AR}}-\lambda_{\mathrm{NoA}}=\pi,\qquad \lambda_{\mathrm{PA}}-\lambda_{\mathrm{AF}}=\pi,\qquad \lambda_{\mathrm{PH}}-\lambda_{\mathrm{AF}}=\pi.$$

The discrepancies between the left and right sides of these relationships are about a few degrees.

2 EQUATOR OF LITHOSPHERE AND PRINCIPAL MERIDIONAL CIRCLES

We have determined the position of the lithosphere equator from the coordinates of the plate centres (of the epicentres of their centres of mass). This equator plays an important role for the understanding and interpretation of numerous phenomena in the geological life of the Earth (in the dynamics of its envelopes) and is characterized by many geological indications. Here we indicate some of them.

First, the lower and upper points of the lithosphere equator with respect to the Earth's equator, figuratively speaking, hit the centres of two 'targets' (Figs. 4, 5).

In particular, the upper point of the equator is situated in the vicinity of South Tibet and has coordinates 26.7° N, 86.6° E (very close to the highest mountain Everest) and practically coinciding with the centre of the thickening of the crust, which is indicated by isolines in Fig. 4.

This region is well known for its high tectonic activity, which is connected with the observed creeping of the Indian plate under the Eurasian plate. As a consequence of this tectonic process, an uplift of the Tibet plateau is taking place (Ushakov and Sorochtin, 1993).

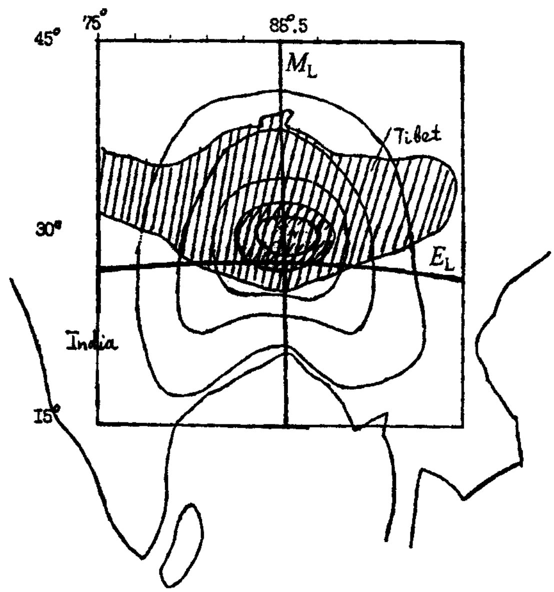

Figure 4 Details of the crust structure of the Tibet region. Isolines show the thickness of the crust (the extremum value is about 50 km).

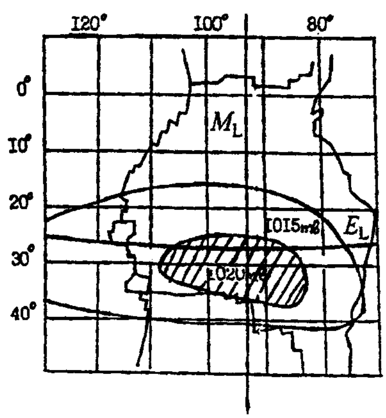

Figure 5 Region of high thermal and seismic activity of the Nasca plate and details of the field of atmospheric pressure.

The south point of the equator of the lithosphere (SL) is also located in a zone of enhanced seismic activity. This zone is situated along the East-Pacific ridge, in the region of latitudes 20° S, 40° S (Fig. 5). In this region, the ridges are characterized by maximum velocities of spreading; large amounts of energy are generated here due to submarine volcanism and hydrothermal activity.

The Nasca and Pacific ocean plates are more mobile and active (Ushakov and Sorochtin, 1993). This region is also characterized by weak persistent variations or displacements of the atmosphere-pressure field know as the trigger Ninos (Walker, 1988).

To the region of the SL point, too, these corresponds a submarine raising around Easter Island with a mean height of 2.5 km. Thus, both characteristic points of the lithosphere equator (E_{L}) are marked with high-altitude elevations.

The points of intersection of the lithosphere equator and the Earth's equator have geographic coordinates (0° N, 3.4° W) and (0° N, 176.6° E). The Ox_{L} axis of the the LRS is fundamental for the Earth's envelopes. Many structural peculiarities, features of slow relative motions of the envelopes, of the structure and the evolution of the Earth's physical fields are connected with this axis and with the LRS in general. As a result of an analysis of a wide set of the Earth's physical fields, the author has shown that new properties of symmetry of these fields manifest themselves precisely in the inclined LRS ($Ox_{\mathrm{L}}y_{\mathrm{L}}z_{\mathrm{L}}$). Thus, the problem of the asymmetry of the Earth's physical fields and the envelopes of the Earth and of their relative motion has a unique solution.

The O_{L} meridian (zero meridian of the LRS) crosses the Buve triple junction between the African, Antarctic and South-American plates. O_{L} passes orthogonally to the ridge zone of the Agulias plateau, and the Marinion hot spot (4.7° S, 88° E) under the Antarctic plate. The Aguljas plateau is another wide platform, which is raised by 2.5 km above sea bottom at a depth of 5 km. It is separated from the South Mozambique ridge of the small Transkey hollow.

The Mascaren–Chagos–Laccadives volcanic lineament extends parallel to meridian M_{L} of the LRS. It is a large system of aseismic ridges, connected with volcanic activity of the triple Reunion junction. The ridge at 90° E, which is situated in this region, is a trajectory of the Reunion hot spot. Both ridges, extending from North to South, trace the northward motion of the Indian subcontinent from the stationary hot spots in the vicinity of the Reunion and Kargelen islands (Ben-Avraham *et al.*, 1995).

To the plate's geometrical regularities considered above, we also add features of their boundaries, which are most conspicuous in the LRS.

3 PROPERTIES OF THE PLATE BOUNDARIES

Over their enormous extent, the plate boundaries demonstrate important properties of symmetry with respect to the lithosphere equator. These properties are briefly considered below.

First, we point out an important peculiarity of the plate boundary position: all the boundaries of the plates are situated in the zone of latitudes ±70° with respect to the LRS (Fig. 2). The northern polar zone (in the LRS) is fully occupied by the North-American plate, and its centre practically coincides with the northern pole of the LRS (north-west of Hudson Bay). The southern polar zone (in the LRS) is occupied by the Antarctic plate.

For long sections of plate boundaries, transform trenches of the rifting zones and orientation of the axes of these zones have pronounced latitude and longitude orientation in the LRS. These geometrical properties are most clearly visible for the east and south-east boundary of the Pacific plate, for the northern and southern boundaries of the Nasca plate, for the southern and east boundaries of the Somalia plate (SO), etc. (see Fig. 2).

Global symmetry properties of the plates are observed with respect to the plane of the lithosphere equator. This plane is a plane of symmetry for long extensions of the plate boundaries, situated, respectively, in the northern and southern hemispheres of the LRS.

In Fig. 2 plate boundaries are shown directly in the LRS projection. We readily see that the lithosphere equator forms the plane of symmetry for the boundaries of the Pacific and Indian plates in the zone of LRS longitudes from 165° E to the eastern outskirts of the Pacific plate (260° E).

The boundaries of the African plate are characterized by similar properties of symmetry in the zone of longitudes from 35° W to 45° E.

The boundaries of the Eurasian and Antarctic plates are arranged symmetrically with respect to the equator of the lithosphere in a zone of longitudes from 0° E to 95° E. These boundaries are rifting zones.

Small plates: the Caribbean and Scotia (SC) plates as a whole are placed symmetrically with respect to the lithosphere equator. This property refers to the boundaries of the plates, to their centre positions and to the positions of the junction points with other plates. Even the subduction zones of these two plates (in the regions of the arcs of the Sandwich and Antilles islands) have latitude 40° S and 40° N and longitude 310° E (in the LRS).

The plate figures of the lithosphere belt have more clearly defined properties of symmetry. The boundaries of the African plate (without the Somalia plate), the Arabian plate (with the Persia plate (PR)), the East-Chinese plate (EC), the South-America plate, and the main part of the Pacific plate resemble butterfly figures oriented ('stringing') along the equator of the lithosphere. The equator of the lithosphere crosses the Philippines plate, which has a rhomboidal form, along its short diagonal. The arc-shaped zones of subduction of the Philippines plate (its west and east boundaries) are sides of this rhombus and are placed symmetrically with respect to the lithosphere equator.

The Nasca plate, having a pitcher form, is symmetrically crossed by the equator of the lithosphere and by the meridian M_L of the LRS. The Easter (ER) microplate and the Marianna plate (MA) on the eastern side of the Philippines plate are crossed symmetrically by the lithosphere equator.

On the largest scales the northern and southern boundaries of the plates, in-

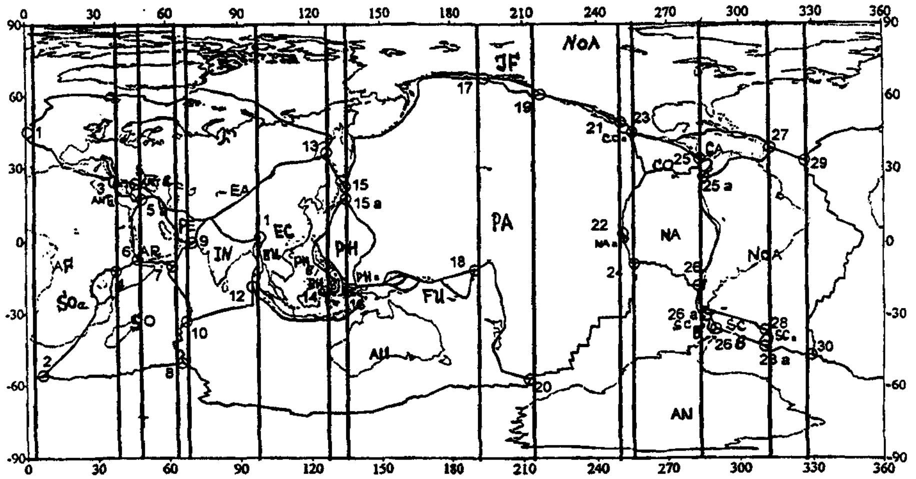

Figure 6 The phenomenon of paired meridional positions of triple junctions in the LRS.

dependently of their constructive or nonconstructive nature, are situated close to parallels ±60° of the LRS, apart from a zone of longitudes from 220° E to 360° E. In the last zone the northern and southern boundaries are located substantially close to the lithosphere equator. In the zone of latitudes (±15)–(±45)° are situated the boundaries of the Nasca and Scotia plates and the corresponding boundaries of the South-American and African plates.

We point out that the main disproportion in the elegant picture of the plate boundary positions is produced by the Australian plate and its irregular motion, briefly in regions of collisions with the Pacific plate.

4 PHENOMENON OF THE ORDERING OF THE TRIPLE JUNCTION POSITIONS IN THE LRS

This phenomenon was discovered as a result of the analysis of the latitudes and longitudes of the plate triple junctions in the LRS. These coordinates are presented in Table 2 The triple junctions of all the main, medium and small plates and some microplates were included in this list.

We consider here all plates, the boundaries of which are shown in Fig. 6. From them, we can identify the Scotia plate (SC) and its 'satellites', the SCa, SCb microplates, the COa microplate (a 'satellite' of the Cocos plate), the Easter plate (a microplate of the Nasca plate, NAa), the Persia plate (PE), the Somalia plate (SO) and its 'satellite' SOa, the Antalia plates (ANa and ANb), the Burma plate (BU) and the 'satellites' of the Philippines plate (PHa, PHb, PHc) in its southern part, and the Fudji basin (FU) (see also Fig. 2). These abbreviations are shown in Fig. 6

Table 2. Coordinates of the triple junctions of the plates in the LRS.

N	*Longitude (degrees)*	*Latitude (degrees)*	Triple Junctions
1	2.0	46.5	NoA, AF, EA
2	6.0	−58.2	AF, AN, SO
3	35.3	25.9	EA, AF, ANTa
4	38.6	−13.1	AF, SOa, SO
5	45.0	19.2	EA, ANTa, ANTb
5a	48.5	16.0	ANTb, AF, AR
6	47.5	−7.8	AR, AF, SO
7	61.5	−11.0	AR, SO, IN
8	65.8	−50.7	AU, SO, AN
9	71.2	0.0	PE, AR, IN
10	67.9	−32.9	IN, SO, AU
11	97.4	1.1	EC, IN, BU
12	94.9	−18.8	BU, IN, AU
13	127.5	35.9	NoA, EA, EC
14	127.0	−21.7	EC, PHc, PHb
15	135.6	20.9	NoA, EC, PA
15a	136.4	16.1	EC, PH, PA
16	136.4	−20.9	PHa, EC, AU
17	193.9	67.0	NoA, PA, JF
18	189.6	−11.7	PA, FU, AU
19	216.5	60.6	NoA, JF, PA
20	212.6	−56.7	PA, AU, AN
21	249.6	48.2	NoA, PA, COa
22	250.6	1.1	PA, NAa, NA
23	253.5	44.3	NoA, COa, CO
24	255.7	−8.9	NA, PA, AN
25	284.4	34.1	CA, CO, NA
25a	285.5	26.2	NA, SoA, CA
26	282.6	−18.4	NA, AN, SoA
26a	286.2	−32.9	SC, AN, SCb
26b	286.4	−33.8	SC, SCb, AN
27	312.4	37.2	NoA, CA, SoA
28	311.3	−37.6	SoA, SC, SCa
28a	312.0	−43.4	SCa, AN, SoA
29	326.7	32.3	NoA, SoA, AF
30	329.2	−47.9	AF, SoA, AN

and are used for notations of the triple junctions of all the above-mentioned plates in Table 2.

For every triple junction in Table 2 abbreviations of the three plates taking part in this junction and definite numbers are given. These numbers mark the corresponding junctions in Fig. 6 and in Fig. 2 also.

The values of longitudes of the triple junctions (shown in Figs. 2, 6), listed in Table 2, illustrate the phenomenon of pairing of their meridional positions in the LRS.

The main conclusion is that the triple-junction points are arranged in pairs on the same (or close to) meridians of the LRS, as a rule to the north and to the south of the lithosphere equator.

Acknowledgements

This work was supported by grants of the RFFI (96-05-65015; 99-05-64889) and by the Programm 'Universities of Russia – fundamental studies' (theme 9-5240).

The author is grateful to academician RAN Yu. G. Leonov, academician RAN E. I. Schemiakin and member correspondent RAN L. N. Rykunov for the useful discussions and for valuable comments and advice.

References

Artushkov, E. V. (1979) *Geodynamics*, Nauka, Moscow (in Russian).

Barkin, Yu. V. (1994) *Proceedings of the International Conference 'Planetar Problems of the Earth's Studies' (Kazan, 15–18 November, 1994)*, Rfz. G.U., p. 1 (in Russian).

Barkin, Yu. V. (1996) *Vestnik Mosk State University, Ser. 3. Phys Astron.* **37**, No. 2, 70 (in Russian).

Ben-Avraham, Z., Hartnady, C. J. H., and Ie Roex, A. P. (1995) *J. Geophys. Res.* **100**, NB4, 6199.

Ushakov, S. A. and Sorochtin, O. G. (1993) *Itogy Nauky y Techniky. Fiz. Zemly* bf 12 (in Russian).

Walker, D. A. (1988) *EOS* **69**, 857.

Zonenshain, L. P. and Kuzmin M. I.(1993) *Paleogeodynamics*, Nauka, Moscow.