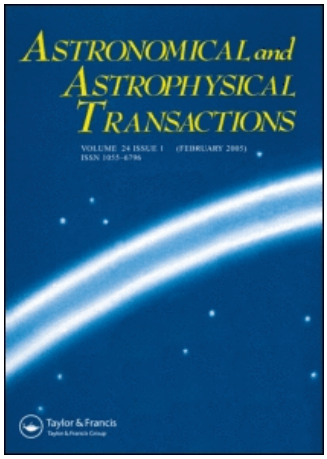

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

Kinematic regularities in plate motion

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

Online Publication Date: 01 June 2000
To cite this Article: Barkin, Yu. V. (2000) 'Kinematic regularities in plate motion', Astronomical & Astrophysical Transactions, 18:6, 763 - 778
To link to this article: DOI: 10.1080/10556790008208171
URL: http://dx.doi.org/10.1080/10556790008208171

Astronomical and Astrophysical Transactions, 2000, Vol. 18, pp. 763–778
Reprints available directly from the publisher
Photocopying permitted by license only

KINEMATIC REGULARITIES IN PLATE MOTION

Yu. V. BARKIN

Sternberg Astronomical Institute, Moscow, Russia

(Received November 5, 1998)

Plate motion in the mantle reference system (with respect to hot spots) is characterized by definite kinematical regularities and features. These regularities are observed very clearly in the inclined special reference system – in the lithosphere reference system. The most important conclusion of the work is that the plate motion has an ordered character which reflects the dynamic asymmetry of the lithosphere structure. Evolutionary phenomena in the plate dynamics are discussed. Among them are (1) a fundamental tendency of the plate centre of mass displacements towards the northern hemisphere; (2) the phenomenon of grouping of the plates and the formation of a supercontinent, (3) a decrease of the velocities of rotation of the plates in the process of their growth.

KEY WORDS Plate kinematics, regularities of motion, ordering of motion

1 INTRODUCTION. GENERAL KINEMATIC CHARACTERISTICS OF THE PLATES

In our paper (Barkin, 1998), geometric regularities in the positions of the plate centres, their boundaries and junctions have been described. The main result is the conclusion that the plate centres display an elegant order in their positions, namely, these centres are placed on the Earth's surface along three great circles with mutually orthogonal planes.

On the basis of this property, a new geocentric lithosphere reference system $Ox_Ly_Lz_L$ (LRS) was introduced. The general coordinate plane of this system (Ox_Ly_L) was called the plane of the lithosphere equator. This plane is inclined to the Earth's equator by 26°7 and has a longitude of ascending node of 3°4 W in the Greenwich reference system. The polar axis Oz_L is directed towards Hudson Bay, and its pole has geographic coordinates 63°3 N, 93°4 W. The Ox_L axis is directed along the line of intersection of the planes of the Earth's equator and the lithosphere equator at the western coast of Africa. The Earth's reference system $Oxyz$ (ERS) is connected with the hot-spot system and its axes coincide with corresponding axes of the Greenwich reference system in the present geological epoch.

Table 1. Mass of the plates. Cartesian and spherical coordinates of the plate centres.

N	*Plates*	m_σ	x_σ	y_σ	z_σ	$\varphi_{C\sigma}$	$\lambda_{C\sigma}$
1	EA	4.360	0.022	0.531	0.619	49°3	87°6
2	AF	3.441	0.831	0.212	0.125	8°3	14°3
3	PA	2.959	−0.711	−0.281	0.024	1°8	201°6
4	NoA	2.380	−0.018	−0.449	0.740	58°8	267°7
5	SoA	2.176	0.510	−0.686	−0.287	−18°6	306°7
6	AU	2.097	−0.455	0.632	−0.416	−28°1	125°7
7	AN	2.065	0.035	0.068	−0.885	−85°1	62°8
8	IN	0.447	0.205	0.899	0.314	18°8	77°2
9	NA	0.415	−0.035	−0.899	−0.345	−21°0	267°8
10	AR	0.376	0.629	0.657	0.364	21°8	46°2
11	PH	0.137	−0.651	0.665	0.323	19°1	134°4
12	CA	0.122	0.325	−0.907	0.241	14°0	289°7
13	CO	0.101	−0.039	−0.983	0.135	7°8	267°7
14	JF	0.019	−0.428	−0.562	0.706	45°0	232°7

In this paper, for the interpretation of the kinematic regularities in plate motion, we use the standard projection of the Earth's surface (on the coordinate plane 'longitude–lattitude') and a similar projection with respect to the LRS. Main attention is paid to the kinematics of the plate centres and to the intrinsic rotation. The coordinates of plate mass centres (and corresponding epicentres) and plate masses were determined in our earlier papers (Barkin, 1996a, b; 1999) as a result of an approximate calculation of volume integrals (with respect to volumes of the plates) on the basis of the simple models of the plate by the trapezium method.

Table 1 lists the plate masses m_σ (1 unit = $10^{-3}m_\oplus$, $m_\oplus$ is the Earth's mass), the Cartesian coordinates x_σ, y_σ, z_σ of the epicentres of the plate mass centres (for brevity we will call them the centres of the plates) in units of the Earth's radius $R_\oplus$, and the geographic coordinates of these centres φ_σ and λ_σ (latitude and longitude) in degrees.

The goal of this paper is to study kinematic features and regularities of the plate motion. We will show that plate motion has an ordered character. This phenomenon is most pronounced in the LRS.

This phenomenon is extremely important for a reconciliation of the opposite concepts of fixity and mobility in tectonics.

We will consider the main and medium plates (14 plates) and will use their abbreviated notations (Barkin, 1999): EA – Eurasian, AF – African, PA – Pacific, NoA – North-American, SoA – South-American, AU – Australian, AN – Antarctic, IN – Indian. NA – Nasca, AR – Arabian, PH – Philippines, CA – Carribean, JF – Juan de Fuca. In Section 4 we also include into our consideration the East-Chine plate (EC).

The plate motion with respect to the mantle reference system is described by the modern geologic theory HS2-NUVEL1 (Greep and Gordon, 1990; Argus and Gordon, 1991).

Table 2. Kinematic characteristics of spherical plate motion in accordance with the HS2-NUVEL1 theory.

N	*Plates*	$\Omega_{\sigma x}$	$\Omega_{\sigma y}$	$\Omega_{\sigma z}$	Ω_σ	$\varphi_{\Omega\sigma}$	$\lambda_{\Omega\sigma}$
1	EA	0.034	0.055	−0.064	0.091	−44°5	58°9
2	AF	0.144	0.013	−0.017	0.146	−6°8	5°3
3	PA	0.001	0.487	−0.846	0.976	−60°1	89°9
4	NoA	0.107	−0.023	−0.259	0.281	−67°1	−102°2
5	SoA	0.030	0.107	−0.301	0.320	−69°7	74°4
6	AU	0.042	0.094	−0.026	0.106	−14°3	66°0
7	AN	0.564	0.506	0.129	0.769	9°7	41°9
8	IN	0.491	0.199	0.158	0.553	16°6	22°1
9	NA	−0.001	−0.320	0.329	0.458	45°8	−90°2
10	AR	0.492	0.165	0.155	0.542	16°7	18°6
11	PH	0.683	−0.245	−0.847	1.116	−49°4	−19°7
12	CA	−0.534	−1.098	0.406	1.287	18°4	−121°4
13	CO	0.081	−0.003	−0.156	0.176	−62°6	−2°0
14	JF	0.392	0.679	−0.544	0.954	−34°8	60°0

According to the general concepts of global tectonics, the plates form the external elastic Earth envelope – the lithosphere. The plates present a rigid and thin envelope with definite boundaries, corresponding to narrow belts of seismicity. Plates interact with one another, with the astenosphere layer and are subject to gravitational forces from the Moon and the Sun, and also to forces of inertia.

As a result of these interactions, the plates execute a motion, which in the first approximation is considered as a slow spherical motion with respect to the geocentric mantle reference system for the given geologic epoch, $Oxyz$.

The motion of every plate P_σ is given by the components of the angular velocity vector $\mathbf{\Omega}_\sigma$ in the reference system $Oxyz$: $\Omega_{\sigma x}, \Omega_{\sigma y}, \Omega_{\sigma z}$. Projections and moduli of the angular velocities $\Omega_\sigma = |\mathbf{\Omega}_\sigma|$ and the geographic coordinates of their poles on the spherical surface of the Earth $\varphi_{\Omega\sigma}$ and $\lambda_{\Omega\sigma}$ (latitude and longitude) for the kinematic theory of plate motion HS2-NUVEL1 are summarized in Table 2. Values of $\Omega_{\sigma x}$, $\Omega_{\sigma y}$, $\Omega_{\sigma z}$ and Ω_σ are given in degrees my^{-1} and $\varphi_{\Omega\sigma}$, $\lambda_{\Omega\sigma}$ in degrees.

In addition to the kinematic characteristics

$$\Omega_{\sigma x}, \Omega_{\sigma y}, \Omega_{\sigma z}; \quad \Omega_\sigma, \varphi_{\Omega\sigma}, \lambda_{\Omega\sigma} \tag{1}$$

we will use other kinematic parameters, which also uniquely determine the plate rotation in the given geological epoch:

$$\dot{\varphi}_\sigma, \dot{\lambda}_\sigma, \omega_\sigma. \tag{2}$$

Here $\dot{\varphi}_\sigma$ and $\dot{\lambda}_\sigma$ are angular velocities of the change of the latitude and longitude of the plate centre O_σ, and ω_σ is the intrinsic angular velocity of rotation of the

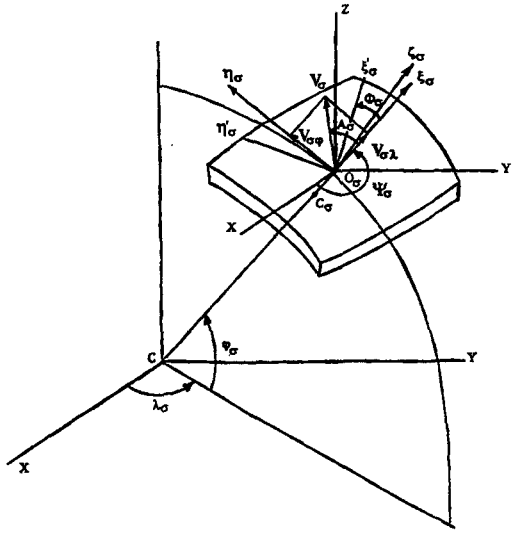

Figure 1 General reference systems and angular variables.

plate P_σ (about the $C\xi_\sigma$ axis which connects the Earth centre of mass C and plate centre O_σ, Fig. 1).

The parameters (2) can be expressed in terms of the components of the angular velocity (1). For this purpose we introduce two Cartesian reference systems, with origins at the centre O_σ of the plate P_σ: $O_\sigma\xi_\sigma\eta_\sigma\xi_\sigma$ and $O_\sigma\xi'_\sigma\eta'_\sigma\xi'_\sigma$. The $O_\sigma\zeta_\sigma$ and $O_\sigma\zeta'_\sigma$ axes coincide. They are directed along the radius-vector of the point O_σ in the main reference system $Cxyz$. The $O_\sigma\eta_\sigma$ and $O_\sigma\xi_\sigma$ axes are directed along the tangents to the corresponding meridian and parallel of the ERS which cross-point O_σ (the axis $O_\sigma\xi_\sigma$ is situated in the coordinate plane $O_\sigma x_\sigma y_\sigma$ and directed to the east, and the axis $O_\sigma\eta_\sigma$ is directed to the north). The coordinate axes $O_\sigma\xi_\sigma$, $O_\sigma\eta_\sigma$ and $O_\sigma\xi'_\sigma$, $O_\sigma\eta'_\sigma$ are located in the plane $O_\sigma\xi_\sigma\eta_\sigma$ which is tangent to the Earth's surface at the point O_σ. In this case, the $O_\sigma\xi'_s$ axis forms an angle Φ_σ with the $O_\sigma\xi_\sigma$ axis (Fig 1.). We suppose that the reference system $O_\sigma\xi'_\sigma\eta'_\sigma\zeta'_\sigma$ is connected with plate P_σ.

Also in Fig. 1, the Eulerian angles Ψ_σ, Θ_σ and Φ_σ (precession, nutation and intrinsic rotation) are given. These angles define the orientation of the reference system $O_\sigma\xi'_\sigma\eta'_\sigma\zeta'_\sigma$, connected with the plate, with respect to reference system $O_\sigma x_\sigma y_\sigma z_\sigma$ with the origin at the point O_σ and with axes that are parallel to the corresponding axes of the main reference system $Cxyz$.

For the algebraic angular velocity of the intrinsic rotation of the plate we will use a different notation: $\omega_\sigma = \dot{\Phi}_\sigma$.

Projections of the angular velocity vector of the plate rotation on the $O_\sigma xyz$ (or $Cxyz$) axes are defined by the kinematic Euler equations (Douboshin, 1975):

$$\Omega_{\sigma x} = \dot{\Theta}_\sigma \cos\Psi_\sigma + \dot{\Phi}_\sigma \sin\Theta_\sigma \sin\Psi_\sigma,$$

Table 3. Kinematic characteristics of plate motion in the HS2-NUVEL1 theory.

N	*Plates*	$\dot{\varphi}_\sigma$ (° my^{-1})	$\dot{\lambda}_\sigma$ (° my^{-1})	ω_σ (° my^{-1})	v_σ (cm cy^{-1})	$\omega_\sigma R$ (cm cy^{-1})	$v_{\sigma\varphi}$ (cm cy^{-1})	$v_{\sigma\lambda}$ (cm cy^{-1})	A_σ (°)
1	EA	0.031	−0.130	0.087	100.1	96.8	34.7	−93.9	159°7
2	AF	0.023	−0.038	0.144	49.0	160.5	25.4	−41.9	148°8
3	PA	0.452	−0.840	−0.179	1060.9	−199.3	503.0	−934.1	151°7
4	NoA	−0.108	−0.290	0.036	205.6	40.4	−119.7	−167.2	−144°4
5	SoA	−0.088	−0.323	−0.072	354.6	−79.7	−97.8	−340.8	−164°0
6	AU	0.753	0.128	−0.003	847.0	−3.2	837.6	125.4	81°5
7	AN	−0.006	1.166	1.197	111.6	1330.8	−6.4	111.4	−3°3
8	IN	0.435	0.054	0.320	486.6	355.9	483.3	57.1	83°3
9	NA	−0.011	0.451	0.342	468.7	380.3	−12.3	468.6	−1°5
10	AR	0.241	−0.029	0.495	269.3	550.9	267.7	−29.8	96°3
11	PH	0.317	−0.621	−0.691	741.3	−768.6	352.6	−652.1	151°6
12	CA	−0.075	−0.164	0.031	195.2	34.3	−83.4	−176.5	64°7
13	CO	0.491	0.253	1.129	612.7	1255.2	545.5	279.0	62°9
14	JF	0.100	0.234	−1.099	214.6	1222.2	110.9	183.7	31°1

$$\begin{aligned}\Omega_{\sigma y} &= \dot{\Theta}_\sigma \sin\Psi_\sigma - \dot{\Phi}_\sigma \sin\Theta_\sigma \cos\Psi_\sigma,\\ \Omega_{\sigma z} &= \dot{\Psi}_\sigma + \dot{\Phi}\cos\Theta_\sigma.\end{aligned} \tag{3}$$

We now invoke the following geometric and kinematic relationships (see Fig. 1):

$$\Theta_\sigma = \frac{\pi}{2} - \varphi_\sigma, \quad \Psi_\sigma = \lambda_\sigma + \frac{\pi}{2}, \quad \omega_\sigma = \dot{\Phi}_\sigma$$

and solve equations (3) for characteristics (2). We have

$$\begin{aligned}\dot{\varphi}_\sigma &= \Omega_{\sigma x}\sin\lambda_\sigma - \Omega_{\sigma y}\cos\lambda_\sigma,\\ \dot{\lambda}_\sigma &= \Omega_{\sigma z} - \omega_\sigma \sin\varphi_\sigma,\\ \omega_\sigma &= \frac{\Omega_{\sigma x}\cos\lambda_\sigma + \Omega_{\sigma y}\sin\lambda_\sigma}{\cos\varphi_\sigma}.\end{aligned} \tag{4}$$

We also introduce into our consideration the linear velocities $V_{\sigma\varphi}$ and $V_{\sigma\lambda}$ which represent latitude and longitude components of the velocity vector $\boldsymbol{V}_\sigma$ of the plate centre O_σ: V_σ is the modulus of the vector $\boldsymbol{V}_\sigma$; A_σ is the angle between the coordinate axis $O_\sigma\xi_\sigma$ and the velocity vector $\boldsymbol{V}_\sigma$. The last kinematic characteristics are given by the following simple formulae:

$$\begin{aligned}V_{\sigma\varphi} &= R\dot{\varphi}_\sigma = R(\Omega_{\sigma x}\sin\lambda_\sigma - \Omega_{\sigma y}\cos\lambda_\sigma),\\ V_{\sigma\lambda} &= R\dot{\lambda}_\sigma\cos\varphi_\sigma = R(\Omega_{\sigma z} - \omega_\sigma\sin\varphi_\sigma)\cos\varphi_\sigma,\\ V_\sigma &= \sqrt{V_{\sigma\varphi}^2 + V_{\sigma\lambda}^2},\\ A_\sigma &= \arctan\frac{V_{\sigma\varphi}}{V_{\sigma\lambda}}.\end{aligned} \tag{5}$$

Values of the kinematic characteristics (4), (5), corresponding to the HS2-NUVEL1 theory of plate motion, are presented in Table 3. Here we also give the values of some characteristic linear velocity $\omega_\sigma R$ (where R is the Earth's radius).

As a result of the analysis of the kinematic plate characteristics (1), (2), (5), important properties and regularities of the structure and motion of the plates were established.

2 FEATURES OF THE POLE POSITIONS OF VECTOR $\boldsymbol{\Omega}_\sigma$

In Fig. 2, the positions of the poles of the plate angular velocities $\boldsymbol{\Omega}_\sigma$ are shown in the polar projections on the lithosphere equator plane. The poles of the northern hemisphere of the LRS are shown by hollow circles and the poles of the southern hemisphere of the LRS are denoted with filled circles.

Below, some geometrical properties of the pole positions and the corresponding phenomena and effects in the plate motion are noted and discussed.

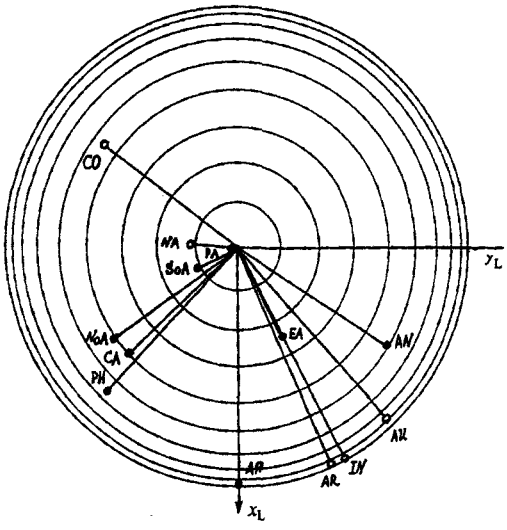

Figure 2 Positions of the poles of the angular velocities Ω_σ of the plate rotations in accordance with the HS2-NUVEL1 theory in the polar projection on the plane of the lithosphere equator. Filled circles denote the poles situated in the southern hemisphere of the LRS.

2.1 Asymmetry in the Pole Positions of the Vectors Ω_σ

1. The poles of the angular velocity vectors Ω_σ of the spherical motion of the plate with respect to the mantle reference system are situated in one hemisphere of the Earth, in the interval of longitudes 120° W – 60° E of the LRS.

2. The poles of the main (more massive) plates EA, AF, PA, NoA, SoA, AU, AN and also CA and PH are situated in the southern hemisphere of the lithosphere (below the lithosphere equator) and only the poles of the medium plates NA, IN and those of the small plates CO, AR are situated in the northern hemisphere of the LRS.

2.2 Ordering in Pole Positions of the Vectors Ω_σ

3. The pole of the angular velocity vector of the Pacific plate virtually coincides with the south pole of the lithosphere (of axis Cz_L).

4. The vectors of the angular velocities of all the plates (except for NA and AF) in their positions are attracted to the meridian planes ±45° of the LRS.

2.3 Phenomenon of the Paired Positions of the Poles of Ω_σ

5. The phenomenon of the paired longitude positions of the vector Ω_σ poles in the LRS takes place. The main point of this phenomenon is the longitudes

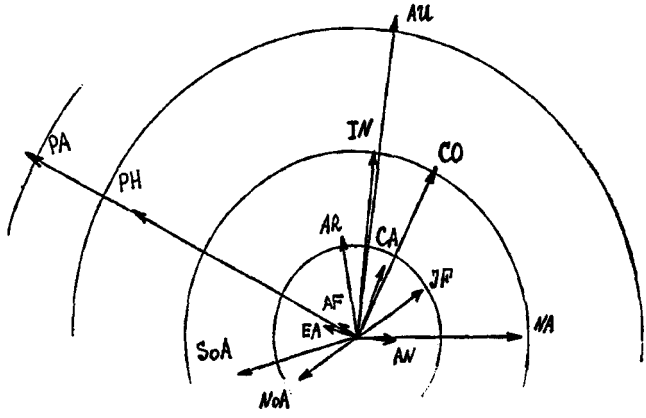

Figure 3 Diagram of the vector velocities of the plate centres in the HS2-NUVEL1 theory (ERS).

of the LRS for definite pairs of vectors $\mathbf{\Omega}_\sigma$ have close values. This conclusion is fulfilled for the following pairs of plates: CA, PH; NoA, SoA; AR, EA; IN, EA; CO, AN.

6. For definite pairs of plates their vectors $\mathbf{\Omega}_\sigma$ are situated in the vicinity of the orthogonal meridional planes of the LRS. Thus, the differences of the longitudes of the vectors $\mathbf{\Omega}_\sigma$ for the following pairs of plates are equal to approximately 90°:

$$\lambda^\Omega_{\mathrm{AF}} - \lambda^\Omega_{\mathrm{NA}} = 91°1, \qquad \lambda^\Omega_{\mathrm{IN}} - \lambda^\Omega_{\mathrm{SoA}} = 88°7, \qquad \lambda^\Omega_{\mathrm{EA}} - \lambda^\Omega_{\mathrm{SoA}} = 87°5,$$
$$\lambda^\Omega_{\mathrm{AR}} - \lambda^\Omega_{\mathrm{SoA}} = 85°8, \qquad \lambda^\Omega_{\mathrm{AU}} - \lambda^\Omega_{\mathrm{CA}} = 86°6, \qquad \lambda^\Omega_{\mathrm{AU}} - \lambda^\Omega_{\mathrm{PH}} = 84°6.$$

3 GENERAL PROPERTIES OF THE PLATE CENTRE MOTION

In Fig. 3, the planar diagram of the velocity vectors of the plates which are known to emanate from common centre O is shown. The azimuth angle A_σ, counted from the $O\xi$ axis (from the corresponding parallel) plays the role of the polar angle. The $O\eta$ axis corresponds to the direction north. This diagram illustrates some properties of plate motion.

3.1 Tendency of Plate Centre Displacements to the Northern Hemisphere of the ERS

1. The centres of the main lithosphere plates (except for the North-American and South-American plates) have a tendency of displacement towards the northern hemisphere of the Earth.

In reality, for most of them (including the more massive ones) the values of $\dot{\varphi}_\sigma$ are positive (see Table 3).

2. Plates, combining in the following groups: (PA, PH, AF, EA), (IN, AU), (CA, CO) and (AN, NA), are characterized by close azimuths of the velocities of their centres. This means that a peculiar phenomenon of the pairing in the azimuths of the velocities takes place for the centres of definite plates: (PA, PH), (AF, EA), (IN, AU), (CO, CA), (AN, CA).

3. Values of azimuths for all the plates are found in the regions between the azimuths of the cenre velocities of the following pairs of the plates: (JF, AR), (AF, NoA), (AN, NA).

For a more complete description of the kinematic properties of the plate motion here (see Figs. 4–6) we also use characteristics of another theory of plate motion, NNR-NUVEL1 (Argus and Gordon, 1991), and some data about the velocities of displacements of GPS stations (Smith *et al.*, 1990; Tatevian, 1996). These characteristics are analogous to the above-mentioned ones, which were obtained for the plate kinematic theory HS2-NUVEL1 (Gripp and Gordon, 1990). We only note that, while the HS2-NUVEL1 theory defines the plate motion with respect to the hot-spot system, the NNR-NUVEL1 theory defines the plate motion with respect to a definite mean lithosphere system of coordinates.

4 ORDERING OF THE PLATE MOTION

4.1 The Plate Motion along the Lithosphere Equator

Positions of the plate centres and their velocities in accordance with the HS2-NUVEL1 and NNR-NUVEL1 theories are shown in Fig. 4. The lengths of the segments correspond to the modulus of velocities of the plate centres from Table 3. Contours of the plates and continents (as in Fig. 2) are given in the standard projection, but with respect to the lithosphere reference system.

In accordance with the NNR-NUVEL1 kinematic theory, the centres of the plates of the lithosphere belt, AF, AR, IN, EC, PH, PA, NA and EA, display a tendency in their motion along the lithosphere equator (Fig. 4). Taking into account that the centre velocities of the plates AF, AR and EA in the HS2-NUVEL1 theory are small, we can say that the above tendency of the equatorial motions (with respect to LRS) is fundamental and takes place for plate motion with respect to the mantle (with respect to the reference system connected with the hot-spot system).

The velocities of the centres of the 'fast' plates, AU, IN, CO, are characterized by considerable meridional components in the LRS. However, the centres of the 'pole plates', AN and NoA , experience a slow motion to the lithosphere equator.

As a whole, these properties point to the existence of principal directions of the centre plate motions – along the lithosphere equator (and some parallels) and along definite meridians of the LRS.

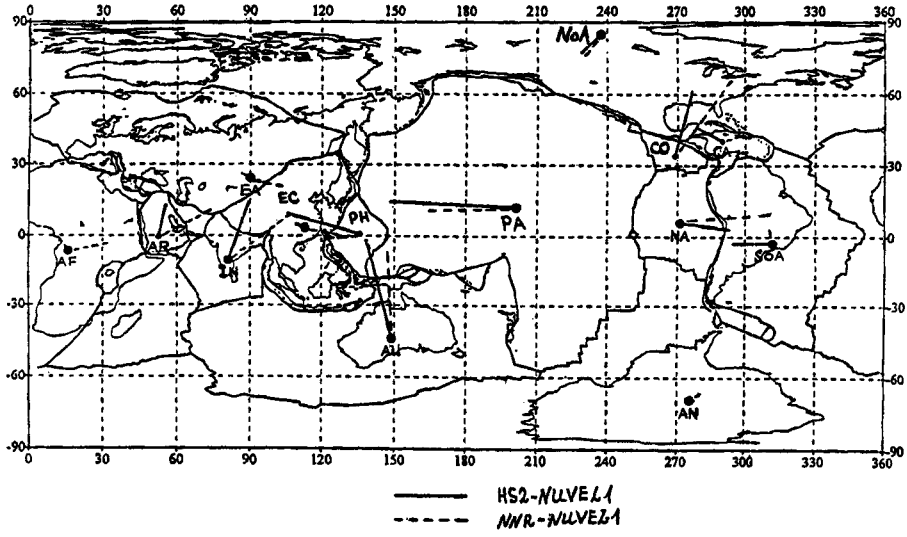

Figure 4 Positions and velocities of the plate centres in the HS2-NUVEL1 and NNR-NUVEL1 theories.

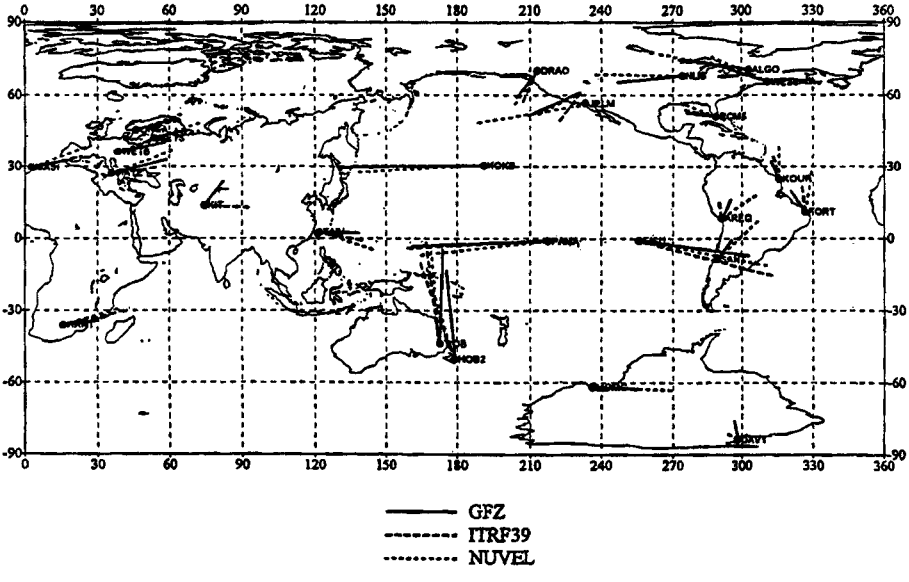

Figure 5 Velocities of the global position stations.

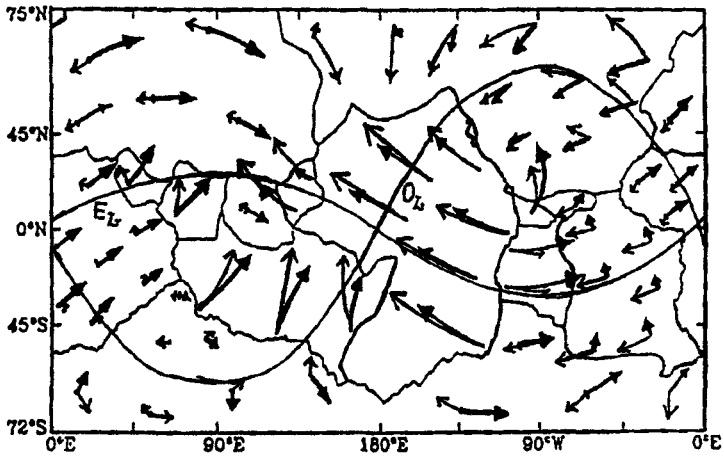

Figure 6 Trajectories of the points of the Earth's surface in 50 my in the HS2-NUVEL1 (thin lines) and NNR-NUVEL1 kinematic theories; lithosphere equator E_L and 0° meridian O_L of the LRS.

These properties are illustrated in Fig. 5. Here the velocities of motion of the majority of the global position stations are indicated. They were calculated on the basis of observations in GFZ Potsdam (in 1993–1995), on the model NUVEL1 and on the generalized model of the set of equalization ITRF-93 (Tatevian, 1996). The results of these model are in good agreement with each other and clearly point to the displacement of the stations of the lithosphere equatorial belt along parallels of the LRS and to meridional displacements of the corresponding stations located on the Australian and South-American plates (Fig. 5).

Figure 6 also illustrates the conclusions formulated. In this figure the trajectories of the plate points during 50 my in accordance with the HS2-NUVEL1 and NNR-NUVEL1 kinematic theories are displayed. The points of the lithosphere belt in their motion are characterized by a fundamental tendency – by motion along (or parallel to) the lithosphere equator.

4.2 Phenomenon of the Grouping of the Plates

Plate motion in the NNR-NUVEL1 theory is characterized by another important tendency – grouping and combining (integration) of the continental plates and the plates with continental fragments, AF, AR, EA, IN, EC, AU, NoA, SoA, AN, to one great continental plate – to a supercontinent (see Fig 4).

The difference between the two kinematic theories NNR-NUVEL1 and HS2-NUVEL1 is caused by global rotation of the lithosphere (Argus and Gordon, 1991). This rotation in a given epoch is accomplished with an angular velocity of 0°33 my^{-1} about the axis directed from the geocentre to the geographic point 40° S, 65° E. This means that the phenomenon of grouping of continental plates takes place in

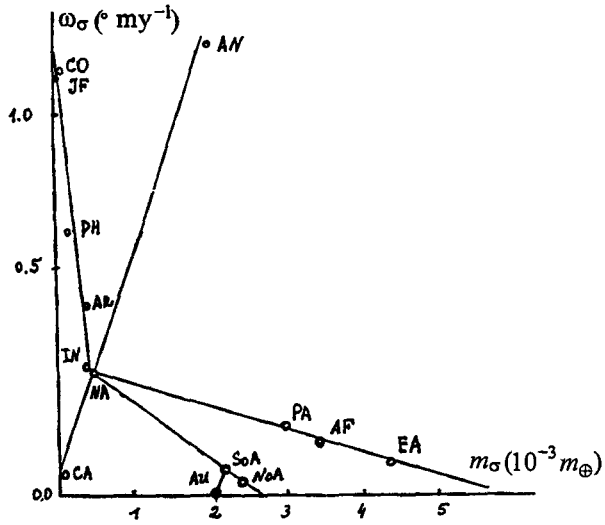

Figure 7 Parameters ν_σ, ω_σ.

the mantle reference system, too. In other words, in the present geologic epoch the global tectonic processes are directed towards forming a new supercontinent.

The formation of the supercontinent in the process of the Earth's evolution has a cyclic character and the antisymmetry of the Earth has a sign-reversal character (Bojko, 1997).

The centre of grouping of the plates (to which the motions of the plate centres are directed) is situated in the region of Indonesia, a region with more active collisional processes of the main lithosphere plates (EA, IN, PA, AU). It is pertinent to note that the a deeper depression of the liquid core is found under the above-mentioned region (Morelli and Dziewonski, 1987). It is in the Indonesia region that the radius-vector of the Earth's magnetic centre (Parkinson, 1986) is directed (coordinates of its pole 14°51 N, 150° E); the vector of momentum of the plate motion in the NNR-NUVEL1 theory (coordinates of its pole 24°9 N, 140° E, Barkin, 1996b) is directed these, too. In a very similar manner, the Earth's centre of mass moves in a relatively liquid core towards the point 21° N , 165° E (Barkin, 1996b; 1997).

5 FEATURES OF THE INTRINSIC ROTATION OF THE PLATES

The graphs in Fig. 7 show that massive plates are characterized by small angular velocities about the geocentric axis crossing from their centres. Furthermore, the greater the mass of the plate m_σ, the lower the velocity ω_σ. This conclusion is fulfilled for all plates, except for the Carribean, Antarctic and Australian plates. Thus, for plates of small and medium sizes (JF, CO, PH, AR, NA, IN), the relationship between the modulus of the angular velocity of the plate and its mass is

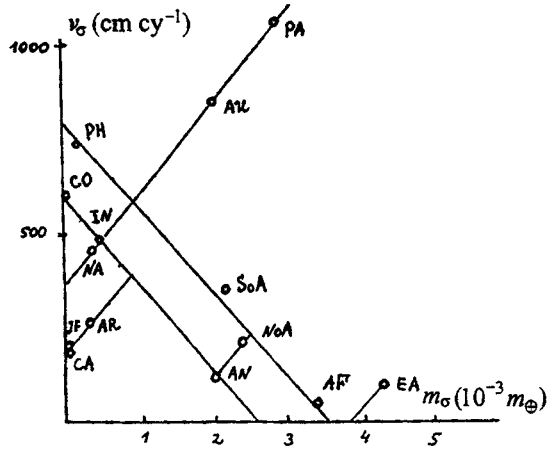

Figure 8 Parameters ω_σ, m_σ.

linear (Fig. 7):

$$\omega = \omega_0 + km,$$

where $\omega_0 = 1.1°$ my^{-1}, $k = -8.8 \times 10^3$ (° $(m_\oplus$ my$)^{-1}$).

For larger and medium plates (EA, AF, PA, NA, IN), a similar relationship has the following form

$$\omega = \omega_0 + km,$$

where $\omega_0 = 0.36°$ my^{-1}, $k = -0.29 \times 10^3$ (° $(m_\odot$ my$)^{-1}$).

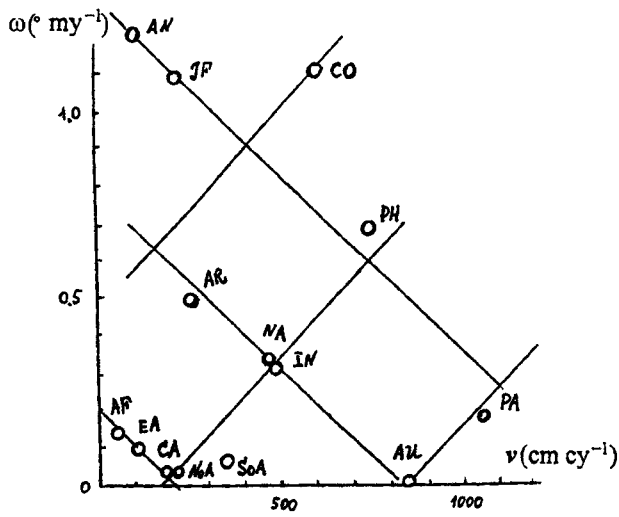

Figure 9 Parameters ν_σ, ω_σ.

Table 4. Mean values $v + \omega R$ for groups of plates and their calculated values VN.

N	$v + \omega R$ (cm cy^{-1})	*Plate group*	VN (cm cy^{-1})
1	231	(EA, AF, NoA, SoA, CA)	230
4	844	(PA, AU, IN, NA, AR)	920
6	1440	(AN, JF)	1380
8	1868	(CO)	1840
0	−27	(PH)	0

In Fig. 8 the dots denote masses and moduli of velocities of the plate centres in the corresponding coordinate plane (v, m). Hence it follows that the centres of the plates with small masses have intermediate values of velocities (in the range 2.0–7.5 cm cy^{-1}), but the centres of the massive plates can have large values (of the order of 10 cm cy^{-1}) as well as small values (of the order of 0.5–2 cm cy^{-1}). Although continental plates or plates with large continental areas (such as SoA, NoA, AN, AF, EA) are characterized by small velocities of their centres, the bigger ocean plates – the Pacific plate and the Australian plate – are the most mobile.

6 KINEMATIC RELATION BETWEEN THE VELOCITIES v_σ, ω_σ

The positions of points corresponding to the kinematic parameters v_σ, ω_σ in the coordinate plane (v, ω) have an interesting structure. These points are arranged along some straight lines, forming a peculiar kind of lattice in the coordinate plane (v, ω) (Fig. 9).

This structure can be explained by the existence of the simple kinematic relation

$$v + \omega R = VN,$$

where N is an integer, $V = 230$ cm cy^{-1} is the characteristic velocity, and R is the radius of the Earth. The mean values of the velocities $v + \omega R$ for corresponding groups of plates and their theoretical values for definite integer N are given in Table 4.

SUMMARY

On the basis of these properties and regularities of plate motion, we can formulate a principal conclusion: the plate motion has an ordered character. In our other papers, we have obtained a similar principal conclusion from an analysis of the geometrical properties and regularities in the plate motion (Barkin, 1996a; 1999). The principal characteristic features of this ordered motion are connected with the

global asymmetry of the Earth's dynamic structure. They reflect and emphasize this asymmetry.

Although in our paper the parameters of the current plate motion were used, important evolutionary mechanisms and features of the Earth's history are perceived. Our results point to the existence of a fundamental mechanism forming the Earth's global asymmetry. We connect this asymmetry with slow (in the geological sense) relative displacements of the Earth's envelopes (of the lithosphere, of the lower and upper mantle and of the liquid and rigid cores first). The cyclicity of similar displacements of the envelopes (their centres of mass) and their slow relative rotations can have as a consequence the cyclicity observed by geologists and the changing antisymmetries of the Earth. The relative displacements of the centres of mass of the main envelopes (the upper and lower mantle and oth.) could define the observed asymmetry of geodynamical processes, and of the structure and evolution of the Earth's physical fields. The directionality of these processes is characterized by geodynamical axes, which lie in the plane of the lithosphere equator and form an angle about 135°– 150° with the OX_L axes of the LRS. The above-mentioned kinematic properties of the plate motion also confirm the directionality of the tectonic process of the Earth's mass redistribution. Many from observed fenomena of the cyclicity, mirrority and inversion of the tectonic, volcanic and seismic processes can be explained by the mechanism of the translational relative displacements of the main Earth's envelopes (the lithosphere, upper and lower mantle and oth.) in particular along mentioned fundamental direction.

In this paper, important evolutionary conclusions also emerged: (1) there is a fundamental tendency of the plate centre of mass displacements towards the northern hemisphere; (2) there seems to be a phenomenon of the grouping of plates and the forming of a supercontinent; (3) there is a decrease of the velocities of the intrinsic rotation of the plates in the process of their growth. The most important conclusion is connected with the establishment of the nature of the observed asymmetry of the Earth. This asymmetry is displayed as ordered plate motion and the structure of the Earth's envelopes in the inclined reference system (LRS). The established kinematic regularities and features of the plate motion must be interpreted in concert with geometric regularities which were described in detail (Barkin, 1999).

Aknowledgements

This work was supported by grants of the RFFI (96-05-65015; 99-05-64889), Program 'Universities of Russia – fundamental studies' (theme 9-5240) and the Program 'Astronomy' of the SCST (theme 1.8.1.3).

I am grateful to academician of the RAN, Leonov, Yu. G., for discussion and valuable advice.

References

Argus, D. F. and Gordon, R. G. (1991) *Geophys. Res. Lett.* **18**, No. 11, 2039.

Barkin, Yu. V. (1996a) *Abstracts Russian Conference on 'Modern Problems and Methods of Astrometry and Geodynamics' (St. Peterburg, 23–27 October, 1996)*, IPA RAN, p. 130.
Barkin, Yu. V. (1996b) *Vestnik Mosk State University, Ser. 3. Phys Astron.* **37**, No. 1, 79 (in Russian).
Barkin, Yu. V. (1997) *Eos Trans. AGU* **78**, No. 46, Fall Meet. Suppl., F145.
Barkin, Yu. V. (1999) *Astron Astrophys. Trans.* (in press).
Bojko, N. A. (1992) *Vestnik Mosk State University, Ser. 4. Geol.*, No. 5, 27 (in Russian).
Douboshin, G. N. (1975) *Celestial Mechanics. General Problems and Methods.*, Science, Moscow (in Russian).
Gripp, A. E. and Gordon, R.G. (1990) *Geophys. Res. Lett.* **17**, 1109.
Morelli, A. and Dziewonski, A. M. (1987) *Nature* **325**, 677.
Parkinson, U. (1986) *Introduction to Geomagnetism*, Mir, Moscow. (in Russian).
Smith, D. E. *et al.* (1990) *J. Geophys. Res.* **95**, 22013.
Tatevian, S. K. (1996) *Contribution of Space Geodesy Methods to Modern Geodynamics. Space Geodesy and Modern Geodynamics*, MID RF, Moscow, pp. 7–48.