PERGAMON

Journal of Geodynamics 31 (2001) 105–118

JOURNAL OF
GEODYNAMICS

www.elsevier.nl/locate/jgeodyn

Effects of the relative lithosphere–asthenosphere motion on the global tectonic features

J. Shahabpour[a,*], P. Trurnit[b]

[a]Department of Geology, Shaheed Bahonar University, P.O. Box 955, Kerman 76135, Iran
[b]Wacholderweg 6, Großburgwedel, D-30938, Burgwedel, Germany

Received 5 March 1999; accepted 19 March 2000

Abstract

The relative eastward rotation of the asthenosphere with respect to the lithosphere is explained by the westward-directed off-center rotation of the spinning Earth around the gravitational center of the Earth–Moon system (principle of hypocycloid gearing), and by the lateral viscosity variations at the base of the lithosphere. Independent geologic data favor a global westward drift of the lithosphere relative to the asthenosphere. Therefore, any attempt to investigate the mode of origin of the global tectonic features and the relationships among their tectonic components must consider this relative lithosphere–asthenosphere motion. As the angular velocity of the relative motion increases from the poles toward the equator, its effect on the global tectonic features also increases toward the equator. Consideration of the diverse effects of this relative lithosphere–asthenosphere motion on the west and east-facing subductions, on ternary plots, allows classification of east-facing island arcs into simple vs complex, and proximal vs distal. © 2000 Elsevier Science Ltd. All rights reserved.

1. Introduction

Le Pichôn (1968) noted that in the hotspot reference frame there exists a 'westward' component of lithospheric motion. Some investigators tried to explain this observation (e.g., Bostrom, 1971; Nelson and Temple, 1972), noting the contrasting nature of east- and west-facing subduction zones (see Table 1). The evidence is also in agreement with the fact that east-

---

* Corresponding author. Tel.: +98-0341-223071; fax: +98-0341-223071.
E-mail address: shahab@arg3.uk.ac.ir (J. Shahabpour).

0264-3707/01/$ - see front matter © 2000 Elsevier Science Ltd. All rights reserved.
PII: S0264-3707(00)00016-8

facing subduction zones in the Pacific (Mariana-type) are in general much steeper and deeper than the west-facing subduction zones (Andean-type; Dickinson, 1978; Uyeda and Kanamori, 1979; Mitchell and Garson, 1981; Table 1). This has been attributed to the westward drift of the lithosphere with respect to the eastward rotating asthenosphere to which the arc-system is anchored by the subducting slab (Dickinson, 1978). Trurnit (1984, 1991a, 1991b, 1993, 1994) explained that due to the westward-directed off-center rotation of the spinning Earth around the gravitational center of the Earth–Moon (–Sun) system, the lower mantle is displaced eastward in relation to the convecting upper mantle–crust system, and the asthenosphere is displaced eastward in relation to the lithosphere (principle of hypocycloid gearing; Trurnit, 1984, 1991a, 1991b, 1993, 1994). Many other investigators also confirmed the westward drift of the lithosphere with respect to the asthenosphere, and proposed the lateral viscosity variations at the base of the lithosphere in a toroidal field of degree 1 as a reason for this delay (e.g., O'Conell et al., 1991; Ricard et al., 1991; Cadek and Ricard, 1992). Therefore, any attempt to investigate the relationships among the tectonic components of the subduction zones must consider this relative lithosphere–asthenosphere motion.

Table 1
Morphologic and tectonic comparison of the west-dipping and east-dipping subductions[a]

	west-dipping	east-dipping
Synonyms	Mariana-type; east-facing	Chilean-type; Andean-type; west-facing
Slab dip	Steep	Shallow
Foreland basin	Deep	Shallow
Nature of slab	Thick–old–dense slab	Thin–young–light slab
Depth of trench	Deep	Shallow
Rate of trench subsidence and sediment supply	High rate of subsidence and low rate of sediment supply	Low rate of subsidence and high rate of sediment supply
Morphology of the oceanic crust at the subduction zone	Forming bulge	No bulge
Nature of back arc	Back-arc extensional basin	Back-arc compressional basin
Width of thrust belt	Narrow active thrust belt	Wide active thrust belt
Nature of thrust belt	Low structural and morphologic relief; show upper crust rocks	High structural and morphologic relief; show basement rocks
Nature of basal detachment	The basal detachment is never connected to the surface but rather folded and subducted	The basal detachment can bring to the surface deeply buried materials
Direction of migration of the subduction hinge	Eastward	Westward
Relative speed of the interacting plates	Subducting plate is faster	Overriding plate is faster
Example	Apennines, Carpathians	W. Alps, Dinarides

[a] Based on Dickinson (1978), Uyeda (1981), Uyeda and Kanamori (1979), Doglioni et al. (1991), Ricard et al. (1991), Doglioni (1993) and Sabadini and Spada (1988).

2. The hypocycloid gearing model

This model was for the first time proposed by Trurnit (1984, 1989, 1991a, 1991b, 1993, 1996). According to this model, due to the westward-directed off-center rotation of the spinning Earth around the gravitational center of the Earth–Moon (–Sun) system, the lower mantle is displaced eastward in relation to the convecting upper mantle–crust system, and the asthenosphere is displaced eastward in relation to the lithosphere (Trurnit, 1984).

The Earth is rotating around its axis, and the Moon revolving around the Earth towards the east. The Earth is in fact rotating eastward below the eastward revolving Moon at a much faster speed (1 rotation/24 h) than the Moon (1 revolution around the Earth /27.32166 days, or 655.72 h). In 24 h the Earth rotates eastward one full rotation (360°), whereas the Moon has just moved East by approximately 1/28 (13.18°) of its orbit around the Earth. The westerly movement of the center of the Earth–Moon system can be observed in the following experiments.

Put two 360° protractors — one of large size (the Earth, say) and one of small size (the Moon, say) on a table. Insert a needle into the center of the larger protractor (the Earth). Place the 0°(360°)–180° line of the smaller protractor along the same line of the larger protractor, so that the '0°' marks on both points to your north (a stationary object; a marking at '0°' on the table). With a felt tip pen, mark '0°' along the 0°(360°) line on the larger protractor. Rotate the larger protractor (the Earth) in a counterclockwise (eastward) direction around its pivot for about 54.65° with respect to the marking (the stationary object), and at the same time rotate the smaller protractor (the Moon) on an imaginary orbit around the larger protractor in the same direction for about 2° (angular velocity of revolution of the Moon around the Earth is 0.5490°/h). After each stage of rotation [each 54.65° rotation of the larger protractor (the Earth), and 2° rotation of the smaller protractor (the Moon)], join the centers of the protractors by a line and mark consecutive numbers 1, 2, 3,... (gravitational centers) along the line which is drawn onto the larger protractor (Fig. 1; numbers 1, 2, 3,...). After several stages of rotation, the later numbers (gravitational centers) are seen to move westward relative to the faster eastward rotation of the larger protractor (the Earth), indicating the relative westward movement of the gravitational center of the Earth–Moon system relative to the faster rotation of the Earth (Fig. 1).

The following experiment demonstrates the relative movement of each single spheroid of the Earth and also the westward movement of the gravitational center of the Earth–Moon system.

Three rings of about 2 cm in height are cut from cardboard map rolls of different diameters. The outer side of each ring is marked by a vertical line and then they are put one inside the other, so that their markings fall on a straight line (Fig. 2A). The rings are put on the smooth surface of a table and subjected to a westward (clockwise) eccentric rotation by a pen which moves over the outer side of the outer ring in a westward direction, while exerting force (tidal force) to keep the rings in touch. In this experiment the force exerted by the pen acts as a tidal force which makes each inner spheroid of the Earth to roll off into its outer spheroid.

To start the eccentric rotation, the pen is placed along the vertical line marked on the outer side of the outer ring, parallel to the markings along which the rings are touching (Fig. 2A). Assuming that the inner circumference of the outer ring (*d*1) is 21.35 cm, and that the outer circumference of the intermediate ring (*d*2) is 17.59 cm, we find that after 4.68 rounds [$i = d2/$

(*d*1 − *d*2); Trurnit (1989)] of rotation [with respect to the marking on the outer ring (point A)] of the pen, the marking on the outer ring (point A) will be back to the marking on the intermediate ring (point B) (Fig. 2B). In this experiment the inner rings are seen to roll off in the outer rings in the opposite sense to the off-center rotation of the pen (the Moon) (Fig. 2). The Earth–Moon system and the Earth's individual spheres (lithosphere, asthenosphere) work similarly. However, the liquid outer core is an exception, because it behaves like a fluid. It moves in the direction of the off-center rotation; the solid inner core swimming in it moves in that direction too. Therefore, each inner spheroid (except for the core) has a relative eastward movement with respect to its outer ring (westward displacement of the geomagnetic non-dipole field).

One revolution of the Moon about the rotating Earth takes 24.84 h (the time it takes for the Moon to return to a fixed point above the Earth). Therefore, there are $365 \times 24/24.84 = 352.657$ revolutions of the Moon about the Earth in a year (returns of the Moon to a fixed point on the Earth). Owing to the observation that a global tectonic megacycle lasts 200–250 million years (the time it takes the eastwards migrating Pacific to return to a specific setting,

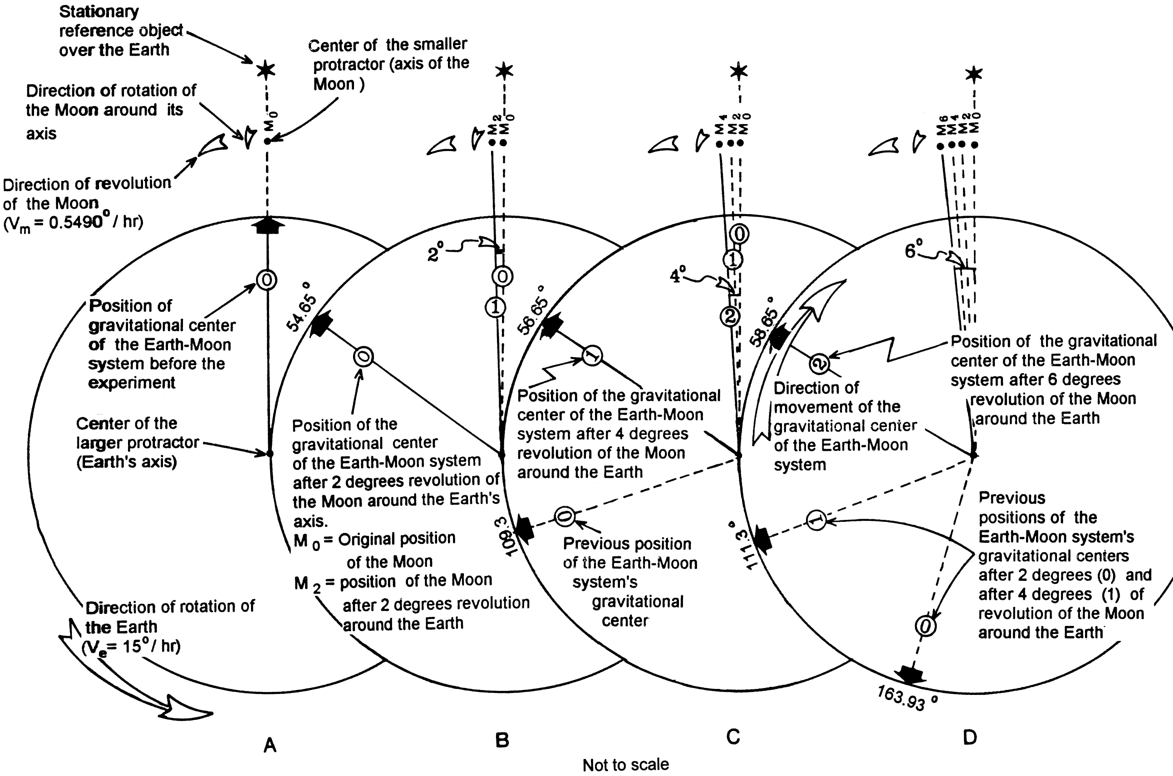
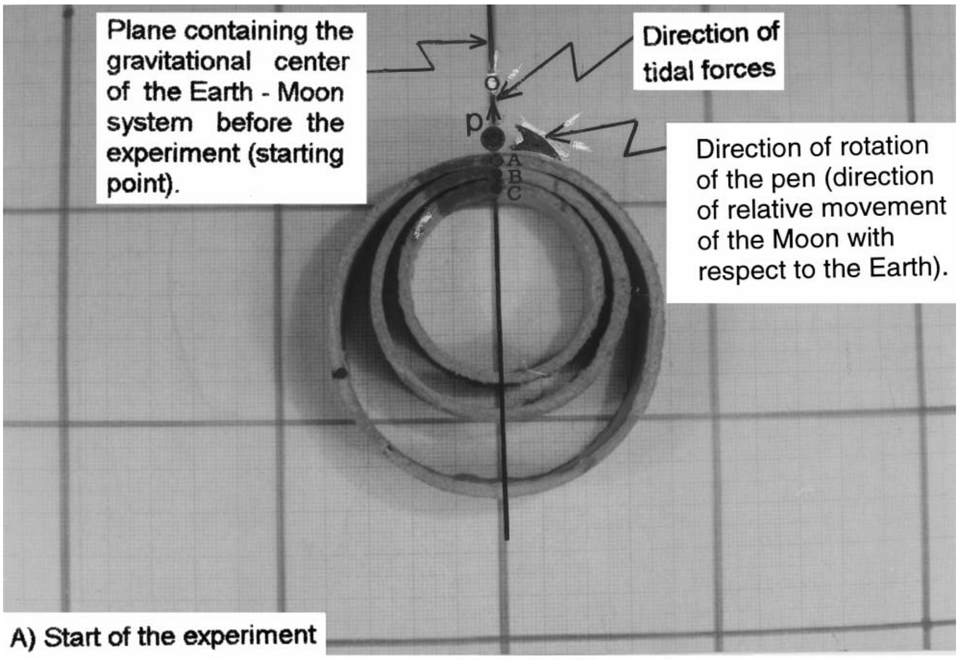
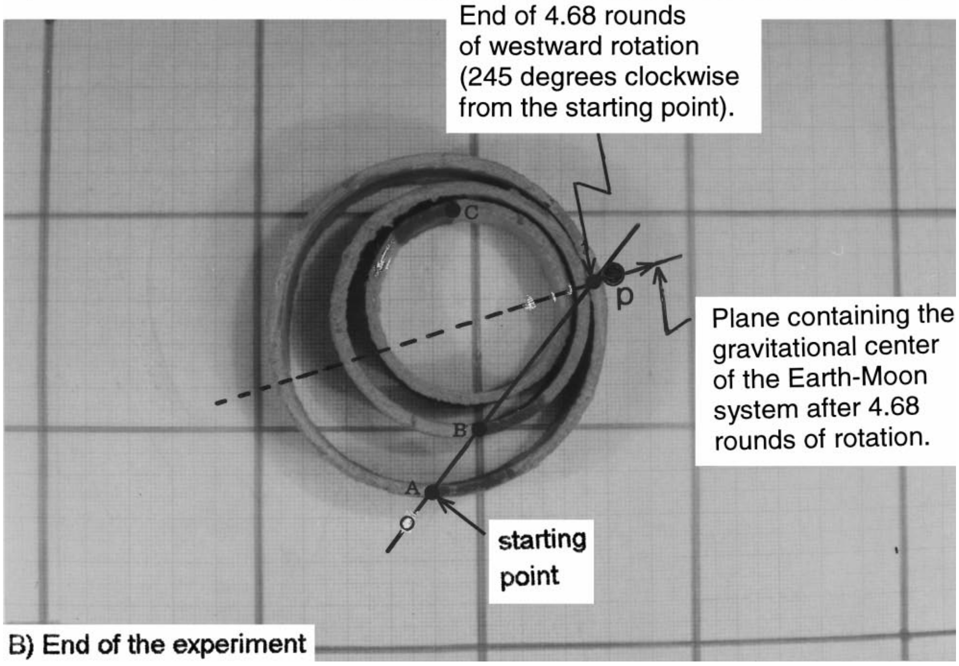


Fig. 1. Experiment showing the westward movement of the center of gravity of the Earth–Moon system during the revolution of the Moon around the Earth. The line containing the gravitational center of the Earth–Moon system is the projection of the line connecting these two bodies onto the Earth's equatorial plane. Positions of the Moon (M0, M2,...) are schematic.



A) Start of the experiment



B) End of the experiment

Fig. 2. Experiment showing the relative movement of the Moon (P, pen), and the spheroids of the Earth (A, B and C), and westward movement of the gravitational center of the Earth–Moon system.

e.g., the collision setting; Trurnit, 1984, 1991a, 1991b, 1993, 1996), and the circumference of the Earth at the equator being 40,000 km, in 24.84 h or one revolution of the Moon about the rotating Earth (the time it takes for the Moon to return to a fixed point on the Earth), the asthenosphere and the lithosphere only shift for about half a millimeter a day ($40{,}000 \times 1{,}000{,}000$ mm/$365 \times 250 \times 1{,}000{,}000$ days = 0.44 mm/24.84 h) relative to each other.

The relative eastward rotation of the asthenosphere with respect to the lithosphere is of great importance to the interpretation of many tectonic features observed in the lithosphere (e.g., see Table 1).

3. Model of lateral viscosity variations at the lithosphere base

The actual global lithospheric rotation has been explained by invoking a subcontinental viscosity that is larger than the suboceanic viscosity by a factor of either eight (Ricard et al., 1991) or six (Cadek and Ricard, 1992). The analysis of the stress pattern also suggests that continents should have a stronger coupling with the mantle than the oceans (Forsyth and Uyeda, 1975). From geological data such as orientation and the morphological characteristics of thrust belts (see Table 1), the existence of a westward lithospheric rotation roughly coincident with the observed global motion has also been documented (Doglioni, 1990). This motion could also be relevant in explaining the differences between the steep inclination of west-dipping slabs and shallow dip of east-dipping slabs (Uyeda and Kanamori, 1979; Cadek and Ricard, 1992; Table 1).

O'Conell et al. (1991), Ricard et al. (1991) and Cadek and Ricard (1992) confirmed the presence of westward drift of the lithosphere with respect to the asthenosphere, and proposed the lateral viscosity variations at the lithosphere base in a toroidal field degree of 1 as a mechanism for this delay.

Ricard et al. (1991) proposed that a net rotation naturally appears in the models where lateral viscosity variations are allowed. The amplitude of this toroidal field is directly related to the amount of lateral variations. A similar conclusion has been drawn by O'Connell et al. (1991). The observed rotation with a pole in the southern part of the Indian Ocean and an amplitude of 1.7 cm/year can be explained by a viscosity contrast between suboceanic and subcontinental mantle (Ricard et al., 1991).

Doglioni et al. (1991) consider the decoupling between the lithosphere and asthenosphere in conjunction with an eastward and northward directed mantle flow as a first-order phenomenon in controlling Mediterranean geodynamics. Thermal anisotropies of the mantle control the amount of decoupling between the lithosphere and the asthenosphere, but lateral anisotropies between continental and oceanic lithospheres are also considered as primary factors generating variations in plate velocity (Doglioni et al., 1991).

The main decollement level should coincide with the low velocity zone (LVZ) at the top of the asthenosphere where partial melting operates (Knopoff, 1983), and could be a useful layer of weakness for decollements.

Convection in the mantle (Spohn and Schubert, 1982; Cserepes and Rabinowicz, 1986; Sabadini and Yuen, 1989; Doglioni, 1990) would help the model to produce lateral mantle heterogenieties, in which different degrees of development of LVZ and the relative lithosphere–asthenosphere decoupling are consequently generated (Doglioni, 1990).

The global plate motions seem to follow well defined flow lines that control the tectonic pattern at the Earth's surface (Fig. 2 of Doglioni et al., 1991). The trend of the flow lines is considered to be produced by the mantle–lithosphere relative motions (Doglioni, 1990). According to him plate tectonics should be the product of the variations in decoupling at the base of lithosphere, resulting in different relative velocities of the plates, and therefore responsible for tectonism at plate margins.

4. Effects of the relative lithosphere–asthenosphere motion

The relative lithosphere–asthenosphere motion, regardless of its origin (Table 2), affects the west-facing subduction zones differently from the ones that are east-facing (Table 1). Because of an increase in the angular velocity of the relative rotation of the asthenosphere with respect to the lithosphere, from the geographic poles toward the equator, the effect of relative rotation is also increased. This is also reflected in plots of latitudinal variation of geometrical and kinematic characteristics of the east-facing island arcs of the western Pacific (Fig. 3A–C; Shahabpour, 1997, 1998). As the pole of rotation of the Pacific plate is at 50°N, 85°W, the near symmetrical shape of the curves in Fig. 3A–C, with respect to approximately 10°N geographic latitude, cannot be attributed solely to the plate rotation around the Euler pole; the relative lithosphere–asthenosphere motion also affects the shape of these curves. Therefore, any attempt to investigate the relationships among the tectonic components of the arc-trench systems must consider the relative lithosphere–asthenosphere motion.

5. Relationships among the tectonic components of the subduction zones

Luyendyk (1970) found an inverse relationship between slab dip and convergence rate for Tonga, Kermadec, Java, and Kamachatka-Kuriles. Except for Java, the rest of the island arc systems used in Luyendyk studies are among the east-facing island arcs of the western Pacific. However, Tovish and Schubert (1977, 1978), based on a larger data set, from island arcs and continental margin arcs of various orientations, have rejected this inverse relationship. As the relative eastward rotation of the asthenosphere affects the west-facing subduction zones differently from those of east-facing (Table 1), therefore the interpretations which are based on mixed data from subduction zones of various orientations lead to misinterpretations. However, the inverse relationship pointed out by Shahabpour (1997, 1998) is based on the data from the east-facing island arcs of the western Pacific and answers this paradox.

Shahabpour (1997, 1998) found the following relationships among the tectonic components of the east-facing island arcs of the western Pacific:

radius of curvature (RC) vs slab dip (SD), positively related;
SD vs convergence rate (VC), negatively related;
strike (ST; with respect to Izu-Bonin) vs radius of curvature, positively related;

Table 2
Comparison of the hypocycloid gearing model and mantle anisotropy model

	Hypocycloid gearing[a]	Mantle anisotropy[b]
The cause of relative westward rotation of the lithosphere with respect to the asthenosphere	Westward-directed off-centered rotation of the spinning Earth around the gravitational center of the Earth–Moon system	Lateral viscosity variations at the lithosphere base in a toroidal field of degree 1
Decollement between the Earth's lithospheric plates and the asthenosphere	Equally active beneath the oceanic and continental lithospheric plates	Enhanced decouplage beneath the oceanic lithosphere, and less effective beneath the continental lithospheric plate
The importance of tidal forces in the lithospheric rotation	Very important	Not important

[a] Trurnit (1984).
[b] Doglioni (1993).

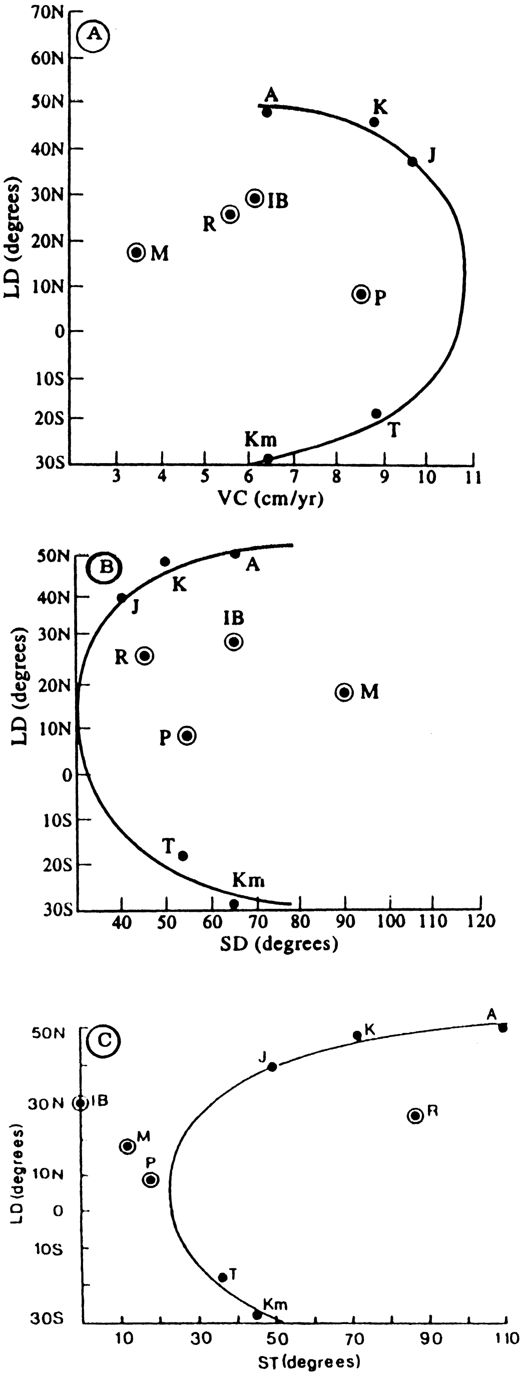


Fig. 3. Latitudinal variation of the VC (Fig. 3A), SD (Fig. 3B), and ST of the subduction zones (with respect to strike direction of Izu-Bonin) (Fig. 3C) of the east-facing island arcs of the western Pacific (from Shahabpour, 1997, 1998). Dots are simple (non-circum Philippine plate) island arcs, and dots and circles are complex (circum Philippine plate) island arcs. Abbreviations: A, Central Aleutian; IB, Izu-Bonin; J, NE Japan; K, Kuriles; Km, Kermadecs; M, Marianas; P, Philippines; R, Ryukyu; T, Tonga; LD, Geographic latitude. SD = slab dip, ST = strike, VC = convergence rate.

ST vs SD, positively related;
ST vs VC, negatively related.

On a binary plot of geographic latitude (LD) vs SD, the east-facing island arcs of the western Pacific are divided into two groups (Fig. 3B):

(a) simple (non-circum Philippine plate) island arcs which are formed in a relatively simple tectonic condition (e.g., Aleutian, Kuriles, NE Japan, Tonga, Kermadecs), and
(b) complex (circum Philippine plate) island arcs which are formed in the relatively complex circum Philippine plate tectonic environment (e.g., Izu-Bonin, Mariana, Ryukyu, Philippine).

These two groups of island arcs are also recognized on the ternary plot of SD vs VC vs distance from the pole of rotation of the Pacific plate (DP; 50°N, 85°W) (Fig. 4A). This division is further confirmed on the following ternary plots:

RC vs ST vs VC (Fig. 4B)
DP vs ST vs VC (Fig. 4C)
DP vs ST vs RC (Fig. 4D)
RC vs ST vs SD (Fig. 4E)
VC vs ST vs SD (Fig. 4F)
SD vs ST vs DP (Fig. 4G)

On a binary plot of RC vs ST of the east-facing island arcs of the western Pacific, Shahabpour (1998) identified two groups of island arcs: (a) proximal intra-oceanic island arcs which are located at a relatively shorter distance from the Eurasian continental margin (Aleutian, Kuriles, Japan, Ryukyu, Philippines), and (b) distal intra-oceanic island arcs which are located at a relatively longer distance from the Eurasian continental margin (e.g., Izu-Bonin, Tonga, Kermadec, Mariana). This division is further confirmed on the following ternary plots:

VC vs SD vs RC (Fig. 5A)
VC vs DP vs RC (Fig. 5B)
RC vs ST vs VC (Fig. 5C)
DP vs ST vs RC (Fig. 5D)
DP vs ST vs VC (Fig. 5E)
SD vs ST vs DP (Fig. 5F)
VC vs ST vs SD (Fig. 5G)
RC vs ST vs SD (Fig. 5H)

On most of these plots Philippine trench falls in a transitional position between proximal and distal settings (e.g., Fig. 5C–H).

6. Summary and conclusions

1. The relative eastward rotation of the asthenosphere with respect to the lithosphere is due to tidal forces (hypocycloid model) and lateral viscosity variations at the base of the lithosphere.

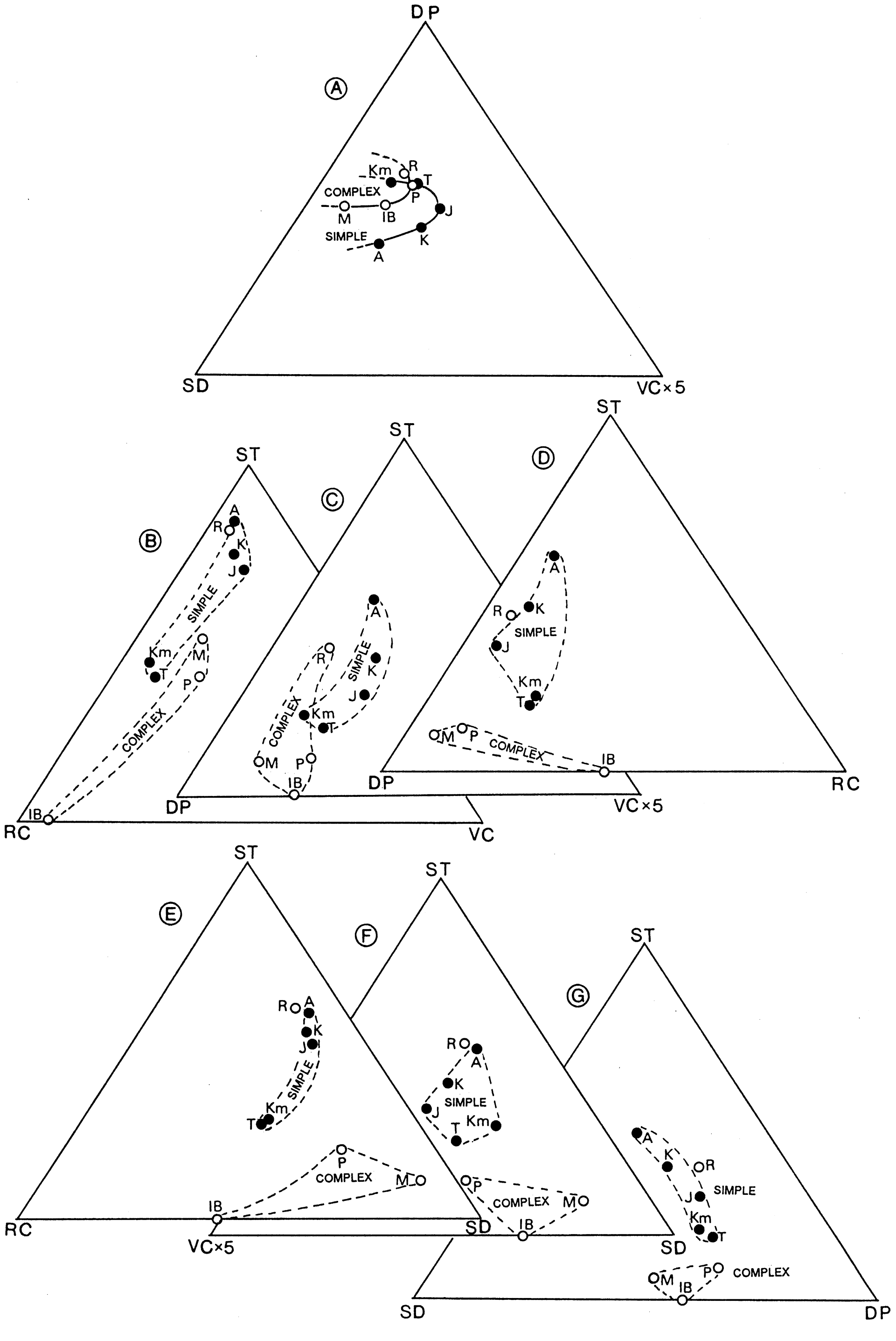


Fig. 4. Separation of the east-facing island arcs of the western Pacific into simple (dots) and complex (circles), on the ternary plots of their tectonic components (data from Shahabpour, 1997, 1998). Abbreviations: DP, distance from the pole of rotation; SD, slab dip; RC, radius of curvature; ST, strike (with respect to the strike direction of Izu-Bonin); VC, convergence rate. Other abbreviations as in Fig. 3.

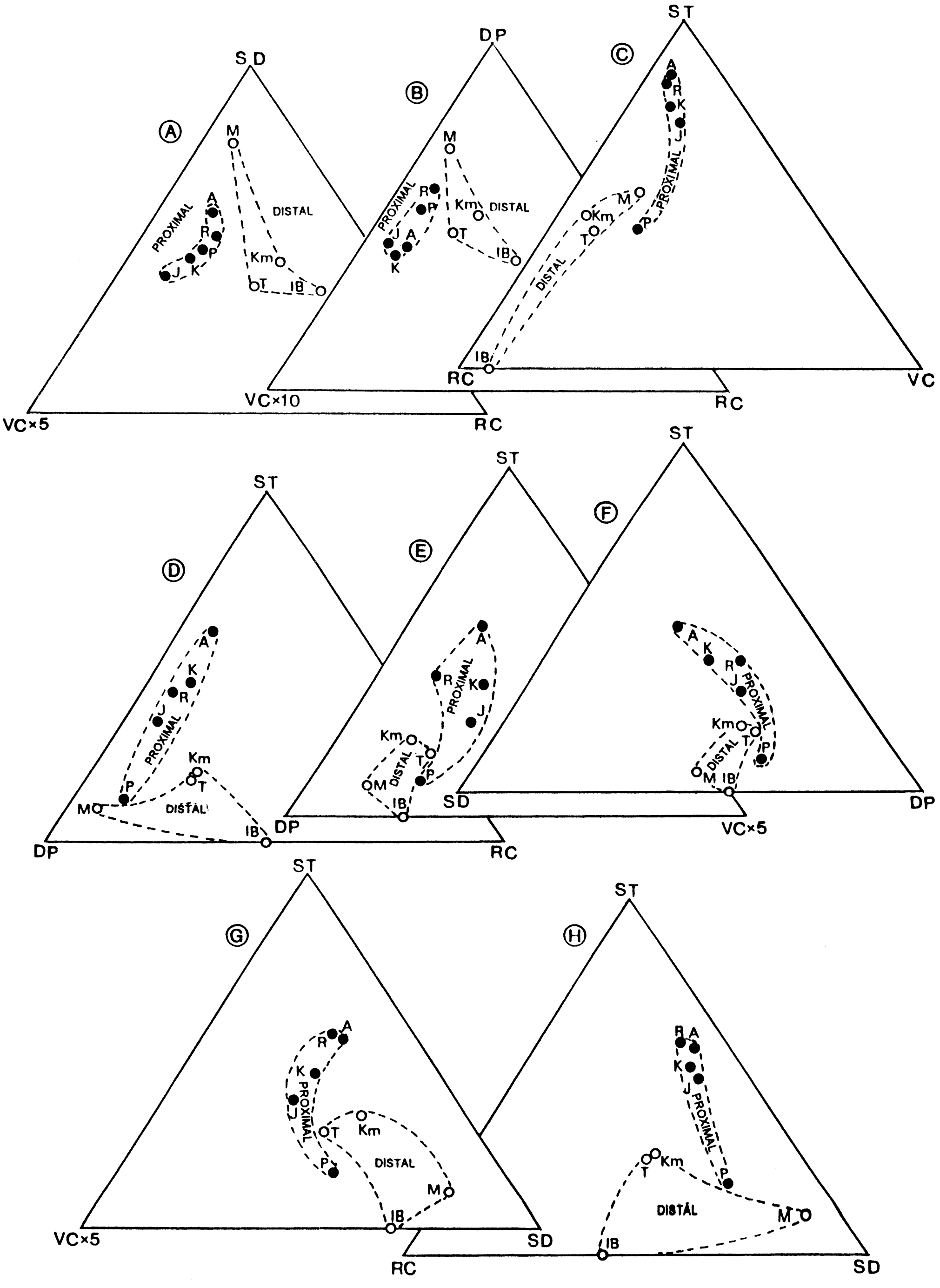


Fig. 5. Separation of the east-facing island arcs of the western Pacific into proximal (dots), and distal (circles), on the ternary plots of their tectonic components (data from Shahabpour, 1997, 1998). Abbreviations as in Figs. 3 and 4.

2. Because of an increase in angular velocity of the relative eastward rotation of the asthenosphere with respect to the lithosphere, from the geographic poles towards the equator, the effect of this relative rotation is also increased. This latitudinal variation is also reflected in the latitudinal variation of the geometrical and kinematic characteristics of the island arcs.
3. From point 2, it is concluded that any attempt to investigate the relationships among tectonic components of subduction zones, must consider relative lithosphere–asthenosphere motion.
4. Consideration of the diverse effects of this relative lithosphere–asthenosphere motion on the west and east-facing subductions, on ternary plots, allows classification of the east-facing island-arcs, into simple vs complex, and proximal vs distal.

References

Bostrom, R.C., 1971. Westward displacement of the lithosphere. Nature 234, 536–538.

Cadek, O., Ricard, Y., 1992. Toroidal/poloidal energy partitioning and global lithospheric rotation during Cenozoic time. Earth Planet. Sci. Lett. 109, 621–632.

Cserepes, L., Rabinowicz, M., 1986. Gravity and convection in a two-layer mantle. Earth Planet. Sci. Lett. 76, 193–207.

Dickinson, W.R., 1978. Plate tectonic evolution of the north Pacific rim. In: Uyeda, S., Morphy, P.W., Kobayashi, K. (Eds.), Geodynamics of Western Pacific. Advances in Earth and Planetary Sciences, vol. 26. Center for Academic Publishers, Tokyo, pp. 1–19.

Doglioni, C., 1990. The global tectonic pattern. J. Geodynamics 12, 21–38.

Doglioni, C., 1991. A proposal of kinematic modelling for west-dipping subductions — possible applications to the Tyrrhenian–Apennines system. Terra Nova 3, 423–434.

Doglioni, C., 1993. Some remarks on the origin of foredeeps. Tectonophysics 228, 1–20.

Doglioni, C., Moretti, I., Roure, F., 1991. Basal lithospheric detachment, east-ward mantle flow and Mediterranean geodynamics: a discussion. J. Geodynamics 13, 47–65.

Forsyth, D., Uyeda, S., 1975. On the relative importance of driving forces of plate motion. Geophys. J. R. Astron. Soc. 43, 163–200.

Knopoff, L., 1983. The thickness of the lithosphere from the dispersion of surface waves. Geophys. J. R. Astron. Soc. 74, 55.

Le Pichôn, X., 1968. Sea-floor spreading and continental drift. J. Geophys. Res. 73, 3661–3697.

Luyendyk, B., 1970. Dips of down going plate beneath island arcs. Geol. Soc. Amer. Bull. 81, 3411–3416.

Mitchell, A.H.G., Garson, M.S., 1981. In: Mineral deposits and global tectonic settings. Academic Press, London/New York/Toronto/Sydney/San Francisco 405 pp.

Nelson, T.H., Temple, P.G., 1972. Mainstream mantle convection: a geologic analysis of plate motion. Am. Assoc. Pet. Geol. Bull. 56, 226–246.

O'Connell, R., Gable, C.G., Hager, B., 1991. Toroidal–poloidal partitioning of lithospheric plate motions. In: Sabadini, R., Lambeck, K., Boschi, E. (Eds.), Glacial Isostasy, Sea-Level and Mantle Rheology, vol. 334. Kluwer Academic Publishers, Dordrecht, pp. 535–551.

Ricard, Y., Doglioni, C., Sabadini, R., 1991. Differential rotation between lithosphere and mantle: a consequence of lateral mantle viscosity variations. J. Geophys. Res. 96, 8407–8415.

Sabadini, R., Spada, G., 1988. Ground motion and stress accumulation driven by density anomalies in a viscoelastic lithosphere. Some results for the Apennines. Geophys. J. 95, 463–480.

Sabadini, R., Yuen, D.A., 1989. Mantle stratification and long-term polar wander. Nature 339, 373–375.

Shahabpour, J., 1997. Relationships among the tectonic components of the island arcs and their plate tectonic implications. J. Geodynamics 23, 79–93.

Shahabpour, J., 1998. Corrigenda: relationships among the tectonic components of the island arcs and their plate tectonic implications. J. Geodynamics 25, 337–340.

Spohn, T., Schubert, G., 1982. Modes of mantle convection and the removal of heat from the Earth's interior. J. Geophys. Res. 87, 4682–4696.

Tovish, A., Schubert, G., 1977. Correlation between angle of subduction, arc curvature, and convergence velocity. Am. Geophys. Union Trans. 58, 1232.

Tovish, A., Schubert, G., 1978. Island arc curvature, velocity of convergence, and angle of subduction. Geophys. Res. Lett. 5, 329–332.

Trurnit, T.P., 1984. Mineral deposits in relation to the global tectonic megacycle. In: Wauschkuhn, A., Kluth, C., Zimmermann, R.A. (Eds.), Syngenesis and Epigenesis in the Formation of Mineral Deposits. Springer, Berlin, pp. 62–91.

Trurnit, T.P., 1989. Sequence of mineral deposits related to the theory of eastward migrating global tectonic megacycles. Global Tectonics and Metallogeny 3, 125–158.

Trurnit, T.P., 1991a. Is the recent plate tectonic setting of the Arabian plate (Greenland of Africa) comparable with the Early Tertiary evolutionary state of the Greenland plate (Africa of South America)? Mineralia Slovaca, 23:479–514, Newsletter No. 3, Project IGCP, No. 276.

Trurnit, T.P., 1991b. Space-time analysis of structural pattern of continents. Geojournal 25, 305–358.

Trurnit, T.P., 1993. Critical reappraisal of Late Mesozoic–Cenozoic Central and North Atlantic, Caribbean and Mediterranean evolution. Ciencias da Terra (UNL) 12, 23–34.

Trurnit, T.P., 1994. La cordillera de los Andes dentro de la secuencia de tipos de cadenas de montañas continentales. In: 8th Peruvian Geological Congress, 255–267 (extended abstract).

Trurnit, T.P., 1996. The sequence of plate tectonic settings through which Variscan belt mineral deposits have passed and been altered, since the Middle Devonian. In: Guecula, P. (Ed.), Variscan metallogeny in the Alpine orogenic belt, pp. 1–92.

Uyeda, A., 1981. Subduction zones and back-arc basins: a review. Geol. Rundsch. 70, 552–569.

Uyeda, S., Kanamori, H., 1979. Back arc spreading and the mode of subduction. J. Geophys. Res. 84, 1049–1061.