Vol. 42 No. 1 *Journal of the Communications Research Laboratory* *March 1995*
Printed in Tokyo, Japan *pp. 65 – 72*

III. GEODETIC RESULTS OF THE EXPERIMENTS

III.3 MOVEMENT OF THE SHANGHAI STATION: IMPLICATION FOR THE TECTONICS OF EASTERN ASIA

By
Kosuke HEKI[1], Yasuhiro KOYAMA, Noriyuki KAWAGUCHI[2], Jun AMAGAI,
Hiroshi KUROIWA[3], Shin'ichi HAMA[4], QIAN Zhi-Han[5], YE Shu-Hua[5], WU Lin-Da[5],
HUA De-Min[5], XU Sui-Di[5], Michito IMAE, Noriyuki KURIHARA, Yuji SUGIMOTO,
Taizoh YOSHINO, Fujinobu TAKAHASHI, Hitoshi KIUCHI, Yukio TAKAHASHI,
Hiroshi TAKABA, Takahiro IWATA, Yuko HANADO, Mamoru SEKIDO, Tetsuro KONDO,
and Akihiro KANEKO

(Received on November 21, 1994)

ABSTRACT

Very Long Baseline Interferometry (VLBI) data between the Shanghai station, China and other stations in the world suggest that Shanghai is moving east-southeastward by ~1 cm/year with respect to the stable interior of the Eurasian plate. This agrees with a kinematic model of crustal blocks in Central and Eastern Asia inferred from geologic and neotectonic observations(1) and the results of geophysical numerical studies of the continental collision(2). The present result gives the first space geodetic evidence supporting the hypothesis that the northward movement of the Indian subcontinent after its collision with Eurasia is partly accommodated by eastward displacements of crustal blocks in Central and Eastern Asia(3).

Keywords: VLBI, Shanghai, plate tectonics, extrusion

1. Introduction

Ocean magnetic anomaly data suggest that the Indian subcontinent has moved northward by as much as 1500 km since it started to collide with Eurasia ~40 million years ago(3). India has experienced little deformation after the collision suggesting that a certain amount of 'room' was somehow created, e.g. by north-south contraction of the Eurasian lithosphere, to enable such a movement. Molnar and Tapponnier(3) pointed out the possibility that large crustal blocks north of the collision zone have been extruded eastward one after another and interpreted large scale strike-slip faults in the Tibetan plateau as boundaries separating such crustal blocks.

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[1] now at Earth Rotation Division, National Astronomical Observatory
[2] Nobeyama Radio Observatory, National Astronomical Observatory
[3] National Space Development Agency of Japan
[4] Ministry of Posts and Telecommunications
[5] Shanghai Observatory, Chinese Academy of Sciences

Tibet, in turn, is pushing a crustal block covering the southern part of China (South China block) eastward(4), a block sometimes depicted as the independent "China plate(5)." Several recent studies(1)(2) quantitatively estimated its speed to be as fast as 1–2 cm/year, which is well detectable with a few years of space geodetic observations. The Shanghai VLBI station, located on the eastern part of the South China block, started to participate in international geodetic VLBI observations in 1988. Its directly measured instantaneous velocity will place an important constraint in modelling the tectonics of Eastern Asia.

2. Movement of Shanghai by VLBI

2.1 VLBI Experiments in China

The first geodetic VLBI experiment in China was performed in 1985 between the 26 m radio telescope at Kashima Space Research Center, Communications Research Laboratory (CRL), Japan and the 6 m antenna at the Shanghai Observatory(6). This and a few test experiments that followed were, however, single-frequency experiments without ionospheric delay calibration data and are hence unsuitable for tectonic studies.

A new 25 m VLBI antenna at Seshan ~24 km from Shanghai and a Mark III dual frequency VLBI data acquisition terminal became operational, and in 1988 April the new Shanghai station started its activity as one of the important VLBI stations in the Crustal Dynamics Project (CDP) and Dynamics of the Solid Earth (DOSE) experiments. Shanghai has also been regularly participating in the Western Pacific VLBI Network (WPVN)(7)(8) of CRL. Here we discuss its movement in terms of (1) the baseline length change between Shanghai and Kashima measured in 1988–1994, and (2) the velocity of Shanghai in the terrestrial reference frame established by the world-wide compiled VLBI data before 1992.

2.2 Kashima–Shanghai Baseline Length Changes 1988–1994

Lengths of the Shanghai–Kashima baseline measured 1988–1994 are plotted in Fig. 1. The squares are data obtained by the WPVN whose details are available in Koyama et al.(7) and Amagai et al.(8). The circles denote CDP/DOSE data taken from Ma et al.(9) (the last two data in 1994 from the personal communication with R. Potash in 1994). The baseline data with the 26 m and the 34 m antenna at Kashima are unified to the latter by correcting for the short baseline vector between these two telescopes, which has been accurately determined by ground survey and short baseline interferometry(10).

The shortening of the baseline of ~3 cm/year (–29.7 ± 1.0 mm/year) comes partly from the displacement of Kashima. By analyzing the VLBI data 1984–1988, Heki et al.(11) estimated the horizontal movement of Kashima with respect to the Eurasian plate to be 2.6 cm/year toward N78W. They also suggested that the compressional stress field applied by the subducting Pacific plate is responsible for the east-west contraction of Japan and thereby the westward displacement of Kashima (the quantitative estimate of the contraction depends on the plate assumed for Northeast Japan; intraplate contraction of Northeast Japan becomes smaller by ~1 cm/year when the North American plate is assumed). Heki and Yoshino(12), using this displacement vector, predicted that the Kashima–Shanghai baseline may shorten by ~2 cm/year. The shortening rate in Fig. 1 is, however, significantly faster and suggests that Shanghai is not fixed on the Eurasian plate but is moving resulting in the additional shortening of ~1 cm/year.

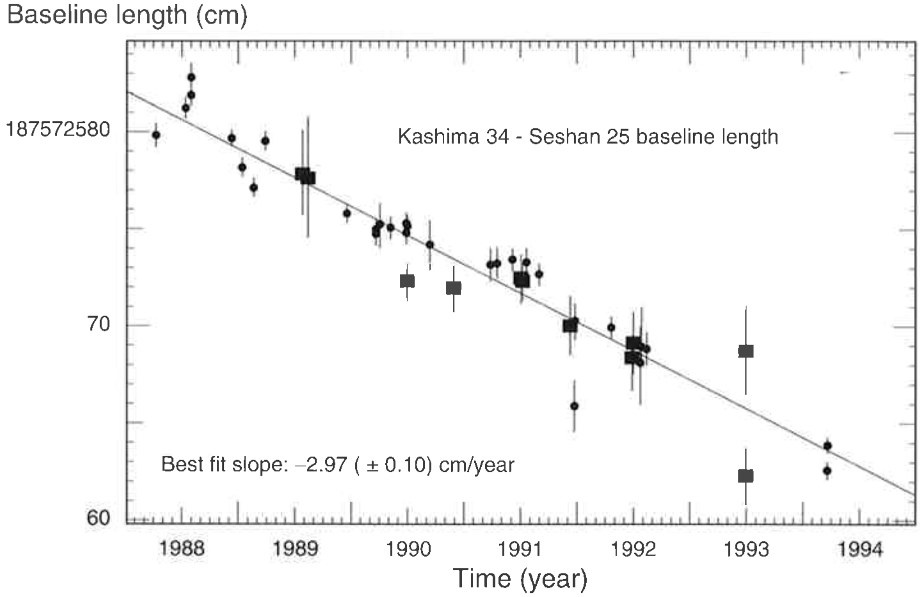

Fig. 1 The time series of the length of Kashima–Shanghai baseline. Out of 43 data, 21 are obtained with the 34 m and 22 with the 26 m radio telescopes at the Kashima station. These data are unified to those of the 34 m antenna by assuming the ~300 m baseline vector between them known, and not discriminated in this figure. 12 data were derived by the Western Pacific VLBI Network experiments (squares) and others were derived by CDP/DOSE experiments (circles). The changing rate of the baseline length estimated by weighted least-squares method is –29.7 mm/year with 1 σ formal error of 1.0 mm/year. The weighted average of the post-fit residuals is 10.7 mm.

2.3 Velocity of Shanghai up to 1992 in a Global Terrestrial Reference Frame

The Goddard Space Flight Center annually issues the results of the combined solution of the available world-wide VLBI data. The GLB907 solution(9) gives the latest terrestrial reference frame type solution, a set of site coordinates and velocities that best explains the delays observed 1979–1992. It gives a direct estimate of the velocity of Shanghai in a three dimensional space.

They achieved the minimum constraints to remove singularities in estimating site velocities by fixing the following six velocity components. Horizontal velocity of Westford (Massachusetts) and the azimuthal change of the Richmond(Florida)–Westford baseline were fixed to the no-net-rotation(nnr)-NUVEL1 plate motion model(13) predictions. The vertical movements of Westford, Richmond and Kauai (Hawaii) were fixed to zero. However, these constraints are not confirmed by other geodetic techniques, that is, a small unexpected movement of one of these stations may spuriously rotate or translate the whole kinematic reference frame. In fact, regional post-glacial isostatic rebound due to the melting of the Laurentide ice sheet is suggested to cause displacements of up to a few mm/year in the wide area of North America(14).

In this study, we perform a minor re-adjustment of the site velocities (kinematic reference frame) in the GLB907 solution following the procedure of Heki(15); (1) selection of as many "reference" stations as possible from stable plate interiors, (2) estimation of a translation and rotation that should be added to the whole network in order to minimize their differences from the nnr-NUVEL1

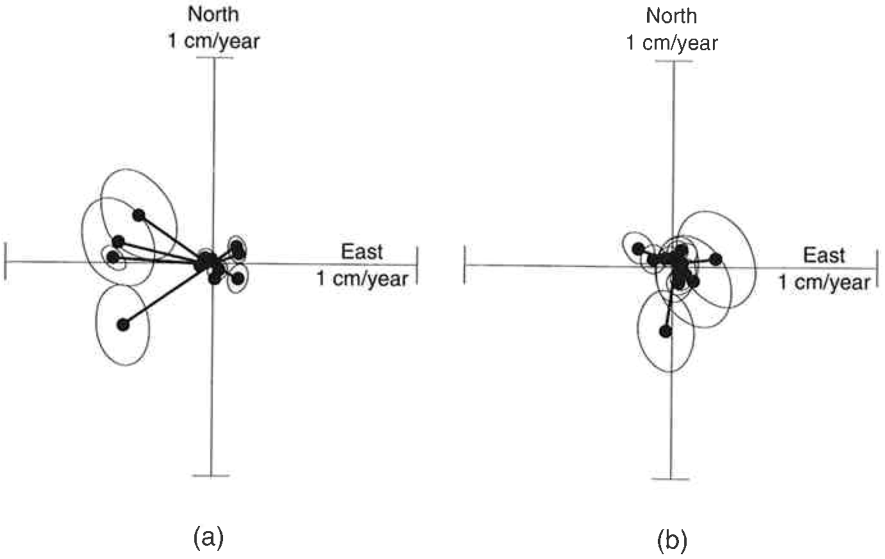

Fig. 2 Horizontal components of the residual velocities (differences between the VLBI and nnr-NUVEL1 velocities) of 14 reference stations in stable plate interiors before (a) and after (b) the re-adjustment of the kinematic reference frame. The basic VLBI data (site coordinates and velocities) are from Ma et al.(9)

predictions. Displacements of other non-reference stations (e.g. Kashima and Shanghai), with respect to the plates they are supposed to reside, are estimated together with the translation/rotation. Here we describe only a few differences from the "global frame" in Heki(15) instead of repeating the whole procedure in detail.

First we used the GLB907 solution while the GLB867 solution in the previous annual report was used in Heki(15). Secondly, we did not use Hartbeesthoek, South Africa as a reference because it was found to lie on the boundary between the original African plate and the Somalia plate(16). Thirdly, we minimized only the differences in the horizontal velocities while Heki(15) fitted both horizontal and vertical components (assumed zero for the vertical movement predictions). Lastly, because the full covariance matrix of the site velocities has not been available, only the within-site inter-component correlations have been used. An isotropic error, added to all the velocity vectors to make the reduced chi-square unity, was 0.52 mm/year, which is much smaller than 2.1 mm/year in Heki(15). This is considered to be the combined effect of (1) the exclusion of Hartbeesthoek from the reference points, (2) improvement of the accuracies of the velocities of two Australian stations and (3) usage of only the horizontal velocities in determining the translation/rotation. In Fig. 2 we compare the residual horizontal velocity vectors before and after the application of the translation/rotation. The improvement of the weighted root-mean-squares (WRMS) was large in the east-west velocities; it decreased from 1.5 mm/year to 0.6 mm/year. The WRMS in the north-south component remained similar (0.6 mm/year).

This small residuals suggest that the nnr-NUVEL1 plate model (i.e. plate motion in the last few millions of years) and the VLBI measurements (i.e. plate motion in the last decade) are consistent at the level of < 1 mm/year in the plate interiors. This validates our interpretation of the movements of the "free" stations(15) estimated here, as their displacement with respect to the interior of the plates to which these stations were assumed to belong. The estimated horizontal displacements of the

Table 1 Displacements of the Shanghai, Kashima and Tsukuba VLBI stations with respect to the stable interior of the Rurasian plate

Station	Longitude	Latitude	North	East	Up
Kashima[1)]	140.67	35.95	2.8 ± 1.3	−20.8 ± 1.0	−5.1 ± 1.3
Tsukuba[1)]	140.08	36.10	2.7 ± 1.7	−20.8 ± 1.4	−5.2 ± 4.4
Shanghai[1)]	121.43	31.02	−4.5 ± 1.7	10.0 ± 1.3	−6.2 ± 3.3
Shimosato (SLR)[2)]	135.93	33.57	13.5 ± 2.1	−24.6 ± 2.1	1.3 ± 2.1

Units are mm/year and errors are 1 σ.

1) Obtained by the readjustment(15) of the GLB907 velocities(9).

2) Taken from the ITRF92(18).

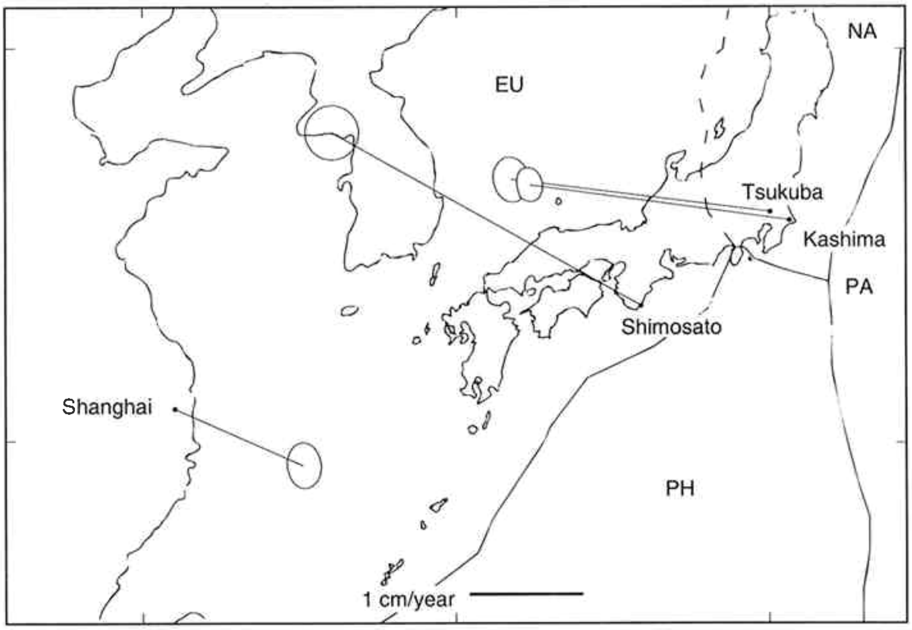

Fig. 3 The horizontal displacement vectors of the Shanghai, Kashima and Tsukuba VLBI stations with respect to the stable part of the Eurasian plate obtained in this study. Horizontal displacement of the Simosato SLR station with respect to the Eurasian plate in ITRF92(18) is also shown. Error ellipses are 1 σ. Components of these vectors are summarized in Table 1. PA, PH, NA and EU denote the Pacific, Philippine Sea, North American and Eurasian plates respectively. The boundary between the North American and Eurasian plate in this region is still in dispute.

Shanghai as well as Kashima and Tsukuba, with respect to the Eurasian plate, are plotted in Fig. 3 and listed in Table 1. Shanghai's movement is ~1 cm/year toward east-southeast (11.0 mm/year, N114E). As demonstrated before by Heki(15), such velocities are considered to be fairly stable against the selection of reference stations and plate motion models (e.g. NUVEL1a(17)). Shanghai also shows a fairly large subsidence (~6 mm/year) but we do not discuss this because (1) this is less than 2 σ, i.e.

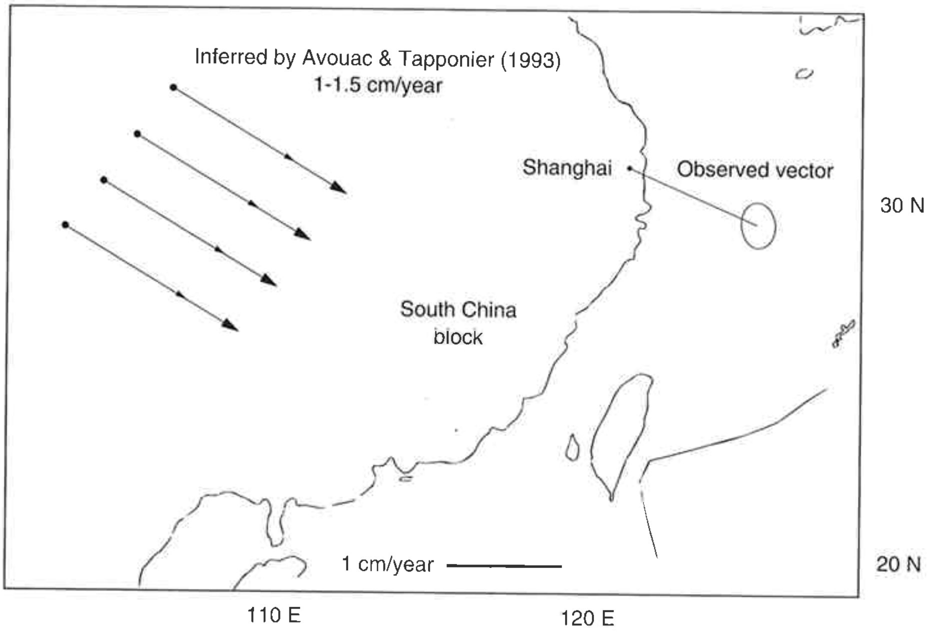

Fig. 4 The movement of Shanghai agrees well with the 'Inferred Vector,' the movement of the South China block inferred by Avouac and Tapponnier⁽¹⁾. It is also consistent with the numerical experiments based on a thin viscous sheet model of the lithosphere⁽²⁾.

not significantly different from zero and (2) we do not have a tide gauge record near Shanghai to be compared with this.

3. Discussion and Conclusion

In spite of the controversy on the partition of the strain produced by the Indian-Asian collision between crustal thickening and eastward displacement(1)(2), there seems to be a rough agreement on the current extrusion rate of the southern China. Avouac and Tapponnier(1) estimated the velocity field of present-day deformation in Central Asia as rotations of four blocks (Siberia, Tarim, Tibet, India) on a spherical earth using geologically estimated shortening-rates across the main thrust zones and measured slip-rates along the principal strike-slip faults separating the blocks. Tibet's present-day rate of motion at its center is predicted to be ~40 mm/year northeastwards by this model. They inferred that this motion causes southeastward displacement of the eastern edge of Tibet at ~20 mm/year by a transfer mechanism involving escape and clockwise rotation of curved blocks separated by left-lateral strike-slip faults. They further suggested that this movement is attenuated to 10–15 mm/year at the western edge of the South China block across a minor thrust fault system separating Tibet from the South China block. Figure 4 shows that the observed velocity of Shanghai agrees well with this inferred velocity of the South China block.

Numerical experiments(2) based on a thin viscous sheet model of the lithosphere show that during collision the eastern boundary is smoothly displaced at a rate about a quarter of the indentation rate (i.e. the rate of the northward movement of India) with only minor variation due to geometry or rheology. The current velocity of India is ~5 cm/year and its quarter roughly agrees with the Shanghai's velocity detected by VLBI. Our study thus also gives a direct support for their numerical scheme.

Our knowledge about the present-day motion of the plates is based mainly on marine geophysical observations and so a plate motion model does not tell us much about the motions deep within the continent e.g. in Central Asia. Therefore the role of space geodetic observations is more important in such a region than in elsewhere on the Earth. A new VLBI station at Urumqi(19) in Western China, along with complementary regional GPS networks, will enable us to draw a more detailed picture of the current crustal movements in Central and Eastern Asia.

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