Preliminary GPS results and a possible neotectonic interpretation for South Korea

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Crustal velocities within South Korea were estimated using GPS data and interpreted in terms of neotectonics. Twenty months of data for the seven GPS stations in South Korea were analyzed to estimate velocities relative to Taejon (DAEJ), a central region of South Korea. From the time series of horizontal position of each station, we estimated site velocities with an accuracy of 0.5 mm/year or better mostly. The relative velocities within the Korean peninsula are very small (~1 mm/year), convertible to strain rates in the order of 0.01 ppm/yr. They indicate the Korean peninsula is likely to be tectonically more stationary than other countries in the East Asia, for example, Japan or Taiwan. The result of GPS analysis suggests a possibility that northwestern tectonic force due to the AM (Amurian plate)-PH (Philippine Sea plate) convergence affects the southeastern part of the Korean peninsula, of which the direction is curved due to internal faults in Korea, striking nearly perpendicular to the stress trend.

1. Introduction

Space geodetic techniques, such as GPS, have been a useful tool in investigating global plate motions (Argus and Heflin, 1995; Larson et al., 1997) or regional tectonic movements. A number of tectonic studies using GPS have been done for the East Asia covering Japan, China and Siberia (Kato et al., 1998b; Shen et al., 2000; Holt et al., 2000). Recently, Wei and Seno (1998) and Heki et al. (1999) proposed that the East Asia contained a micro continental plate called the Amurian plate (AM), based on geodetic investigations as well as regional tectonics and seismicity. Compared to other countries, however, the geodetic or neotectonic characteristics for the Korean peninsula have not been known well because of a lack of space geodetic facilities for the past decades. However, from 1998 to 2000, mostly during 2000, a nationwide GPS network has been constructed with about 70 permanent GPS stations (Park et al., 2000).

The Korean peninsula is located between North and South China Blocks and Japanese Island Arc as a part of Eurasian or Amurian continental plate. Geologically, the peninsula is composed of three Precambrian massifs, Nangrim, Gyeonggi and Yeongnam massifs; and two Paleozoic basins, Pyeongnam and Ogcheon sedimentary basins (Fig. 1). The three Precambrian basements are considered as a single tectonic unit until the early Paleozoic period, based on the patterns of regional structural lines and the age of regional metamorphism (250 Ma) (Chwae, 1998). The ENE-trending Haeju-Weonsan Fault (HWFT) divides the peninsula into two parts. NNE-trending Jookgaryeong Fault (Koto, 1903) is one of the first grade deep fractures in the peninsula (Chwae et al., 2000). The neotectonic events in the Korean peninsula can be characterized as reactivation of preexisting faults and intraplate earthquakes (Chwae et al., 1998). The JFT and Ogcheon Fault Belt (OFT) have been reactivated intermittently until the Cenozoic. The seismological focal depth of the Korean peninsula is relatively shallow. Earthquakes usually occur at about 15 to 20 km in depth, which indicates intraplate earthquakes are dominant in the Korean peninsula (Jun et al., 1993).

The purpose of this study is to characterize neotectonic affection for the Korean peninsula based on new GPS data from seven GPS stations of Korean GPS network.

2. GPS Data Analysis

We analyzed the data from seven GPS stations in Korea (Fig. 2). They are Taejon, Suwon, Kwangju, Jeonju, Taegu, Cheju and Kangreung. Taejon (DAEJ) and Suwon (SUWN) are currently participating in the International GPS Service (IGS) (IGS, 1999). Cheju (CHJU) station is located outside of the Korean peninsula. Data collected for twenty months from October 1998 to June 2000, with a roughly five-day interval, were analyzed using Bernese software V4.2. (Beutler et al., 2000). The data from June 1999 to September 1999 were excluded in this analysis because they were not available in most sites.

The double differences of carrier phase data above 15 degrees mask angle have been processed. The quasi-ionosphere-free (QIF) strategy was used for L1/L2 ambiguity resolution. We estimated the baselines with L3 ionosphere-free linear combination. IGS final precise ephemeris was employed as an input value of the GPS satellite orbit. Data of seven sites were simultaneously analyzed to estimate baselines, and coordinates have been estimated in the IERS Terrestrial Reference Frame (ITRF) 96 relative to our reference site DAEJ. Because we are only interested in move-
3. GPS Results and Neotectonic Interpretation

Examples of time series of horizontal coordinates relative to DAEJ in ITRF96, i.e. 29.8 mm/yr eastward, 15.4 mm/yr southward and 0.1 mm/yr downward, we assumed the ITRF96 velocity at DAEJ and estimated velocities relative to it. Although fixing only one site would introduce apparent rigid network rotation, there are some indications that the velocity difference may be small (see the comparison between GPS and VLBI at Shanghai by Kato et al. (1998b) and Takahashi et al. (1999)). We neglected such effect.

The velocities of KWNJ and JUNJ show a pattern that the directions are curved to the northward and the magnitudes are reduced compared with the TEGN velocity. This can be interpreted that the movement direction of the Korean Peninsula have been gradually curved when the tectonic stress of the PH towards the WNW faces the JFT next to the OFT. (3) The force from the PH is reduced by the southwest Japan, first, and then the reduced force affects the southeastern Korean peninsula.

The velocities of CHJU show an apparently different pattern from those of other sites. The ESE-trending JFT was reactivated with a transpressional left lateral strike-slip movement. The NE-trending OFT, mainly developed during the Paleozoic to Mesozoic, was reactivated with a right lateral strike-slip movement. The velocity direction of TEGN is parallel to a small-scaled WNW neotectonic fault zone with a left lateral strike-slip sense which cross-cuts the Yangsan Fault (YFT). This suggests that the northwestward dynamic force due to the AM-PH convergence (Heki et al., 1999; Miyazaki and Heki, 2001) affects the southeastern Korean peninsula and reach to the YFT. It can be interpreted that the initial dynamic force from the PH is reduced by the southwest Japan, first, and then the reduced force affects the Korean peninsula.

Despite of the uncertainty in the velocity, we believe that the GPS velocities may give us a possibility of neotectonic implications. The GPS data were interpreted using recent geological data, about the neotectonics of the Korean peninsula (Fig. 2). Figure 2 shows the neotectonic fault map of the Korean peninsula. The southeastern part of the OFT contacted with a Mesozoic sedimentary basin shows a reactivated WNW-ESE strike-slip fault movement, which is parallel to the movement direction of the Philippine Sea plate (PH). The NE-trending OFT, mainly developed during the Paleozoic to Mesozoic, was reactivated with a right lateral strike-slip movement. The NNE-trending JFT was reactivated with a transpressional left lateral strike-slip movement.

The velocity direction of SUWN, the EW of Kwangju (KWNJ), the NS of Taegu (TEGN) and CHJU show a standard error larger than the velocity value itself. A large velocity error is unavoidable due to the short data span.

4. Conclusions

Based on our GPS analysis, we conclude that, (1) Strain rates within the Korean peninsula are in the order of 0.01 ppm/yr. They indicate the Korean peninsula may be tectonically more stationary than any other countries in the East Asia, for example, Japan or Taiwan. (2) The velocities indicate a possibility that the dynamic force from the PH is likely to affect the southeastern part of the Korean peninsula and probably reaches to the YFT. (3) The force from the PH in the WNW direction may be gradually curved due to internal faults in Korea, striking nearly perpendicular to the stress trend.

This study gives the GPS velocities for the Korean peninsula for the first time, but the current results and interpretation are based on the short span preliminary data. In order to advance our understanding of the neotectonic evolution of the Korean peninsula, in the future, further detailed studies will be required for the longer time span data secured from more stations.
Fig. 2. Neotectonic fault map related with crustal velocities (N.B. Fixed point at Taejon). JFT: Jookgaryeong Fault, OFT: Ogcheon Fault, YFT: Yangsan Fault, thick solid line: reactivated pre-Cenozoic tectonic fault, thin solid line: reactivated fault and weak earthquake zone in southern Korean peninsula. Thick arrows are GPS velocity vectors and thin arrows are two dimensional fault movement directions; Thick blank arrows schematically display the change of the tectonic stress within Korean peninsula, which are independent of vector scale shown left-bottom in the picture.

Table 1. Site velocity relative to DAEJ with a standard error.

<table>
<thead>
<tr>
<th>Station</th>
<th>Name</th>
<th>4 char.</th>
<th>Lat.</th>
<th>Lon.</th>
<th>North (mm/yr)</th>
<th>East (mm/yr)</th>
<th>Magnitude</th>
<th>Azimuth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taejon</td>
<td>DAEJ</td>
<td>36.4</td>
<td>127.4</td>
<td></td>
<td>-0.2(0.4)</td>
<td>0.3(0.4)</td>
<td>0.4</td>
<td>127</td>
</tr>
<tr>
<td>Suwon</td>
<td>SUWN</td>
<td>37.3</td>
<td>127.1</td>
<td></td>
<td>-0.1(0.3)</td>
<td>0.7(0.5)</td>
<td>0.7</td>
<td>354</td>
</tr>
<tr>
<td>Kwangju</td>
<td>KWNJ</td>
<td>35.2</td>
<td>126.9</td>
<td></td>
<td>0.7(0.3)</td>
<td>-0.3(0.2)</td>
<td>0.8</td>
<td>341</td>
</tr>
<tr>
<td>Jeonju</td>
<td>JUNJ</td>
<td>35.8</td>
<td>127.1</td>
<td></td>
<td>0.3(0.4)</td>
<td>-1.1(0.5)</td>
<td>1.1</td>
<td>286</td>
</tr>
<tr>
<td>Taegu</td>
<td>TEGN</td>
<td>35.9</td>
<td>128.8</td>
<td></td>
<td>-0.3(1.4)</td>
<td>1.2(0.4)</td>
<td>1.2</td>
<td>103</td>
</tr>
<tr>
<td>Cheju</td>
<td>CHJU</td>
<td>33.5</td>
<td>126.5</td>
<td></td>
<td>-0.9(0.5)</td>
<td>-2.0(0.5)</td>
<td>2.2</td>
<td>246</td>
</tr>
<tr>
<td>Kangreung</td>
<td>KANR</td>
<td>37.8</td>
<td>128.9</td>
<td></td>
<td>-0.9(0.5)</td>
<td>-2.0(0.5)</td>
<td>2.2</td>
<td>246</td>
</tr>
</tbody>
</table>

Velocity of a reference site DAEJ is fixed to zero. Values in the parentheses are standard errors of linear regression. Azimuth is measured clockwise from the north.
Heki, K., S. Miyazaki, H. Takahashi, M. Kasahara, F. Kimata, S. Miura, Tool (GMT), was used to plot the figures. N2-01-04-A-01 and KINS. A software package, Generic Mapping Tool (GMT), was used to plot the figures.

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