SUPPLEMENTARY: Strength of the lithosphere derived by geological and geophysics data: the Graham Land (Antarctic Peninsula) case study

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GPS DATA AND PROCESSING

We processed data recorded at 21 continuous and periodic GNSS time series, that covering a time period from 1997 to 2022 (between January, 1997, and December, 2022), for the Graham Land, using the database from the Nevada Geodetic Laboratory (NGL), at the University of Nevada, Reno. The GNSS sites are listed in Table 1.

All stations considered have time-series that are at least 2.5 year long that represents the minimum acceptable length to ensure that estimated trends are not significantly affected by biases due to seasonal components [1] [2] [3].

GPS data were processed by using the **MIDAS** software (Median Interannual Difference Adjusted for Skewness) median-trend algorithm Introduced by [7], that represents a variant of the Theil-Sen non-parametric median trend estimator [11]. The MIDAS-estimated velocity is essentially the median of the distribution of 1-year slopes, making it insensitive to the effects of steps in the time series if they are sufficiently infrequent.

The uncertainties obtained whit MIDAS have a realistic meaning and usually do not require further scaling [12] [13] [14] [15] [16].

Table 1. GNSS velocities estimated with the MIDAS algorithm at the 21 sites considered in this study and associated uncertainties.

ID	LON (deg)	LAT (deg)	HEIGHT (m)	EAST (mm/yr)	NORTH (mm/yr)	UP (mm/yr)	σ_{EAST} (mm/yr)	σ_{NORTH} (mm/yr)	σ_{UP} (mm/yr)
BSA1	-67.29	-67.81	127.54	1.47	-1.01	1.50	0.18	0.26	0.87
CAPF	-60.56	-66.01	100.19	1.25	-2.58	2.62	0.16	0.19	0.54
DUPT	-62.82	-64.80	43.46	-1.35	-0.94	8.82	0.17	0.22	0.70
FONP	-61.65	-65.24	76.28	0.79	-5.07	15.62	0.36	0.48	1.07
FREI	-58.98	-62.19	72.30	-4.70	5.90	-4.40	0.52	0.55	1.09
HUGO	-65.67	-64.96	20.64	0.52	-0.44	-0.70	0.15	0.22	0.67
MBIO	-56.62	-64.24	221.47	4.11	-2.41	3.86	0.29	0.36	0.87
PAL2	-64.05	-64.77	31.06	-0.85	-0.83	4.94	0.15	0.21	0.61
PALM	-64.05	-64.77	31.06	-1.02	-0.68	4.75	0.13	0.18	0.48
PALV	-64.05	-64.77	31.13	-1.20	-0.95	5.05	0.22	0.29	0.80
PRPT	-65.34	-66.01	17.61	1.00	-1.04	-0.10	0.22	0.27	0.98
ROBN	-59.44	-65.25	57.89	2.86	-3.53	6.63	0.28	0.30	0.58
ROTH	-68.12	-67.57	39.69	0.96	-1.20	3.42	0.18	0.25	0.71
SGP1	-61.72	-65.56	250.31	0.29	-3.34	6.74	0.35	0.47	1.26
SGP4	-62.46	-66.68	258.43	0.00	-1.57	1.46	0.38	0.44	1.42
SGP5	-64.89	-67.28	272.49	0.73	-0.40	-0.70	0.41	0.42	2.24
SMR5	-67.10	-68.13	26.85	0.65	-0.15	2.61	0.32	0.44	1.44
SPGT	-61.05	-64.29	34.23	1.37	0.75	8.88	0.19	0.27	0.79
SPRZ	-56.99	-63.39	27.67	2.63	-1.77	1.87	0.32	0.39	1.18
UYBA	-58.90	-62.18	33.71	-3.99	5.92	-2.24	0.51	0.75	2.16
VNAD	-64.25	-65.24	20.99	-0.75	-1.23	4.21	0.23	0.30	0.84

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NUMERICAL MODEL

- ***STRAIN RATE***

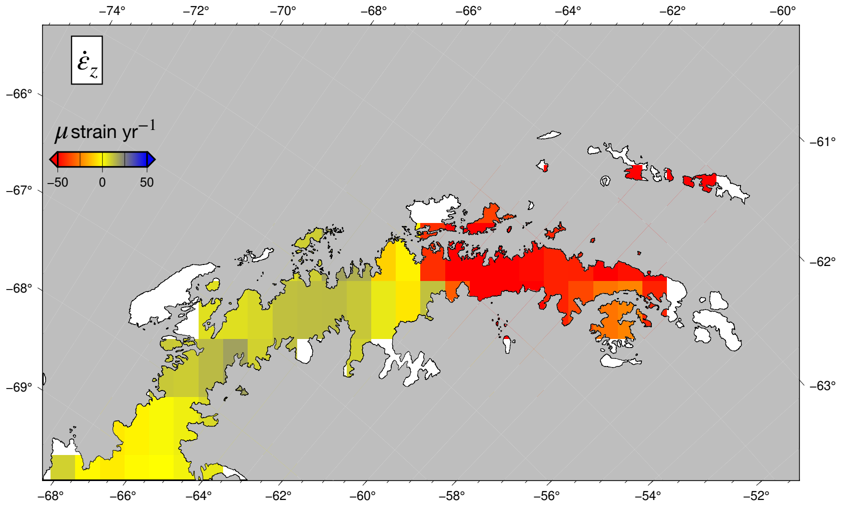
From Eq. (1), (2) and (3) *R* denotes the Earth's radius, u_θ is the velocity along the longitude and u_λ is the velocity along the latitude. $\dot{\varepsilon}_{\theta\theta}$, $\dot{\varepsilon}_{\lambda\lambda}$ and $\dot{\varepsilon}_{\theta\lambda}$ represent the three independent strain rate components of the strains rate tensor. Similarly, the vertical strain rate is :

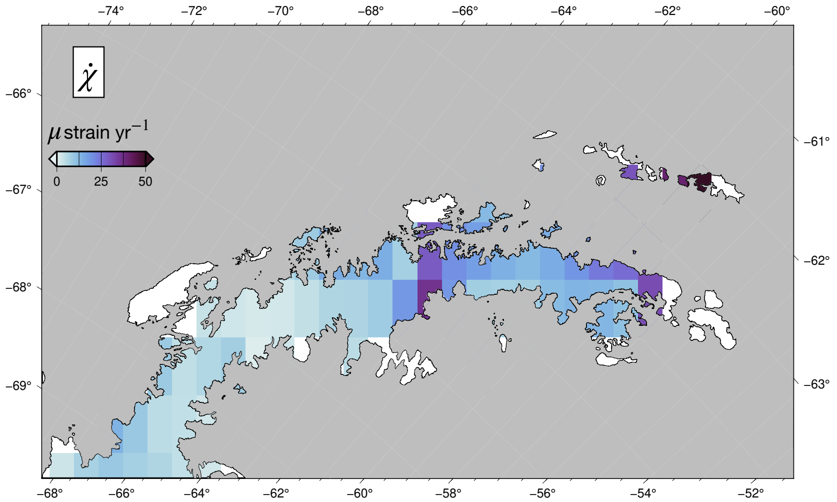
$$\dot{\varepsilon}_z = -\dot{\varepsilon}_{\theta\theta} - \dot{\varepsilon}_{\lambda\lambda} \tag{11}$$

where $\dot{\varepsilon}_z$ denotes the velocity along the *z* axis.

Likewise, following Eq. (5) and Eq. (6), the maximum shear strain-rate ($\dot{\chi}$) can be expressed as:

$$\dot{\chi} = 0.5\ (\dot{\varepsilon}_{max} - \dot{\varepsilon}_{min}) \tag{12}$$





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NUMERICAL MODEL

• STRENGTH OF THE LITHOSPHERE

From Eq. (7), (8) and (9) ρ_{litho} is the density of the crust or mantle, g is gravitational acceleration, z is depth, λ' is the pore fluid factor, $\dot{\varepsilon}^{II}$ is the second invariant of the strain rate, $\dot{\chi}$ is the shear strain rate, β and ξ_z are material constants (listed in Table 2). For plastic deformation, the value of *500 MPa* is based on the plasticity limit of olivine [17].

The critical shear stress value is given by the minimum of three upper bounds:

$$\tau_s(z) = (\tau_s^{fric}, \tau_s^{creep}, \tau_s^{plast}) \qquad (13)$$

Assuming that no heat is produced inside the lithospheric mantle, the temperature increases linearly with depth [4]. The temperature gradient inside the lithospheric mantle is determined by the temperature and heat flux at the Moho boundary, since crust and mantle are assumed to be in thermal equilibrium [18].

The Temperature T, in Eq. (8), as function of depth z is:

$$\begin{aligned} T_z &= T_s + \frac{q\,z}{k_c} - \frac{H\,z^2}{2k_c}, && \text{if } z \le z_c \\ T_z &= T_c + \frac{(q - Hz_c)\,(z - z_c)}{k_m}, && \text{if } z_c < z \end{aligned} \qquad (14)$$

were q is the surface Geothermal Heat Flow (GHF), k_c and k_m are the conductivities of the crust and mantle, z_c is the thickness of the crust, T_s and T_c are the temperatures at the surface and at the base of the crust and H is the radiogenic heat production rate within the crust (*H = 0* in the mantle).

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MODEL PARAMETER

Table 2. Rheological model parameters. Mantle values are given in parentheses. (A), (B), and (C) represent the three profiles.

Description	Parameter	Units	Value
geothermal heat flow (GHF)	q	$mW\ m^{-2}$	55 – 65 – 65
radioactive heat production	H	$W\ m^{-3}$	$4e^{-7}$ ($2e^{-8}$)
thermal conductivity	k_t	$W \cdot m^{-1}K^{-1}$	2.5 (3.5)
pre-exponential constant in creep rheology	α	MPa	2.3 (0.0195)
depth coefficient in creep rheology	ξ	$K\ m^{-2}$	0 (0.0171)
stress exponent in creep rheology	n		0.3333
temperature coefficient in creep rheology	β_1	K^{-1}	8600 (18000)
	β_2	K^{-1}	9600 (18500)
	β_3	K^{-1}	10650 (19000)
	β_4	K^{-1}	11650 (19500)
mean density crust	ρ_{litho}	$kg\ m^{-3}$	2899 (3332)
mean density water	ρ_{water}	$kg\ m^{-3}$	1032
surface temperature	T	K	273
standard coefficient of friction	μ		0.85
pore fluid factor	λ'		0.36
moho depth		km	38 (A) - 34 (B) - 36 (C)

Thermal rocks properties and rheological parameters were taken from various sources in the literature.

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