**A CERBERUS FOSSAE SEISMIC NETWORK** S. C. Stähler [1], M. P. Panning[2], D. Antonangeli[3], W. B. Banerdt[2], D. Banfield[4], M. Banks[5], S. Ceylan[1], C. Charalambous[6], J. Clinton[1], I. J. Daubar[7], B. Fernando[8], D. Giardini[1], M. Grott[9], A. Horleston[10], K. Hurst[2], T. Kawamura[11], A. Khan[1], D. Kim[1], M. Knapmeyer[9], B. Knapmeyer-Endrun[12], R. Lorenz[13], L. Margerin[14], A. Marusiak[2], S. Menina[14], A. Mittelholz[15], N. Murdoch[16], Y. Nishikawa[17], C. Nunn[2], C. Perrin[18], W. T. Pike[6], C. Schmelzbach[1], N. Schmerr[19], M. Schimmel[19], A. Spiga[3], A. Stott[16], J. Taylor[9], and R. Weber[20]. [1]ETH Zürich, Switzerland (simon.staehler@erdw.ethz), [2]JPL, Pasadena CA, USA [3]Sorbonne U, Paris, France [4]Cornell, Ithaka NY, USA [5]NASA GSFC, Greenbelt MD, USA, [6]Imperial College, London, UK, [7]Brown U, Providence RI, USA [8]U Oxford, UK [9]DLR, Berlin, Germany, [10]U Bristol, UK [11]IPGP, Paris, France [12]U Cologne, Germany, [13]APL, JHU, USA, [14]U Toulouse, France, [15]Harvard U, MA, USA, [16]ISAE-Supaero, Toulouse, France, [17]KUT, Kochi, Japan, [18]LPG, Nantes, France [19]U Maryland, College Park MD, USA and [20]NASA MSFC, Huntsville AL, USA

**Scientific Rationale:** It is by now widely accepted that Mars had a wet and periodically warm past in the Noachian e.g. [1], but it is still open whether liquid water has played any role geologically in recent times or is even present in significant amounts near the surface today e.g. [2]. One key young area are the Cerberus Fossae (C.F.), a system of $< 10$ Ma old, 1200 km long grabens in Eastern Elysium Planitia. They connect to sediments in Athabasca Valles that have been interpreted as fluvial sediments from a frozen water layer molten by volcanism 8-10 Ma ago [3], but could alternatively be explained by very low viscosity lava as well [4].

The InSight mission [5] deployed the first successful seismometer to the surface of Mars and detected a significant number of marsquakes over four Earth years. Most large quakes were located specifically in the Cerberus Fossae system [6, 7]. This means that at least in the same hemisphere as InSight, tectonic activity is not primarily driven by cooling and contraction of the planet (as proposed by [8, 9], among others), but by highly localized stress, potentially related to a plume system below Elysium Planitia [10]. A second type of shallow marsquake indicates an upper crust that combines strong heterogeneities and low seismic attenuation, reminiscent of lunar quakes [12, 13], at least in the upper kilometers. These observations seem incompatible with large amounts of water in the crust, either as a frozen groundwater layer or as water sequestered within minerals (which has been proposed as the sink of the water lost since the Noachian [14]). In combination, InSight has therefore shown that even the first analysis of seismic data challenges the concept of dominant tectonics on single plate planets, as well as fluid content in the accessible part of the crust. Cerberus Fossae is an ideal focal point to explore these questions further, addressing the issue of whether habitable pockets might survive over long periods in an otherwise barren world.

This results in the following **mission goals** of a proposed Cerberus Fossae Seismic Network:

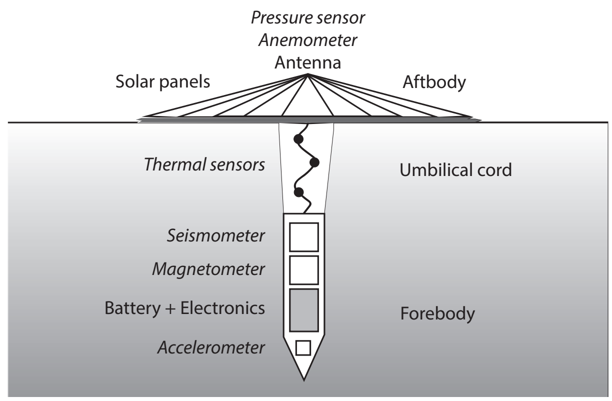


Figure 1: Cross section of an exemplaric penetrator. The forebody contains a seismometer, a magnetometer, an accelerometer, as well as electronics. The aftbody disconnects during impact and stays above the surface. It contains 1 square meter solar panels and a basic meteorological suite, connected to the forebody by an umbilical cord with thermal sensors. The seismometer is the main instrument of the mission. More refined rough lander concepts, such as SHIELD [11] could deliver the same instrument suite.

- **G1: Locate shallow and deep marsquakes with a location uncertainly of less than 20 km.** Determine the regional stress field and the driving mechanism behind the opening of C.F.
- **G2: Determine a velocity and attenuation model of the crust and uppermost mantle in the Cerberus Fossae region.** Constrain the temperature gradient in the uppermost 20 km and find the bottom of the uppermost fractured, low attenuation layer. Confirm or exclude the existence of a frozen water layer below C.F..
- **G3: Constrain the ground rigidity and thermal diffusivity of the top meter at the landing site.** Distinguish between fluvial sediments and coherent lava flows as a top layer.
- **G4: Observe wind and air pressure continuously on a regional scale.** Refine regional climate models

to understand aeolian deposition as seen from orbit.

**G5: Observe meteoritic impacts** Constrain the rate of impactors with $> 2$ m crater size around the network.

**Mission trade space:** The InSight mission has proven the value of a carefully deployed very broadband seismometer (VBB) [15] to determine the deepest structure [16] and infer the composition of the planet as a whole. However, local seismicity cannot be reliably located from a single instrument, given the strong scattering and therefore lack of polarization [12]. A seismic network of multiple stations could use arrival times to more precisely locate quakes, but the deployment effort of the VBB, including the usage of a robotic arm for 90 Sols, is prohibitive in terms of power, lander complexity, mission complexity and thus staffing. The InSight seismic data has shown, however, that local and shallow marsquakes can be observed well with a much more robust short period seismometer, which would have significantly lower installation effort [17]. If the lander has a low wind cross section and good ground coupling, operation from inside the lander is possible.

A soft lander has a significant cost penalty due to the EDL system, which can be avoided by planning a rough landing. A seismic network can operate successfully with four instruments. Reliability requirements can be reduced from the typical '3 $\sigma$' values, if loss of one or two landers during EDL is considered acceptable, which significantly reduces the design and qualification cost of each single lander.

**Instruments:**

**Short period seismometer** The seismometer is located in the forebody and well-connected to the ground. The burial and the distance to the aftbody reduce ambient noise (G1, G2).

**Accelerometer** By measuring the deceleration during impact, the accelerometer determines the rigidity of the upper subsurface (G3).

**Pressure and anemometer** Build the first regional meteorological network on Mars and distinguish marsquake signals from noise. The Solar panels would allow continuous cloud coverage monitoring [18] and constrain times of Phobos eclipses [19] (G4).

**EM Sounder or magnetometer** Installation of a magnetometer network or concurrent measurement of the electric field would allow for direct inversion for conductivity and therefore mineralogy [20] (G2, G3).

**Thermal sensors** Determine the thermal diffusivity and from it constrain the material properties at the landing site (G2, G3).

**Retroflectors** Determine geodetic deformation from future orbital laser altimeters (G1).

**Mission concept:** To achieve the goal of having at least four successful landings and deployments, we propose an initial fleet of six penetrators or hard landers spread over the center of Cerberus Fossae, each equipped with a 3 component InSight-SP short period seismometer and a meteorological instrument suite (Fig. 1). The penetrators would steer independently towards preprogrammed locations within Cerberus Fossae. Typical landing ellipse sizes of 200x50 km would ensure distribution over the target area.

Impact velocities of Martian penetrators can be reduced with moderate parachutes to values of 50-80 m/s, resulting in decelerations below 500g, as shown in the Mars96 concept [21, 22]. The SP sensor could be hardened for impact by subducting it in wax that evaporates after landing. One option is to disconnect the forebody mechanically from the surface aftbody, to reduce wind-induced seismic noise and improve ground coupling, similar to the Mars96 concept (Figure 1). Alternatively, the JPL-developed SHIELD flat platform for rough landing [11] would be ideal for network deployment. We propose a mission duration of one Martian year, which should result in observation of several deeper and $> 100$ shallow marsquakes and up to 10 meteoritic impacts.

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