Analysis of Fault Zones Associated with Large Earthquakes in South African Gold Mines

Preliminary report

by

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EXECUTIVE SUMMARY

We initiated a study of active faults in deep gold mines, South Africa. The first field work (25.9.2000-7.10.2000) included mapping the Dagbreek fault in Matjhabeng mine (Eland shaft, Welkom) and the “Bosman fault” in Hartebeestfontein mine (No. 2 Shaft, Kleksdorp field); we also visited the Break Zone fault in Tautona mine (West Rand field).

It was found that the fault-zones which moved in the recent large earthquakes (local mag. 4.6, 1999, on the Dagbreek fault, and mag 3.7, 1997 on “Bosman fault”) range in width from 6 m to more then 30 m. Each of the zones contains tens of individual slip-surfaces that are characterized by the well known “rock flour”. The slip on an individual slip-surface ranges from a few millimeters to 21 cm. Some observations suggest that the Dagbreek fault has continued to creep after the April 1999 earthquake.

The next fieldwork in the above sites is planned for February 2001. It will include further mapping to evaluate structural details and local stability, as well as geodetic surveying to recognize the possibility of continuous fault creep. The structural data, surface-area of gouge-zones and microstructure collected in the present work, would allow better correlation of seismic data to rock mechanics observations.

ACKNOWLEDGMENTS

Many thanks to G. van Aswagen who kindly organized our field work and provided invaluable comments and advises. Thanks to G. Myburgh, K. Bosman and S Murphy for kind help and advise on the surface and in the mines. We greatly appreciate the assistance of many people in ISSI and Open House Mining Services. The work could not be done without the permission and logistic support provided by Anglogold and Durban-Roodepoort Deep.

INTRODUCTION

Active faults are generally inaccessible at the focal depth of large earthquakes. Thus it is practically impossible to directly relate measured seismic parameters of an earthquake to the structure of the associated fault [1]. To overcome this difficulty, we recently initiated a study of faults associated with large earthquakes in deep gold mines of South Africa. The study has two main objectives: (1) better understanding of earthquake processes by direct observations at focal depth; (2) better characterization of active faults in deep mines.

The study includes detailed 3D mapping of the active faults with emphasize on the internal structure of the fault-zones (fault-zone width, sense, amount and distribution of slip along secondary faults, and micro-structural features); we also started a microstructural analysis of the collected samples. Finally the structural and rock mechanics results will be compared with the available seismic data of ISSI (in collaboration with Dr. G. van Aswagen). The effectiveness of this approach was first demonstrated by McGarr et al. [2] and later extended by Ortlepp [3]

The preliminary results of the field work during the period of 25/9/2000 - 7/10/2000 are reported here. We worked at the hypocenter depth of two recent earthquakes. In Matjhabeng mine (Eland shaft, Welkom) the earthquake was analyzed by van Aswagen [4], and in Hartebeestfontein mine (No. 2 Shaft, Kleksdorp field) the earthquake fault was identified by Bosman [5]. The observations at Tautona mine are too preliminary to be reported here.

MATJHABENG MINE, ELAND SHAFT, WELKOM

The Dagbreek fault accommodated a few kilometers of slip during Archean times. It was reactivated recently in a series of three earthquakes larger than magnitude 4.0 during the last 26 years [4]. We documented parts of the Dagbreek fault that slipped during the last earthquake of local magnitude 4.6, April 1999. All observations were conducted at three sites at level 45, following the suggestions of G. van Aswagen [4] and Mr. Gerhard Myburgh.

Observations at Site 1 (Location: Z3388 in 45H18)

The tunnel at this site was reconstructed after the earthquake and most of the damage products were removed. The local dip of the fault is 37º/253º, roughly normal to the local inclination of the quartzite layers. The local slip is normal dip-slip. We measured the vertical displacement of the rail tracks (H in Fig. 1) to find H = 44 cm across the fault; this estimate is 24 cm larger then the post earthquake survey results (van Aswagen, personal communication). The apparent displacement increase by 24 cm could indicate post seismic slip along the Dagbreek fault. To verify this option, we will conduct an accurate geodetic survey of accessible portions of the Dagbreek fault with an EDM instrument. This is a total station system with resolution of ± 2 mm. We carefully examined the tunnel walls and could recognize slip-surfaces and displaced blocks to distance of up to 45 m from the main fault, but only in the foot wall block.

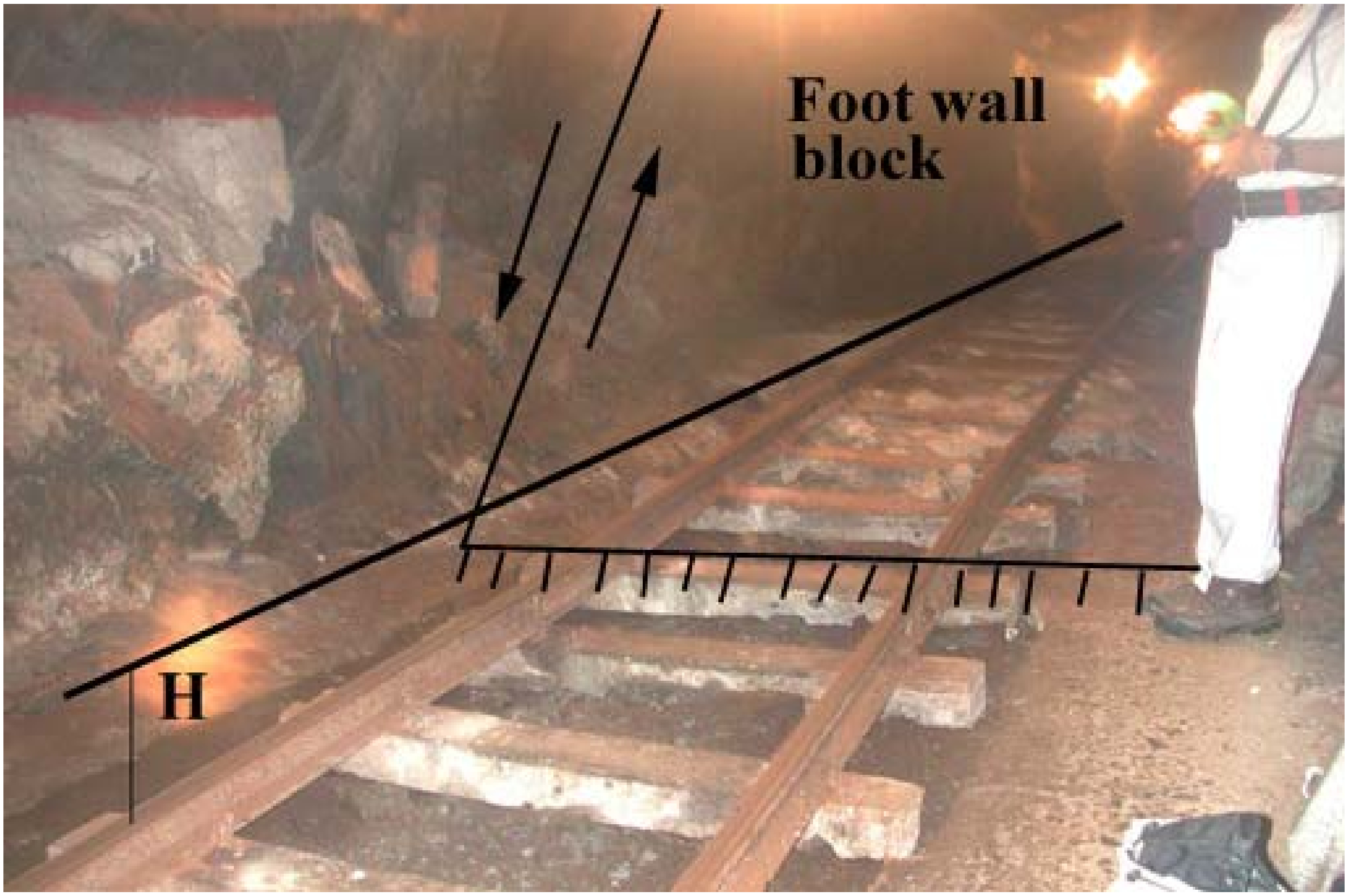


Fig. 1. Displaced tracks in site 1, level 45, Eland shaft. H indicates the vertical displacement across the fault zone (line with short bars). Distributed damage (fractures and crushed zones) were found primarily in the uplifted foot wall.

Observations at Site 2:

Site 2 is located on the Dagbreek fault, about 500 m south of Site 1. This area was highly damaged during the earthquake with no cleaning and recovery and the exposures are restricted to a small region. We identified here a fault-zone of 9.5 m width which is controlled by the local accessibility; actual width is most likely larger (see site 3 below). We found several small slip-surfaces with displacements of 0.5 cm and smaller, most of them have a thin clayey gouge zone (pyrophillite?). The "rock flour" gouge is not common here (unlike in site 3). Slickenside striations in various directions and scales are distributed on most of the slip-surfaces; some of the striations could form in previous events. It is also possible that the odd striations reflect movement into the open tunnel during the 1999 earthquake. The main slip-surface here displays 21 cm of dip-slip as evident by the displacement of the red line (Fig. 2). The 21 cm slip is distributed within 3-5 cm thick fine grain gouge zone (pyrophillite?).

Many broken rock bolts are observed at this site. Apparently, these rock bolts did not yield only in the event of April 1999, and some of them yielded in previous events or by creep. The possibility of on-going damage at this site will be investigated. Some rock bolts that penetrated into and parallel to the slip-surfaces surprisingly do not display evidence for deformation or shear. The intense damage at this site may be related to site effect associated with the Y shaped local tunnels or may reflect the damage heterogeneity close to the tip of a propagating earthquake.

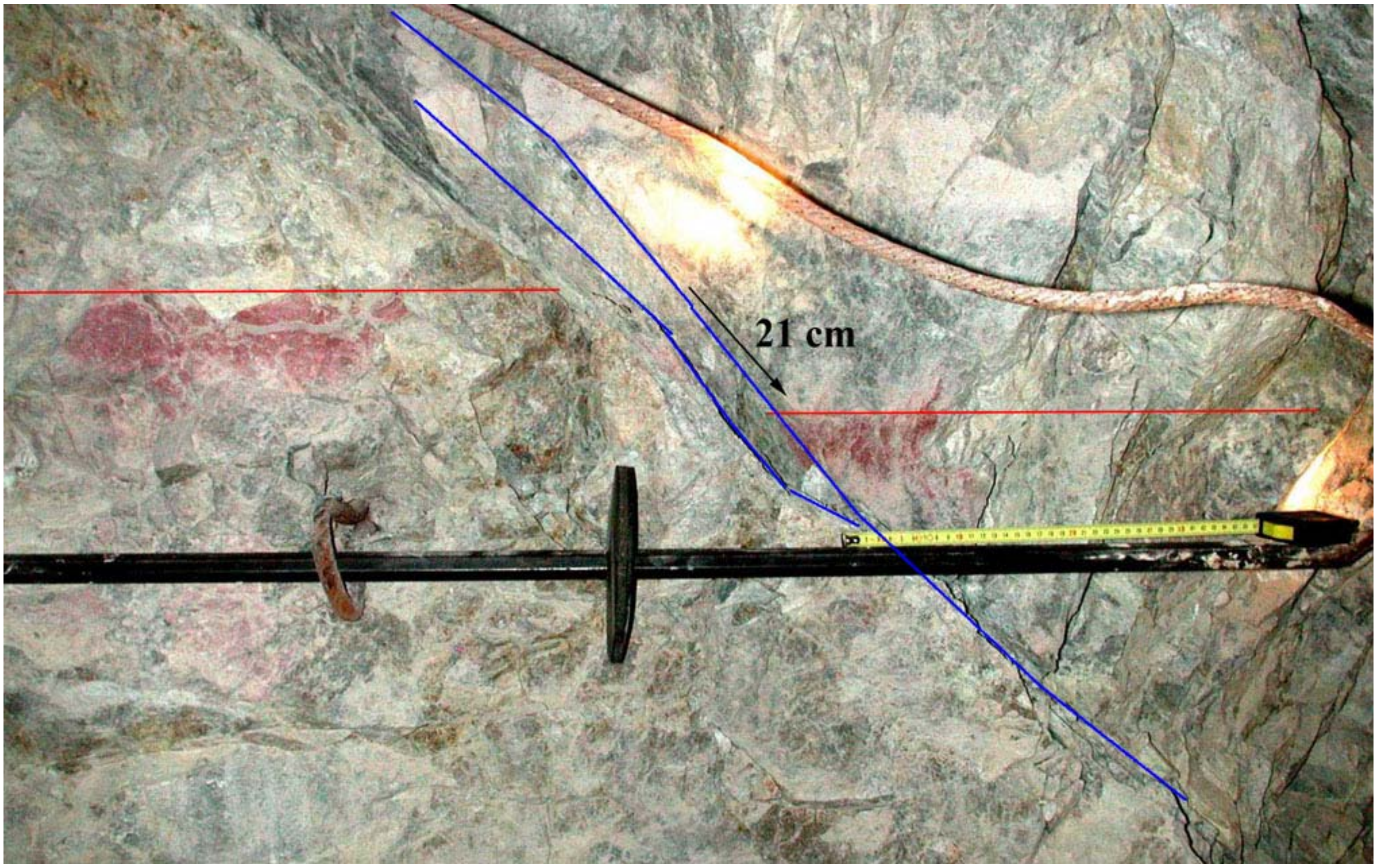


Fig. 2. The main slip-surface (blue line) dipping to the west in site #2. The red line is displaced by 21 cm of dip-slip along the thick gouge zone.

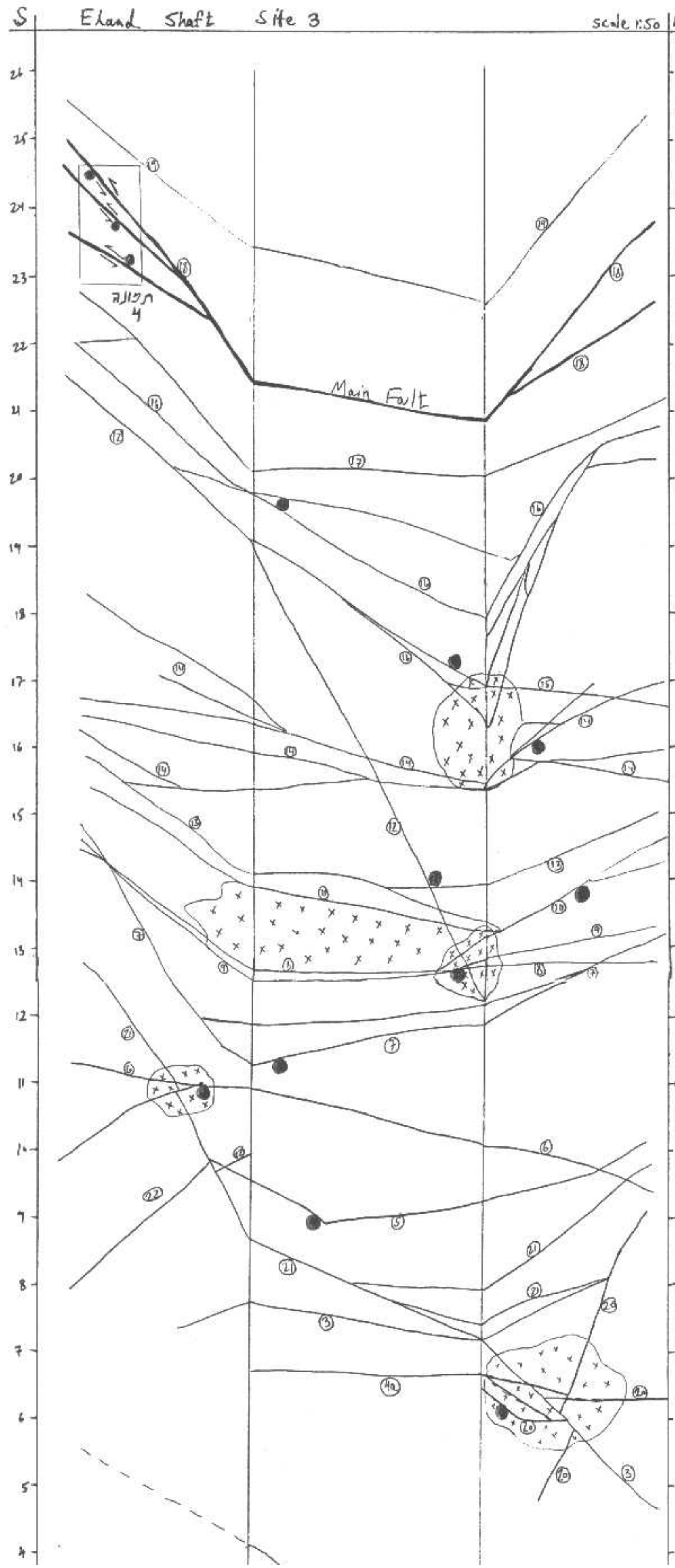
Observations at Site 3:

Site 3 is located on the Dagbreek fault about 50 m north of site 2 in a damaged, yet accessible tunnel. This site provided the best exposures of the fault zone, and we mapped here a 27 m segment of the E-W tunnel, normal to the fault. The mapped part is almost entirely in the foot wall block as the hanging block is inaccessible due to damage.

The fault-zone includes about twenty slip-surfaces generally dipping westward and arranged in five clusters (Fig. 3). Most of these slip-surfaces (excluding fault #18 that will be described below) are coated with white "rock flour" of comminuted quartzite of the host rock [3]. Similar powder+fragments mass was found in Hartebeestfontein mine [5] (see below).

One type of evidence for slip are the displaced boreholes of rock bolts in which both dip-slip and strike-slip components of the displacement could be evaluated (Fig. 4). We found displaced boreholes at 10 slip-surfaces and they revealed slip from 0.5 cm to 6 cm. The sense of slip and the orientations of the surfaces diverse significantly between the individual surfaces; we found evidence for right-lateral, left-lateral, normal and reverse motion. These contradicting slip directions will be investigated in the future.

Probably our most amazing finding was observed inside the Archean fault-zone of Dagbreek fault (fault #18 in Fig. 3). This is a 25 cm thick gouge-zone of pyrophillite with quartzite fragments and it dips 26° /280° . A steel drill bit used for rock bolting was left inside this gouge-zone during the tunnel, and it was "chopped" into four pieces during the earthquake (Fig. 5). The broken pieces were found in the rubble, immediately below their original position. Using rust stains, we reconstructed the pieces to their position and measured 11 cm of dip-slip and 5 cm of right-lateral slip accumulated three crosscutting slip-surfaces within the gouge-zone (Fig. 5). To the best of our knowledge, this is a unique observation in earthquake research and its implications will be investigated.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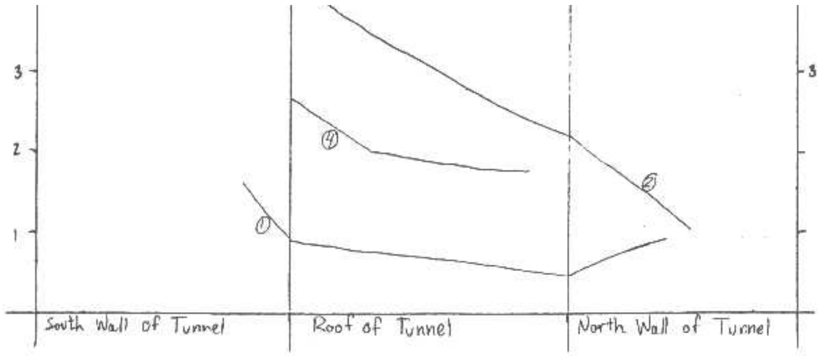

Fig. 3. Map of slip surfaces (solid lines) of the Dagbreek fault at site 3. The central panel is the tunnel top with south and north sidewalls on left and right, respectively. Scale in meters; black dots indicate point of slip indicator; heavy line indicates fault #18; (Archean gouge-zone); areas with small cross indicate intense fracturing.

Fig. 4. Displaced borehole at site 3. Upward view on the roof; the slip-surface is sub-parallel to the roof; displacement about 15 mm.

Fig. 5. The Archean fault zone of Dagbreek fault system at site 3. The gouge-zone here is 25 cm thick, and it cut the steel drill bit (see text).

HARTEBEESTFONTEIN MINE, SHAFT 2, KLERKSDORP

We studied here the “Bosman fault” that generated a 3.7 magnitude earthquake in October 1997 [5]. This earthquake occurred within a solid, previously unfaulted quartzitic rock at distance of about 80 m from the face. We mapped the currently exposed part of the fault-zone at depth of 1950 m and our main findings appear in Fig. 6.

This is a normal fault-zone with cumulative dip-slip of at least 25 cm. It is 6-8 meter wide, with 6-9 sub-parallel slip-surfaces that dip 60° -85° and display zigzag pattern (Fig. 6). Crosscutting relations and conjugate occurrence occur at several scales (see Fig. 6 and details in Fig. 7). The slip-surfaces are always coated with white powder of comminuted quartzite of the host rock. SEM pictures show pervasive indicators of slip inside the powder mass. Our surface-area measurements of the undisturbed powder revealed values of about 6 m2/gr, hundreds of times the surface-area of the intact rock. Locally, the slip-surfaces are zones up to 10 cm thick composed of the white powder and rock fragments.

The “Bosman fault” provides a unique opportunity to analyze the internal structure of a mining induced fault-zone that developed inside intact rock and away from the face. This analysis is complementary to the above analysis of Dagbreek fault.

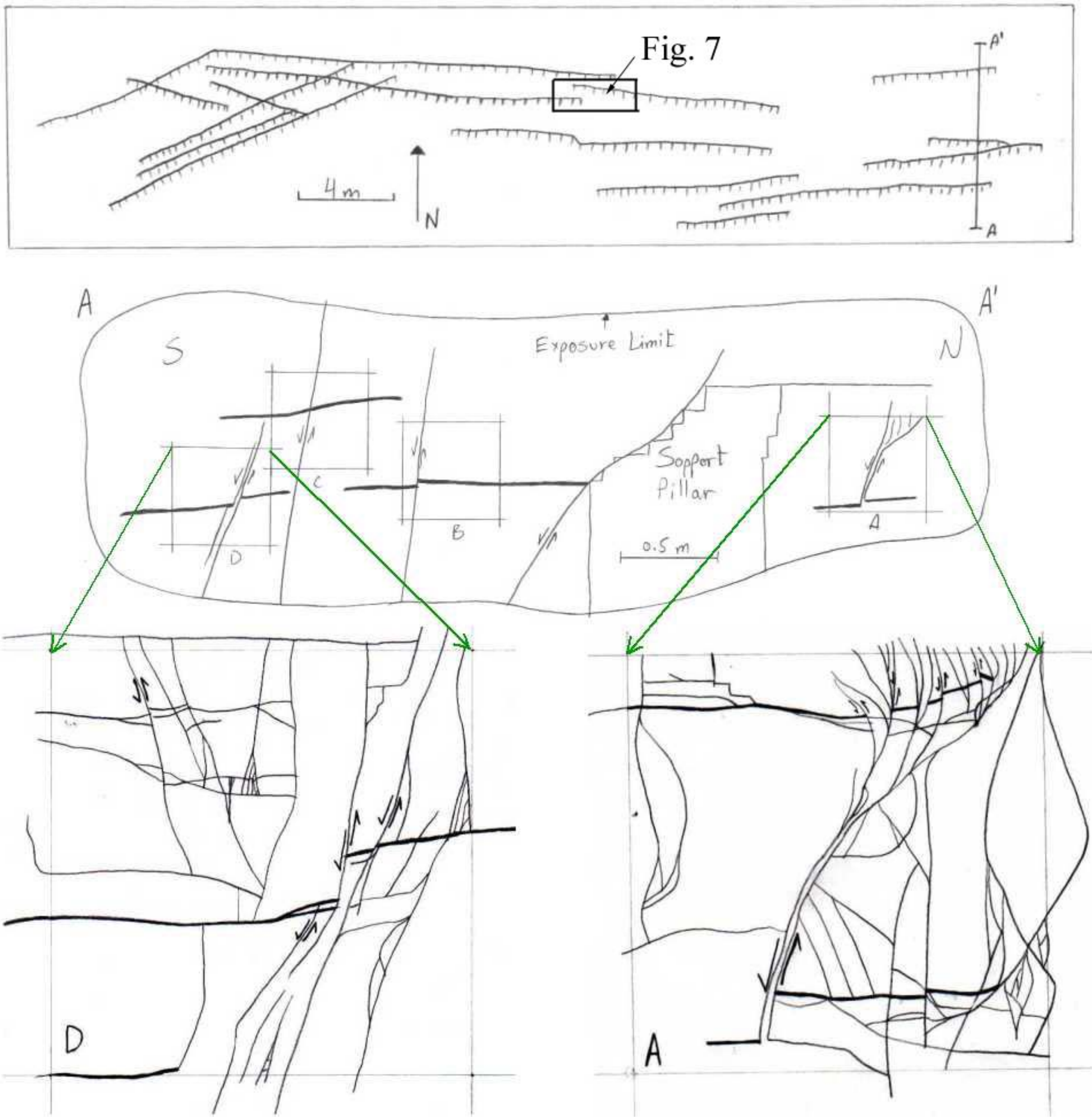

Fig. 6. Maps and cross-sections of Bosman fault, Hartebeestfontein mine. The map is shown in the upper part, general cross-section in the center and two detailed sections below; lines with bars indicate faults (bars on downside), heavy lines indicate layering; note scale bars of 4.0 m in map and 0.5 m in general cross-sections.

Fig. 7. View on tunnel's roof in the Bosman fault-zone. Note dense pattern of cross-cutting, zigzagging slip-surfaces of several scales; width of photo is about 1 m (see also figures in [3] and [5].

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