GPS Surveys to detect active faulting in the Transantarctic Mountains, Antarctica

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Summary The Transantarctic Mountains Deformation (TAMDEF) network is a GPS array deployed on bedrock throughout the Victoria Land region of Antarctica, aimed at investigating modern vertical and horizontal crustal motions. Embedded within this network are three local GPS arrays established around known or potential neotectonic faults to test for modern fault displacements. These local fault arrays were surveyed a minimum of three times between the 1996-97 and 2005-06 austral summer field seasons. Preliminary analysis of baseline length changes is consistent with active extension, suggesting there may be modern tectonic activity in the West Antarctic Rift System.

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Introduction

The Transantarctic Mountains, spanning over 3000 km and separating East and West Antarctica, represent an uplifted rift shoulder resulting from extension and rifting in the West Antarctic Rift System (Fitzgerald, 2002). There are constraints on the history and kinematics of rifting within the West Antarctic Rift System through the Cenozoic (Wilson, 1995; Salvini et al., 1997; Stock and Cande, 2002), but the extent of modern tectonic activity along the Transantarctic Mountains and in the West Antarctic Rift System remains widely debated. Winberry and Anandakrishnan (2004) argue that the distribution and limited amount of recorded seismicity suggests the rift system is no longer active. However, the Terror Rift within the West Antarctic Rift System extends between two active volcanoes, Mount Melbourne and Mount Erebus, and evidence exists for neotectonic faulting within the Transantarctic Mountain Front, the border fault zone separating the uplifted Transantarctic Mountains rift flank from the offshore rift basin. Jones (1996) provides geomorphic observations suggesting Quaternary age faulting, and faults linked between the offshore Terror Rift and onshore Transantarctic Mountain Front (Salvini and Storti, 1999) cut the seafloor, suggesting neotectonic activity (Behrendt, 1991; Salvini and Storti, 1999; Rossetti et al., 2006). Further, it is unclear whether seismic activity recorded along the David fault system outlined by Salvini et al., (1997) is due to ice failure, glacial shearing, or tectonic faulting (Bannister and Kennett, 2002; Danesi et al., 2004).

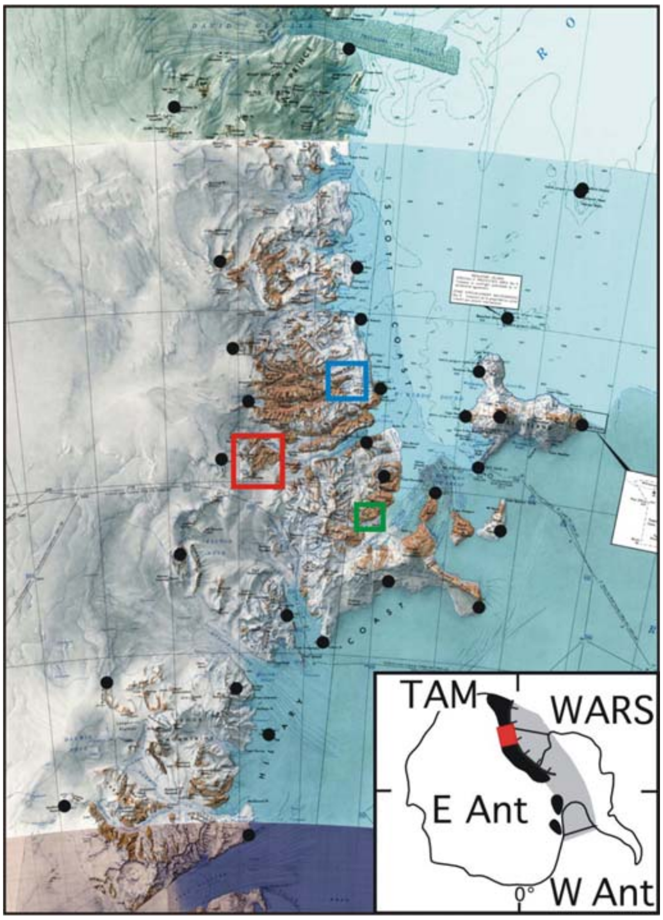

Figure 1. Location of fault arrays. Hidden Valley is shown in green, Beacon Valley is shown in red, and Doorly ridge is shown in blue. Black points represent TAMDEF GPS sites. Inset map shows the study location (in red) with respect to the Transantarctic Mountains (TAM, shown in black) and the West Antarctic Rift System (WARS, shown in gray).

Preliminary results from three local GPS surveys around known or possible neotectonic faults within the Transantarctic Mountains are presented here. Crustal motions detected by the surveys provide support for the presence of modern tectonic activity within the West Antarctic Rift System.

The TAMDEF GPS Network

The Transantarctic Mountains Deformation (TAMDEF) network is a relatively dense GPS array deployed on bedrock throughout the Victoria Land region of Antarctica (Willis et al., 2006; Willis et al., 2007). The network covers nearly a quarter million square kilometers, extending approximately 675 km N-S and 350 km E-W. It spans the uplifted Transantarctic Mountains rift-flank block, the border fault zone between the mountains and the rift, and the offshore Terror Rift. Embedded within this network are three local arrays of GPS sites established around known or possible neotectonic faults to test for modern displacements. These fault arrays are located in Hidden Valley, Beacon Valley, and on Doorly ridge (Figure 1).

Hidden Valley Fault Array

Jones (1999) identified a NE-SW trending lineament in Hidden Valley from aerial photography. The surface expression of this lineament is also clearly delineated in LIDAR data acquired during the 2001-2002 austral summer field season (Csatho et al., 2005). Trending NE-SW with an approximate length of 4km, the lineament shows left-lateral strike separation and cuts a hanging valley moraine and rock debris, indicating Quaternary age faulting (Jones, 1999). Jones (1999) suggests if the rock glacier cut by the fault is still active, the age of the fault would likely be younger than a few thousand years. Five GPS monuments covering a 3 km^2 area were installed to test for modern displacements, with two monuments located to the north of the NE-SW trending fault, and three monuments placed to the south.

Doorly Ridge Fault Array

A series of NE-SW trending faults occur on Mt. Doorly spur and have normal sense displacements of Jurassic and older crystalline rocks. Gleadow and Fitzgerald (1987) and Fitzgerald (1992) used offset sills and isochrons from apatite fission-track analysis to establish fault throws on the order of 10’s to 100’s of meters, stepping down through the Transantarctic Mountain Front to the east, and a post-55 Ma age for the faulting. Wilson (1995) documented NW-SE extension from fault kinematic studies of both major and minor faults along Doorly spur. To test for modern displacements along these faults, two GPS monuments, placed 7 km apart, spanning the zone of faulting, were installed.

Beacon Valley Fault Array

The third fault array surrounds Beacon Valley in the interior of the Transantarctic Mountain range, where two faults with normal-sense displacement of bedrock units have a clear linear expression in surficial glacial deposits. McElroy and Rose (1987) map these faults cutting through Quaternary glacial deposits, suggesting neotectonic motions. The faults trend roughly NE-SW, stepping down to the north with a combined throw of up to 400 meters of Paleozoic rock units. Six monuments, three to the north of the faults and three to the south, cover a 31 km^2 area.

Data collection and processing

Data collection began in 1997 for the Doorly ridge and Hidden Valley fault arrays and in 1998 for the Beacon Valley array. All networks were surveyed during the 2005-2006 field season. Table 1 outlines the number of 24-hour solutions available per year for each fault array.

Table 1. Number of 24-hour solutions available from each field season. During the 1998-1999 field season, Beacon Valley and Hidden Valley were each occupied twice, approximately 1 month apart.

Fault Array	**1997-1998**	**1998-1999**	**1999-2000**	**2001-2002**	**2005-2006**
Beacon Valley	0	2+2	0	6	4
Hidden Valley	1	1+1	0	0	4
Doorly Ridge	1	2	1	0	7

The NGS software PAGES was used for data processing. An ionosphere-free, double-difference, phase solution approach was used to calculate 24-hour solutions. A 15 degree elevation mask and the Neill mapping function were applied, but no ocean loading model was used. Baseline solutions were resolved for years 1997-1998, 1998-1999 and 2005-2006 for Hidden Valley, 2001-2002 and 2005-2006 for Beacon Valley, and 1998-1999 and 2005-2006 for Doorly ridge. For those years where data was most limited, solutions were not successful.

Given the small baselines between sites, an L1 only solution was also attempted. However, due in part to the limited amount of data, this strategy was unsuccessful with the PAGES processing package. Future processing with the GAMIT processing package will investigate this L1 only approach further.

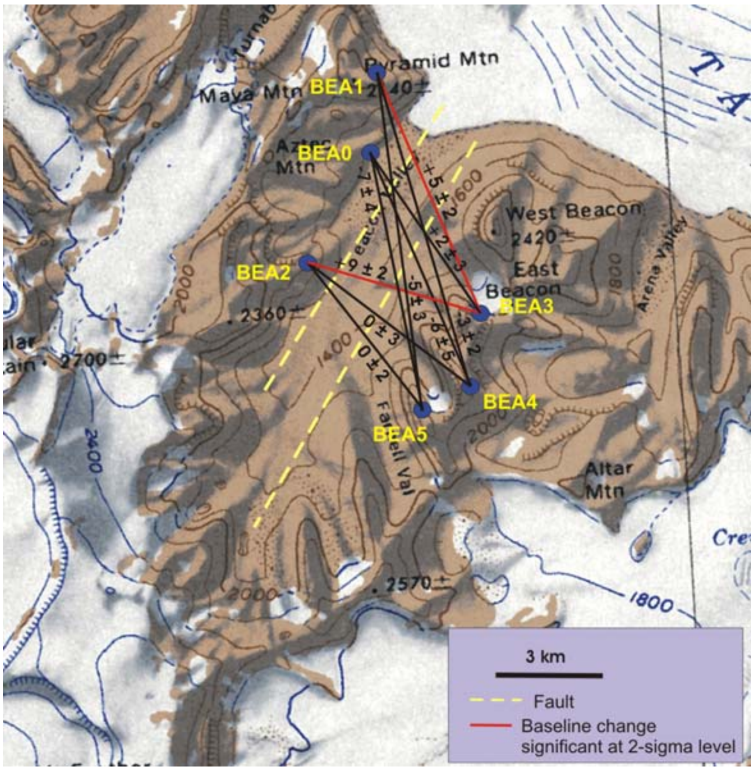

Figure 2. Baseline length changes from 2001-02 to 2005-06 for the Beacon Valley fault array. Values significant at the 2-sigma level are shown in red and indicate active extension across two normal faults.

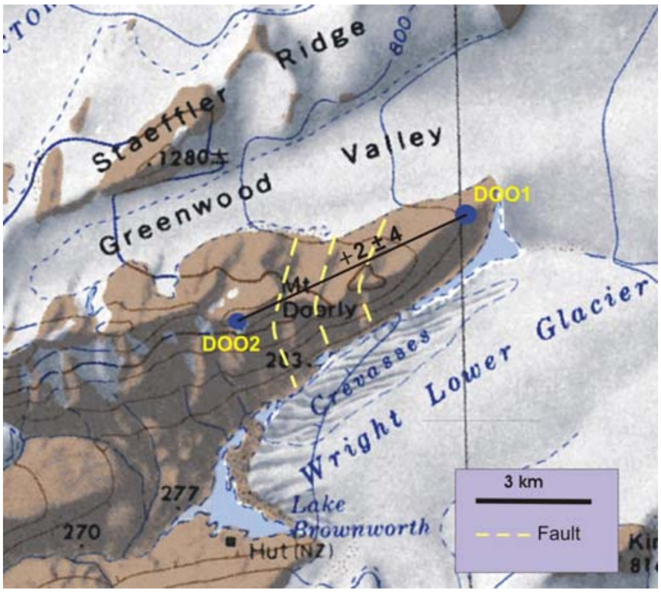

Figure 3. Baseline length change from 1998-99 to 2005-06 for the Doorly ridge fault array. Values not significant at the 2-sigma level.

Results

Baseline length changes observed at Beacon Valley from 2001-2002 to 2005-2006 were significant at the 2-sigma level, and indicate active extension (Figure 2). Baseline BEA1-BEA3 showed an increase in length of 5 mm (± 2 mm) and baseline BEA2-BEA3 showed and increase in length of 9 mm (± 2 mm). These changes in length agree with normal sense displacement across the faults, contraction with modern tectonic movements. While some baseline changes at Beacon Valley showed a decrease in length, indicating compression, these values were not significant at the 2-sigma level and are therefore disregarded.

For Doorly ridge, observed baseline length changes were also not significant at the 2-sigma level (Figure 3). At Hidden Valley, given the distribution of sites with respect to the predicted left-lateral strike-slip faulting, both increases and decreases in baseline length would be expected if displacements were modern, depending on the site pair forming the baseline (Figure 4). For example, if left-lateral motion were recorded across the faults, baseline HDV5-HDV1 would show a decrease in length, while baseline HDV4-HDV0 would show an increase in length. Contrary to this relationship, preliminary results instead suggest right-lateral displacement. However, due to a single solution for 1997-1998, and the 1 month separation between solutions for 1998-1999, the sigma level could not be determined. Therefore, these results are also disregarded. Future processing with only the L1 phase observable and solutions shorter than 24 hours may provide results that are significant within error.

Discussion

The most robust data sets forming baselines for multiple years are from the 2001-2002 and 2005-2006 field seasons for Beacon Valley. Length changes produced by this data set are significant at the 2-sigma level, and suggest modern fault motions. While the data sets for all three fault surveys are limited, the array with the most days of data yields significant results, strengthening the case that the motions observed at Beacon Valley are real. These preliminary results suggest that further data processing is merited. Analysis of the L1 only phase observable, application of an ocean loading model, and analysis of solutions more frequent than 24 hours may provide improved results. In addition to further processing, future occupations of all three networks will better constrain any modern displacements.

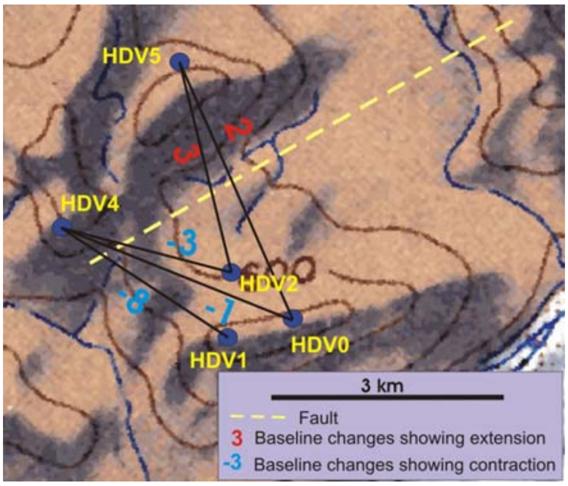

Figure 4. Baseline length change from 1997-98 to 2005-06 for the Hidden Valley fault array. Values not significant at the 2-sigma level.

Summary

Preliminary results from three local GPS surveys around known or suspected neotectonic faults within the Transantarctic Mountains are presented. Baseline lengths that show change significant above error indicate modern extension across a pair of normal faults. If confirmed by further processing, the fault motions provide new evidence of modern tectonic activity within the West Antarctic Rift System.

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