Slow-strain-steps observed with two strainmeters at the proximity of M2-3 seismicity at Mponeng mine

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We detail some slow-strain-steps (Mw less than -1) observed with two strainmeters.

We had attempted to observe the details over an M=2-3 earthquake life-span near the source fault [Iio and Fuakao,'92; Sumitomo'98; Ogasawara et al.'02]. In a preceding study at the Bambanani mine (BAM) site, with a single Ishii strainmeter, we continuously monitored strain changes with a resolution of 25Hz24bit over a 3-year period. For more than 2000 strain events in the seismicity including Mw2.9 within 100m of the strainmeter, no detectable accelerated strain-rate preceded the catalogued earthquakes [Takeuchi et al.'05; Ogasawara et al.'05]. However, Naoi et al. ('06 GRL) found many smaller steps with much longer durations (LDR event) than those seen in normal earthquakes. Some of the especially slow strain steps (Slow-strain-step) were preceded by accelerations in strain [Naoi et al.'06]. LDR events are possibly aseismic events because they had no corresponding catalogued earthquakes. Their moment magnitudes (Mw) were inferred to be less than 1. The Mw upper limits can be smaller, but a single strainmeter allowed neither to further constrain Mw nor to locate the sources of such events [Naoi'07].

To address the problems, we installed two Ishii 3-compornent strainmeters at a depth of 3km in Mponeng gold mine and monitored over an 2.5-year period [Ogasawara et al.'05; Morishita et al.'05; Yasutake et al.'06]. Strainmeters Sa and Sb were, respectively installed within 20m and 10m from the highly damaged zone where M3 earthquakes were expected, with an interval of ˜14m to monitor the event with Mw=1 or smaller within 100m from the strainmeters. They were away from the tunnel (13 and 25m) enough to avoid stress concentration and inelastic deformation around tunnels. Steps associated with earthquakes occurred at distances of 200-300m from strainmeters, which have little difference between Sa and Sb. The earth tidal responses have little difference from both strainmeters. These suggest strainmeters work well [Morishita et al.'06AGU; Yasutake et al.'06]. Some 1e-5 strain steps were observed, being comparable to those at BAM. However, no detectable forerunners preceded them again. Significant differences between two strainmeters were observed in senses in co-seismic steps and post-seismic drifts associated with nearer earthquakes [Yasutake et al.'06].

In the Mponeng recording, we also found some events, as reported at BAM, that have longer durations and no corresponding catalogued earthquake. Most of these events showed changes in different manners between two strainmeters. Some of these look like slow-strain-steps in BAM, a part of which have longer durations than those at BAM. Figure shows an example with the largest strain change at 5:10-5:20 a.m. in 14th June,'04. The forerunner started at 5:12:35 and lasted for 37 seconds, when Ch.3 reached 1e-7, followed by the onset of the main phase, the largest strain rate. Eventually, change of Ch.3 reached 2e-6. Significantly Chs 2 and 3 contracted and extended, respectively, whereas slightly Ch.1 contracted. This is explained by vertical slip at highly damaged zone close to the strainmeters. At the final stage of the event, a sequence of many small steps was seen. For a 2-minute period shown in Figure c), the interval of the step sequence was about 10 seconds in average and increased with time. At BAM we couldn't see such details because the change recorded was about 10 times smaller than this example at Mponeng. In contrast the change in Sa in raw data was no more significant than noise.

The magnitude of strain change is inversely proportional to the cube of distance from source. Also, there are geometrical constraint: Ra+Rb is larger than 14m and |Ra-Rb|is smaller than 14m, where Ra and Rb are, respectively, the distances from te strainmeters Sa and Sb. Taking the above into account, we could constrain, for most slow-steps, the distances to the sources within 30m from strainmeters and Mw about -

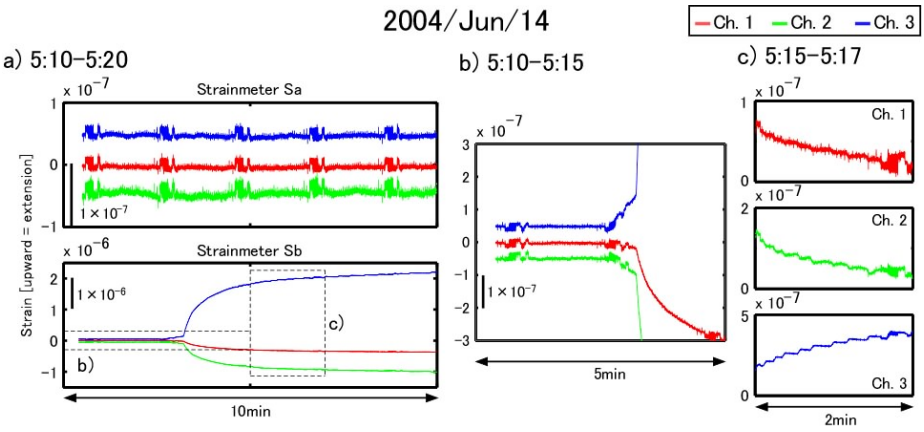

図　Mponeng鉱山地下約3kmの観測サイトにおいて、2004年6月14日5時15分前後に観測されたゆっくりとしたイベント。この他にも発見された、ゆっくりとした変化のうち、最も大きいものである。2分間隔で全てのチャンネルに同時に現れているノイズは、デジタル・データ転送に伴うコモン・モード・ノイズ。a)イベントを含む10分間の記録。推定弱面に近い歪計Sb（下）にのみ1e-6クラスの顕著な変化が確認できる。b)イベントの立ち上がりを含む5分間の記録。約37秒の前駆変化の後に歪速度が最大になった。c)イベント後半の2分間の記録。細かいステップが連続して記録されている。