Supplementary Information for

Evidence for weak seismic attenuation in Mars' deep mantle

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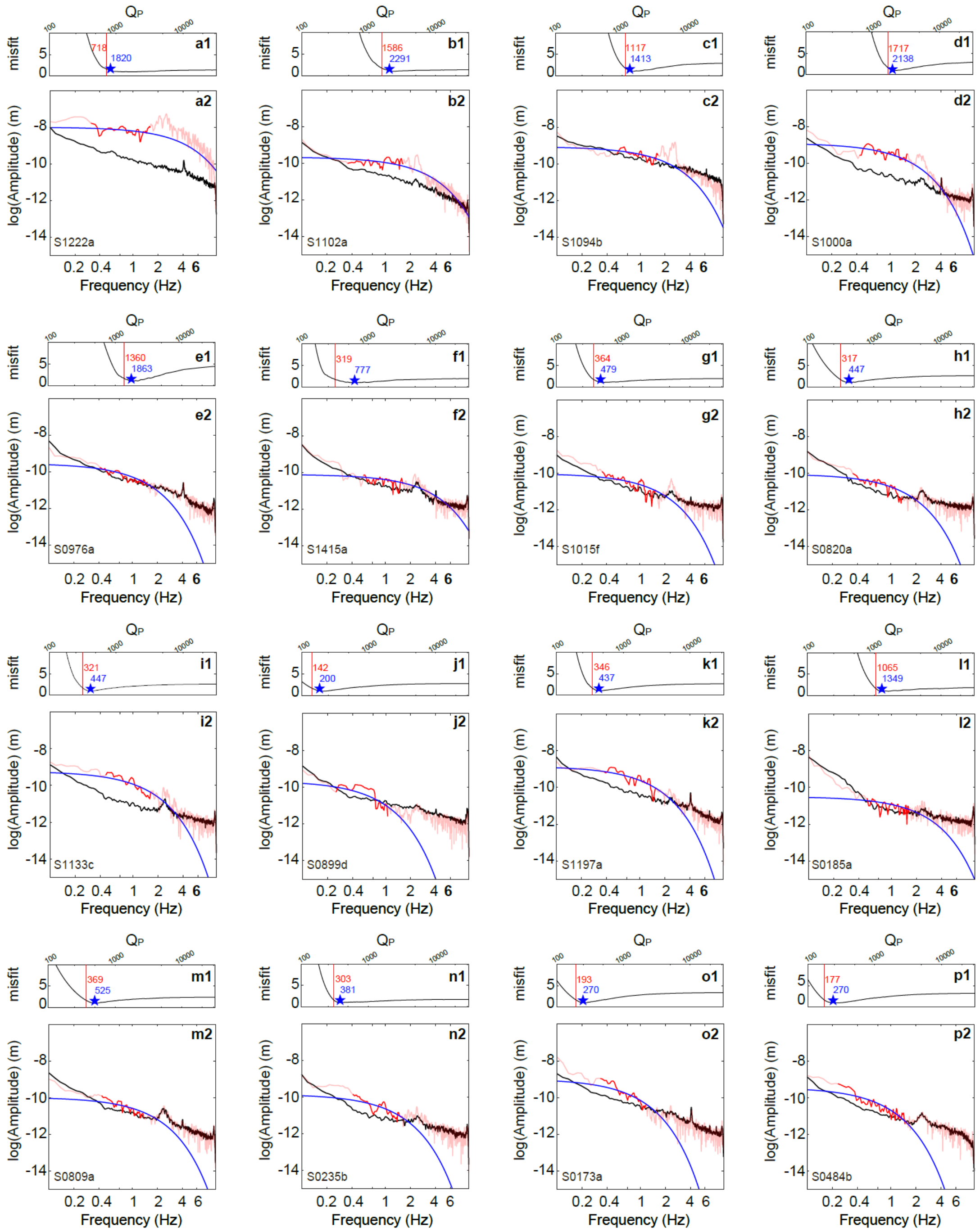
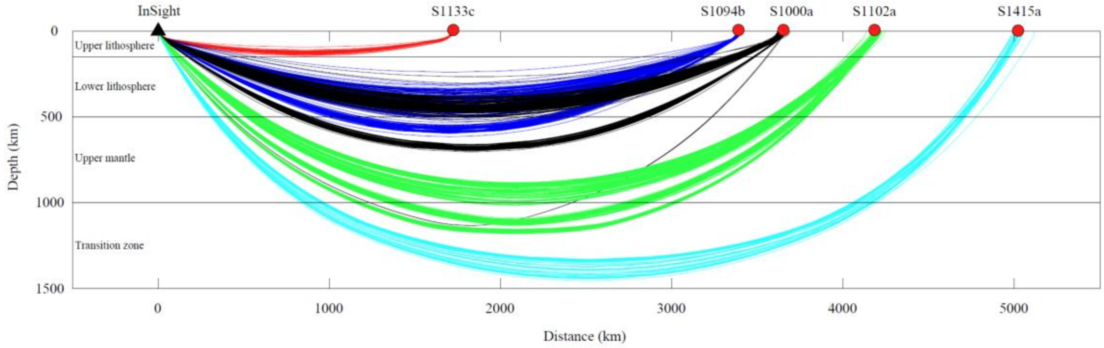
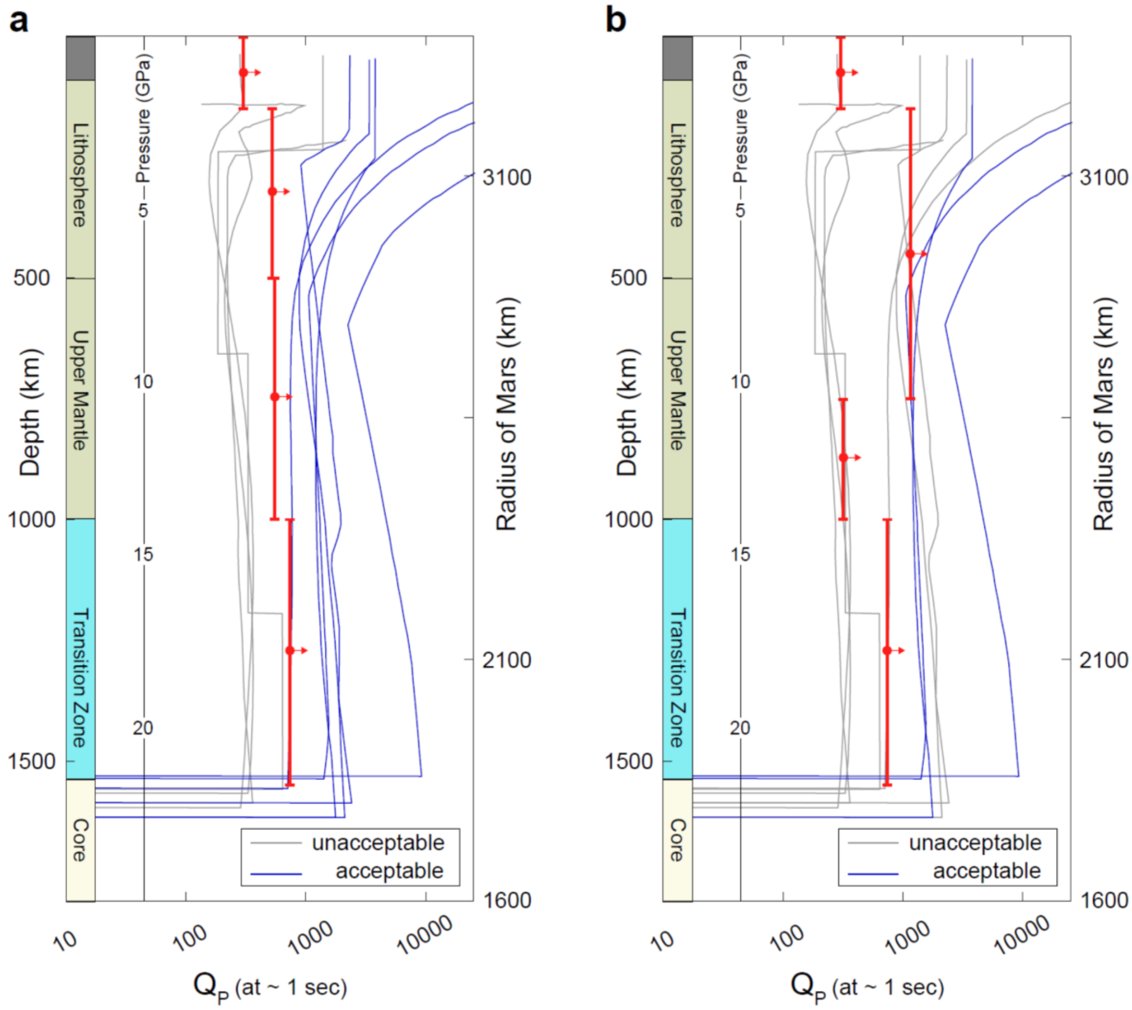
Content



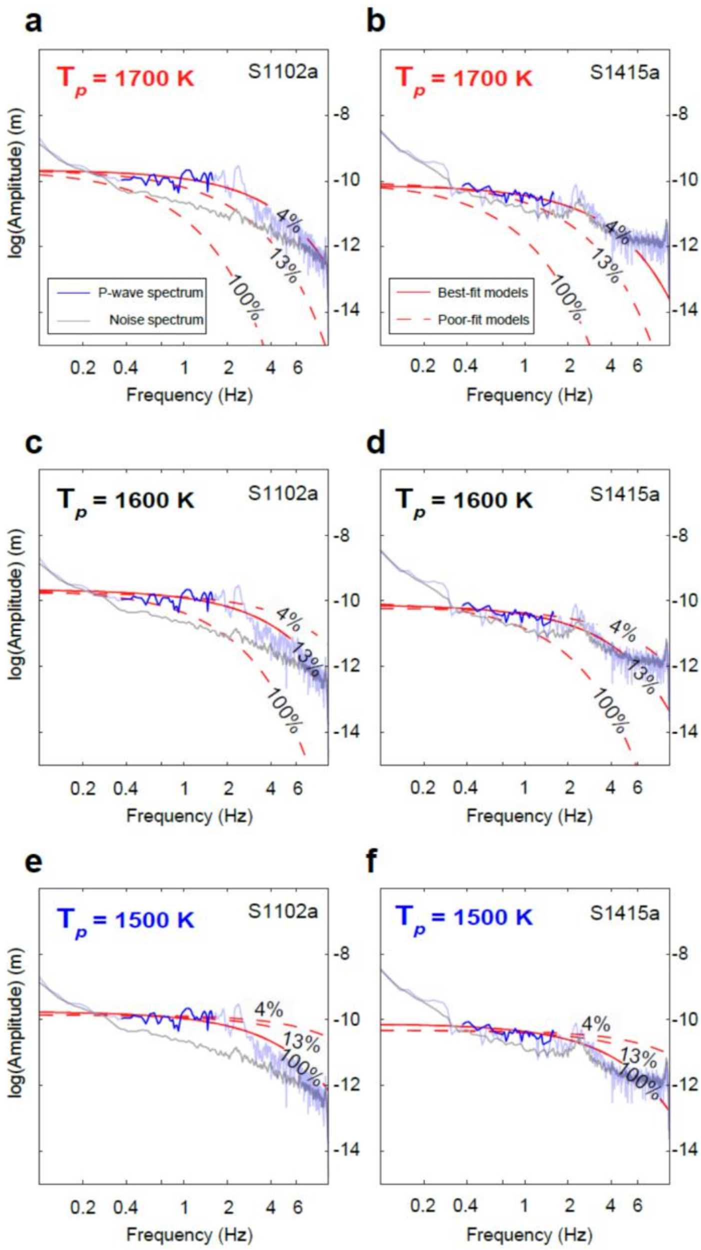
Supplementary Fig. 1 Spectral analysis for the P waves. In the lower panel, the dark red curve represents the P-wave spectrum used for fitting, and the light red curve shows data excluded due to smaller amplitude or site amplification effects. The black curve indicates noise levels. The blue curve represents the synthetic spectrum with the best-fitting effective Q based on equation (3). In the upper panel, the black curve shows the misfit of the spectral fit with different effective Q values, with the best-fitting effective Q and the minimum acceptable effective Q in blue and red, respectively.



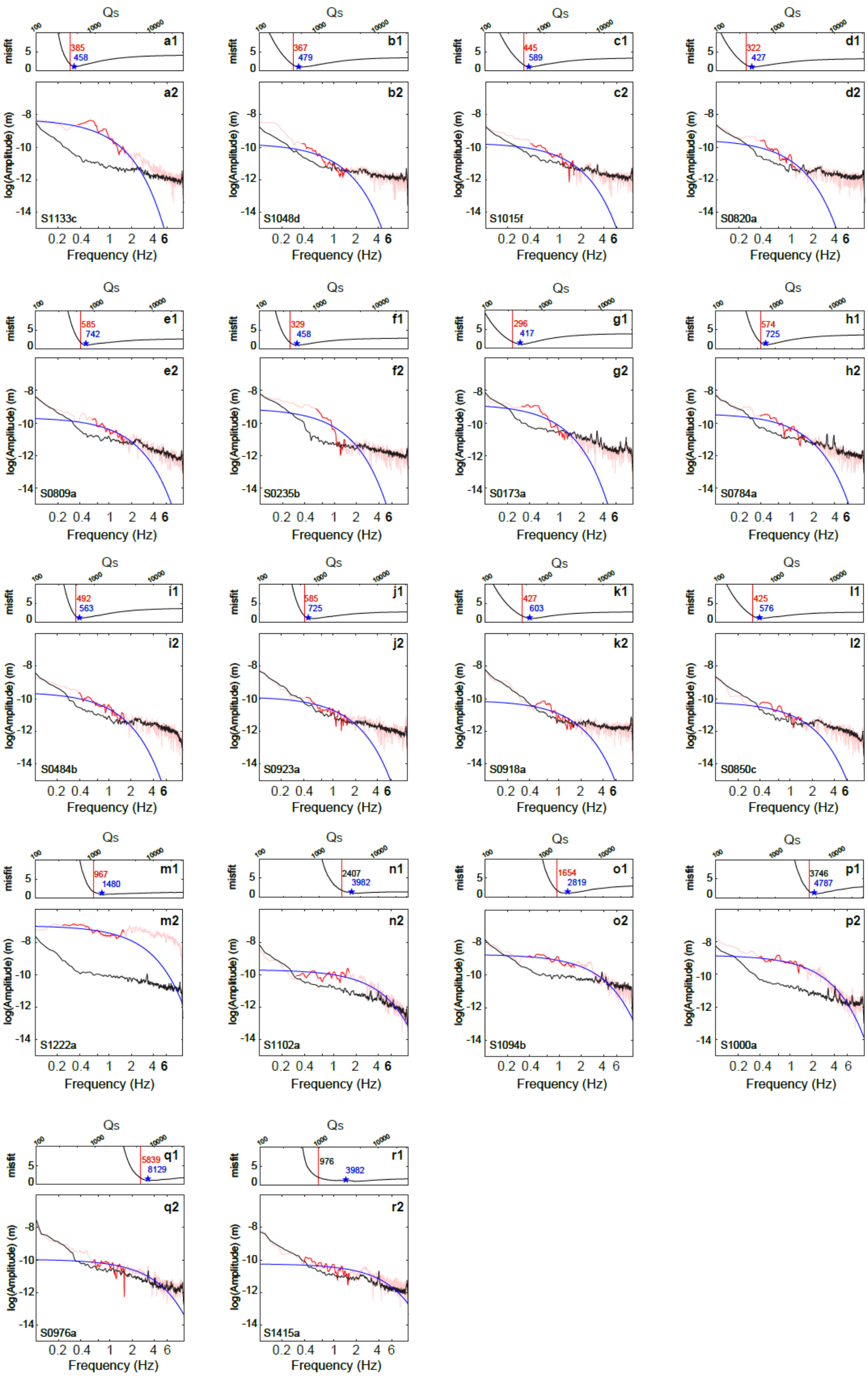
Supplementary Fig. 2 Seismic paths from marsquakes and impacts in different layers of Mars' interior. The paths are calculated based on 1000 possible mantle models from Durán et al. (2022)



Supplementary Fig. 3 (a) P-wave attenuation Q_P (r) profiles at a seismic period of ~1 second (the same as in Figure 2b). Red arrows indicate the seismically constrained minimum Q_P (r) values at each depth ranges of 0–150 km, 150–500 km, 500–1000 km, and 1000–1500 km. The grey lines represent models (i.e., the strong attenuation group) excluded due to their incompatibility with these minimum Q_P (r) values. (b) similar to (a) but with an alternative division. The regions 150–500 km and 500–1000 km are divided into 150–750 km and 750–1000 km. The resulting minimum Q values shift but still favor weakly attenuating (high-Q) models.



Supplementary Fig. 4 (a) Spectral analysis for marsquake S1102a at a potential temperature of 1700 K. The dark blue curve represents the P-wave spectrum used for fitting, and the light blue curve shows data excluded due to smaller amplitude or site amplification effects (Methods). The grey curve indicates noise levels. The red synthetic curves correspond to the Q_P (r) profiles of Mars, with water content ratios of 100%, 13%, and 4% assuming the same grain size (or equivalent to grain size ratios of 1.0, 2.0, and 3.0), and solid curves indicate the best-fitting models. (b) Spectral analysis for marsquake S1415a at a potential temperature of 1700 K. (c-d) similar analysis but at a potential temperature of 1600 K, which is the same as in Figure 3. (e-f) similar analysis but at a potential temperature of 1500 K.



Supplementary Fig. 5 Spectral analysis for the S waves, following the same framework as Supplementary Fig. 1.

Supplementary Table 1 Tidal-constrained models used in Fig. 2a and Fig. 2b. Parameters are summarized by Pou et al. (2021).

Model name	Core radius (km)	Elastic lithospheric thickness (km)	CMB temperature (K)	Frequency dependence α
FN cold	1,790	125	1,694	0.30
FN hot	1,820	275	1,759	0.30
AB Andrade	1,800	270	1,880	0.32
AB Burgers	1,800	260	1,860	0.33
HS1	1,850	290	2,060	0.20
HS2	1,830	260	2,020	0.15
HS3	1,855	320	2,020	0.33
TG	1,828	244	2,075	0.10
AR - TA 85	1,770	262	2,095	0.30
AR - TA 111	1,770	333	2,175	0.30
AR - YO 85	1,780	262	2,095	0.30
AR - YO 111	1,760	333	2,175	0.30

Supplementary Table 2 Information of representative events

Name	Distance (°)	Penetration depth (km)	P arrival (s)	Path-averaged $Q_{effective}$	T_star
S1133c	30.0 ± 1.3	127 ± 7	229	320	0.7146
S1094b	59.7 ± 0.0	464 ± 82	422	1117	0.3823
S1000a	64.2* ± 0.0	530 ± 126	464	1717	0.2702
S1102a	73.3 ± 5.1	1032 ± 111	500	1586	0.3153
S1415a	88.2 ± 11.1	1353 ± 33	576	1802	0.3196

* For S1000a, the penetration depth of PP wave at a distance of 128.3° is equivalent to the penetration depth of P wave at a distance of ~ 64.15°.

Supplementary Table 3 Lower limit of intrinsic Q in different layers.

	UL*	LL*	UM*	TZ*
S1133c	306 ± 3			
S1094b	196 ± 19	638 ± 124		
S1000a	235 ± 15	628 ± 74		
S1102a	162 ± 3	159 ± 4	612 ± 11	
S1415a	153 ± 4	332 ± 5	529 ± 16	746 ± 6

* UL: Upper lithosphere LL: Lower lithosphere UM: Upper mantle TZ: Transition zone

Supplementary Table 4 Mineral stability at the top of the mantle transition zone (1700 K and 14 GPa) for both Earth and Mars.

Stable minerals	Earth		Mars	
	wt (%)	mol (%)	wt (%)	mol (%)
Clinopyroxene (cpx)	11.70	10.63	16.93	17.00
Wadsleyite	57.44	75.29	48.23	65.84
Garnet	30.86	14.08	34.84	17.17