Regional Crustal and Lithospheric Thickness Model for Alaska, the Chukchi Shelf, and the Inner and Outer Bering Shelves

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Abstract

We present an integrated image of the lithosphere of Alaska and its western Chukchi and Bering seas shelves based on joint modeling of potential field data constrained by thermal analysis and seismic data. We also perform 3D forward modelling and inversion of Bouguer anomalies to analyze crustal density heterogeneities. The obtained crustal model shows NW regional thickening (32 to 36 km), with localized trends of thicker crust in the Brooks Range (40 km) and in the Alaska and St. Elias ranges (50 km). Offshore, 28–30 km thick crust is obtained near the Bearing slope break and 36–38 km in the northern Chukchi Shelf. In interior Alaska, the crustal thickness changes abruptly across the Denali fault, from 34-36 to the N to above 30 km to the S, that agrees with the presence of a crustal tectonic buttress guiding block motion W and S to the subduction zone. The average crustal density is 2810 kg[?]m-3. Denser crust (2910 kg[?]m-3) is found S of the Denali Fault related to the oceanic nature of the Wrangellia Composite Terrane rocks. Offshore, less dense crust (< 2800 kg[?]m-3) is found along the basins of the Chukchi and Beaufort shelves. At LAB levels, there is a regional SE–NW trend that coincides with the Pacific plate motion, with a lithospheric root beneath the Brooks Range, Northern Slope, and Chuckchi Sea, that may be a relic of the Chukotka-Artic Alaska microplate. The lithospheric root (> 180 km) agrees with the presence of a boundary of cold, strong lithosphere that deflects the strain to the south. South of the Denali Fault the LAB topography is quite complex. East of 150 °W, below Wrangellia and the eastern side of Chugach terranes, the LAB is much shallower than it is west of this meridian. The NW trending limit separating thinner lithosphere in the East and thicker in the West agrees with the two–tiered slab shape of the subducting Pacific Plate. This research has been funded by the We–Me project (PIE–CSIC–201330E111), AGUR 2017–SGR–847, Alpimed (PIE-CSIC-201530E082), Subtetis (PIE-CSIC-201830E039) and funds from the University of Houston. This is a contribution within the PolarCSIC platform. Ref: M. Torne, I. Jiménez–Munt, J. Vergés, M. Fernàndez, A. Carballo, M. Jadamec. Geophysical Journal International, Volume 220, Issue 1, January 2020, Pages 522–540, https://doi.org/10.1093/gji/ggz424.

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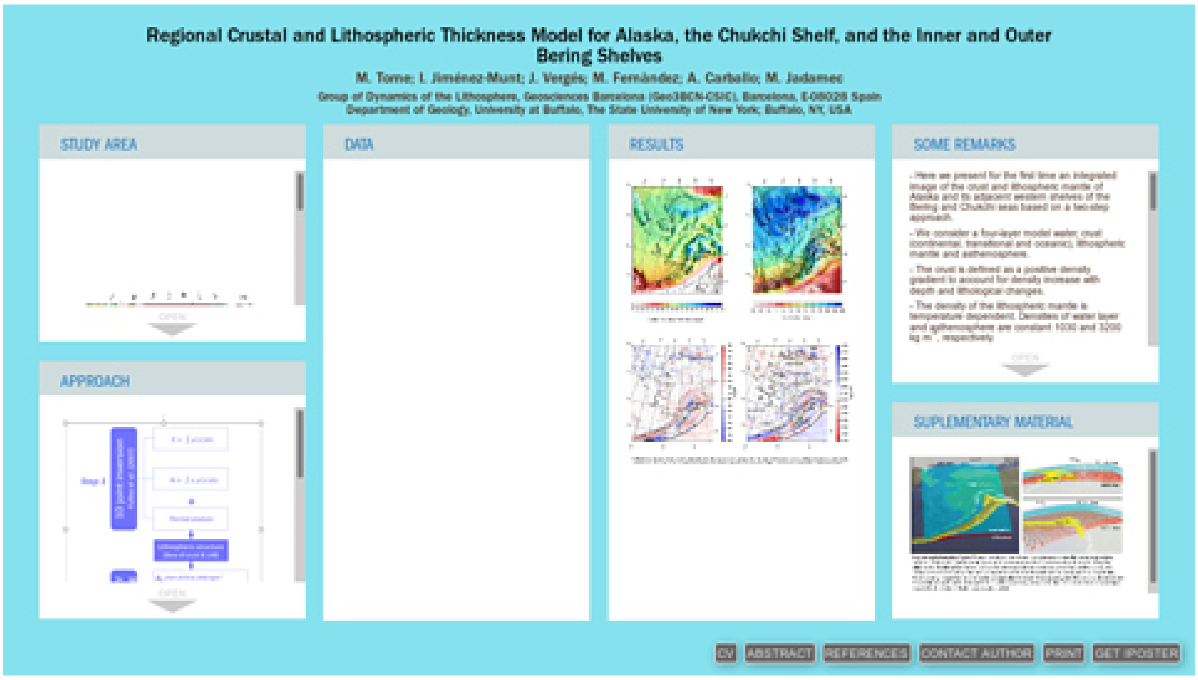

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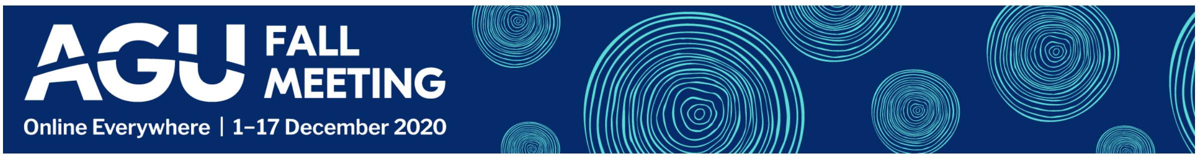
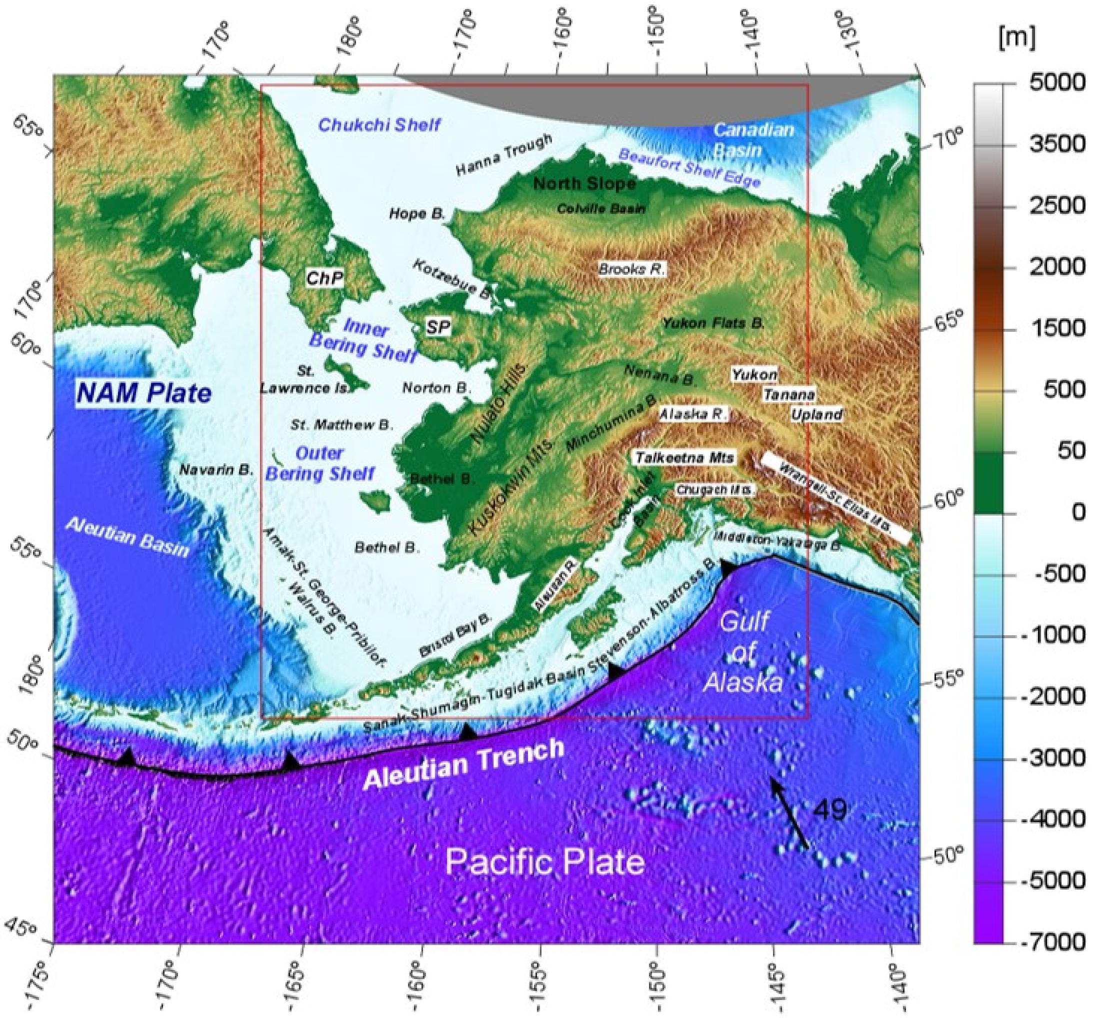


STUDY AREA



One of the main goals concerning the Earth's outermost structure is to provide crucial information not only for interpreting the lithospheric structure, but also how the lithospheric–sublithospheric system responds to perturbations arising from shortening, rifting and sublithospheric convection. Knowledge of the structure of the lithosphere is an essential requirement for understanding (1) the relationship between surface characteristics and deep processes, (2) the physical interactions between the lithosphere and sublithospheric mantle (3) the origin and evolution of the lithosphere and (4) the nature of the lithosphere–asthenosphere coupling.

In mainland Alaska and the western offshore domains, the depth to the lithosphere–asthenosphere boundary (LAB) has been determined in part by global scale models of the thermal lithosphere (e.g., Artemieva 2006) and by seismic tomography studies (e.g., Simmons et al. 2012) also local models based on SRF has added additional information (e.g., O'Driscoll and Miller).

Previous studies have also aimed to resolve the crustal structure for different regions of the Alaska mainland and offshore domains. Active source experiments, seismic tomography imaging, and analysis of receiver functions together with the deployment of the US Transportable Array (TA) have allowed mapping out the Moho topography of onshore Alaska in more detail.

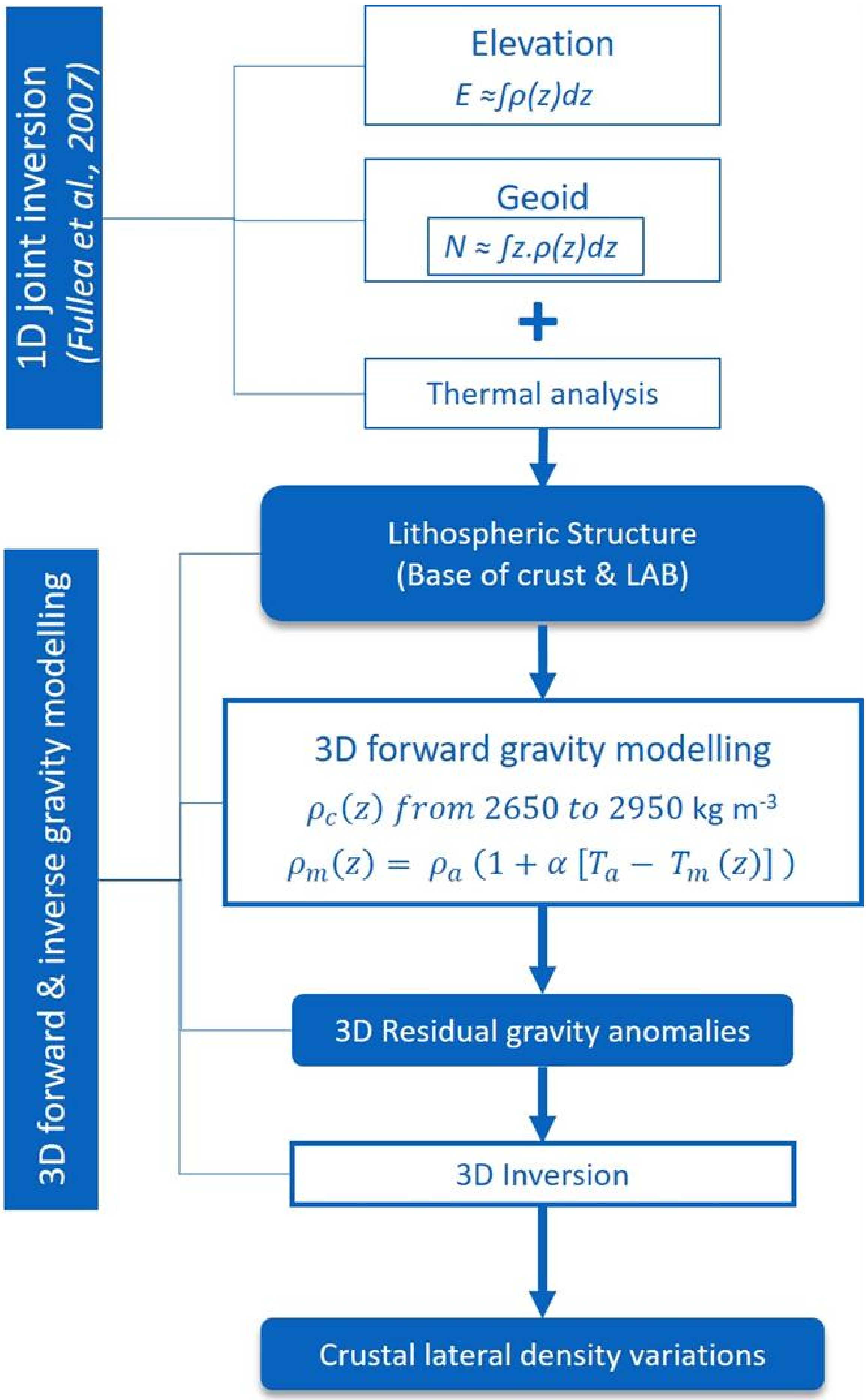
Compilation of available data sets shows that in spite of the tremendous efforts there are still uncovered areas, particularly in the northern onshore and offshore regions, where the location of permanent broadband stations is very limited.

Thus, the main goal of this work is to extend the existing crustal thickness models of mainland Alaska into western Alaska, the eastern Aleutian Islands, the Chukchi Shelf, Inner and Outer Bering shelf, and the easternmost Chukchi Peninsula and to investigate the topography of the thermal LAB over the whole region.

To that purpose, we present a lithospheric model based on joint modelling of elevation and geoid height data together with thermal analysis. We also perform 3D forward and inverse modelling of Bouguer gravity anomalies to validate the obtained lithospheric structure, to analyze areas that depart from local isostasy, and to map crustal density heterogeneities.

The method follows from that applied to estimate the crustal and lithospheric mantle geometry in a variety of tectonic settings, e.g., the Gibraltar Arc System (Fullea et al. 2007), the Arabia–Eurasia collision zone (Jiménez–Munt et al. 2012), Central Asia (Robert et al. 2015), the Iberian mainland (Torne et al. 2015) and the African continent (Globig et al. 2016).

APPROACH

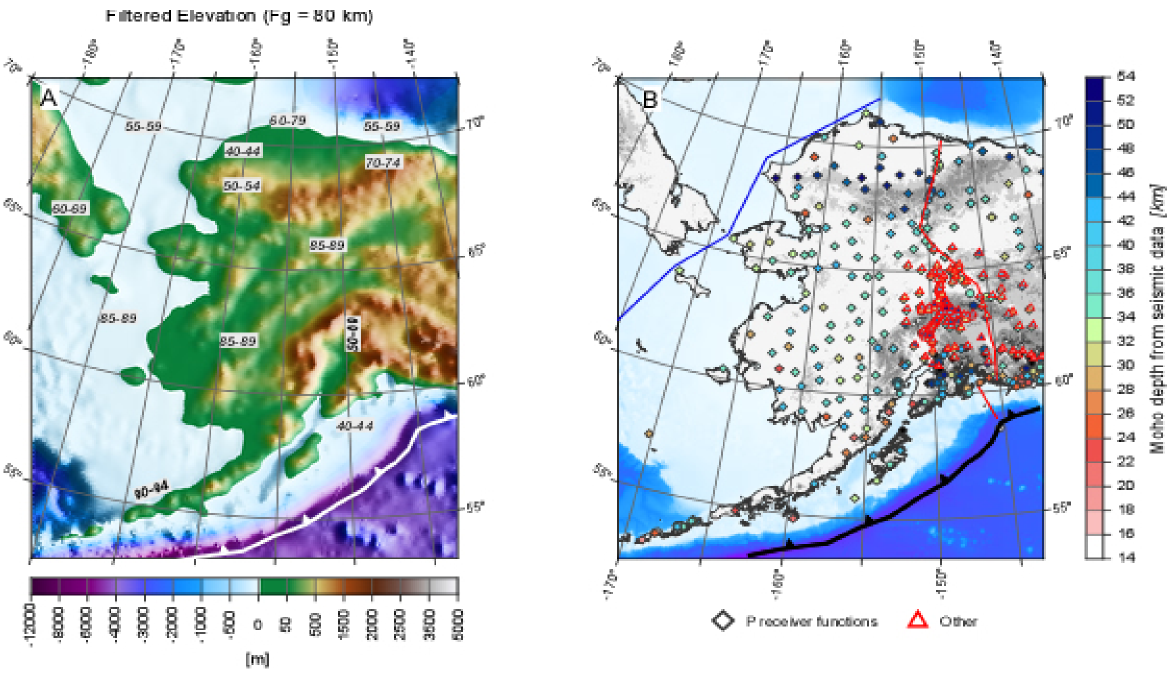

1D joint inversion
(Fullea et al., 2007)
Elevation
$E \approx \int \rho(z)dz$
Geoid
$N \approx \int z.\rho(z)dz$
+
Thermal analysis
Lithospheric Structure
(Base of crust & LAB)
3D forward & inverse gravity modelling
3D forward gravity modelling
$\rho_c(z)$ from 2650 to 2950 kg m^{-3}
$\rho_m(z) = \rho_a (1 + \alpha [T_a - T_m(z)])$
3D Residual gravity anomalies
3D Inversion
Crustal lateral density variations

We consider a four-layer model composed of water, the crust (continental, transitional and oceanic), the lithospheric mantle and the asthenosphere. The crust is defined as a positive density gradient to account for density increase with depth and lithological changes while the density of the lithospheric mantle is temperature dependent. Thermal regime is steady state considering radioactive heat production in the crust but neglecting it in the mantle.

	Heat Production (A) (μW m^{-3})	Thermal Conductivity (k) (W/(K · m))	Density (ρ) (kg m^{-3})
Continental crust	0.8	2.5	Increases linearly with depth
Oceanic crust	0.3	2.1	Increases linearly with depth
Lithospheric mantle	0.0	3.2	T dependent
Sea water	-	-	1030
Top of crust	Same as above	Same as above	2670
Base of crust	Same as above	Same as above	2950
Asthenosphere	-	-	3200

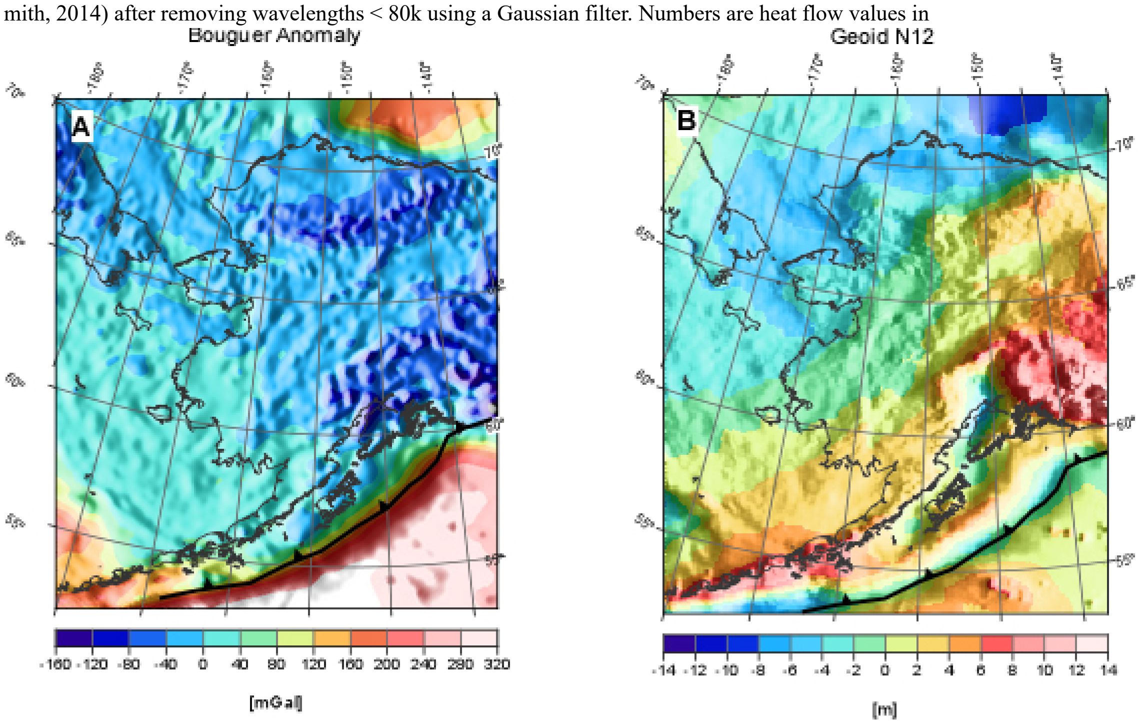
Parameters used in crust and lithosphere models. Average crustal density is 2810 (kg·m^{-3}). Models assume a surface temperature, Ts, of 0 ^{o}C and temperature at the lithosphere-asthenosphere boundary, Ta, of 1330 ^{o}C. The coefficient of thermal expansion, α, is a constant value of 3.5 x 10^{-5} K^{-1}.

DATA



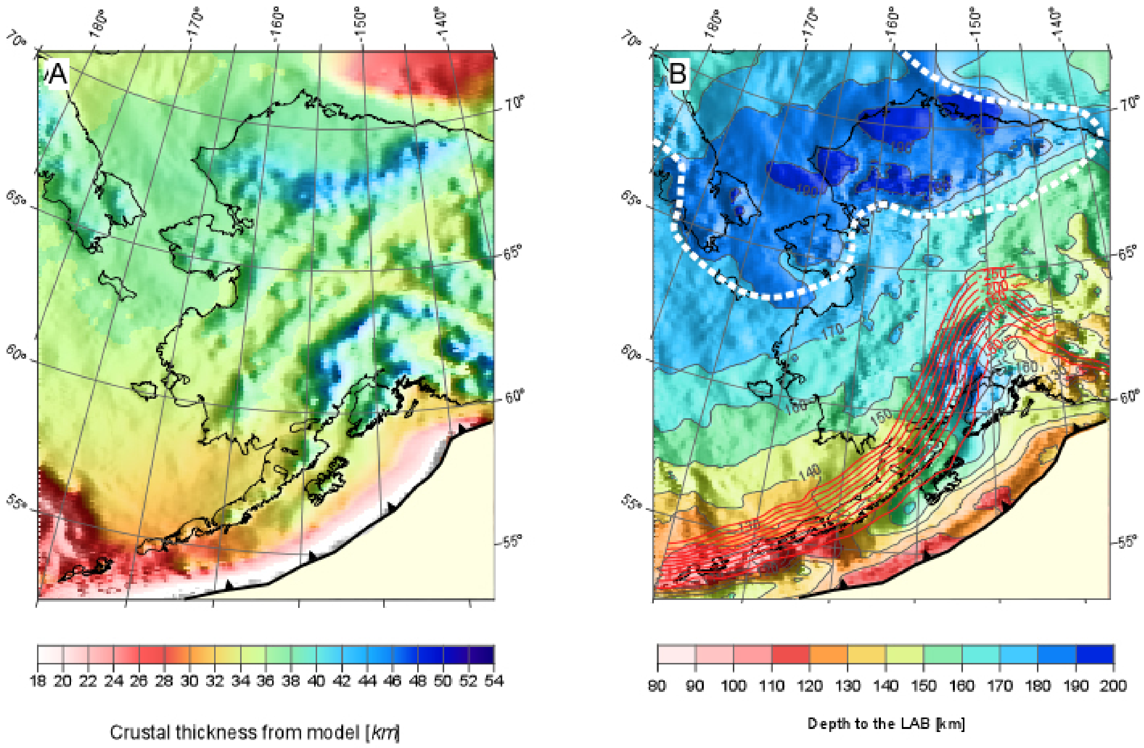
A) Elevation data from topo 19.1 img (Sandwell et al., 2014) after removing wavelengths < 80 km using a Gaussian filter (https://topex.ucsd.edu/pub/global topo 1 min/). Numbers are heat flow values in mWm^{-2}. B) Seismic data collected to constrain the 3D lithospheric model. Diamonds: RF analyses form Miller et al. (2018); Miller & Moresi (2018); Rossi et al. (2006) and Ai et al. (2005). Triangles indicate seismic data from various authors (see references). Onshore red line shows location of the Trans Alaska Transect (Fuis et al., 2008). Offshore blue line shows MCS profile from Klemperer et al. (2002).

mith, 2014) after removing wavelengths < 80k using a Gaussian filter. Numbers are heat flow values in

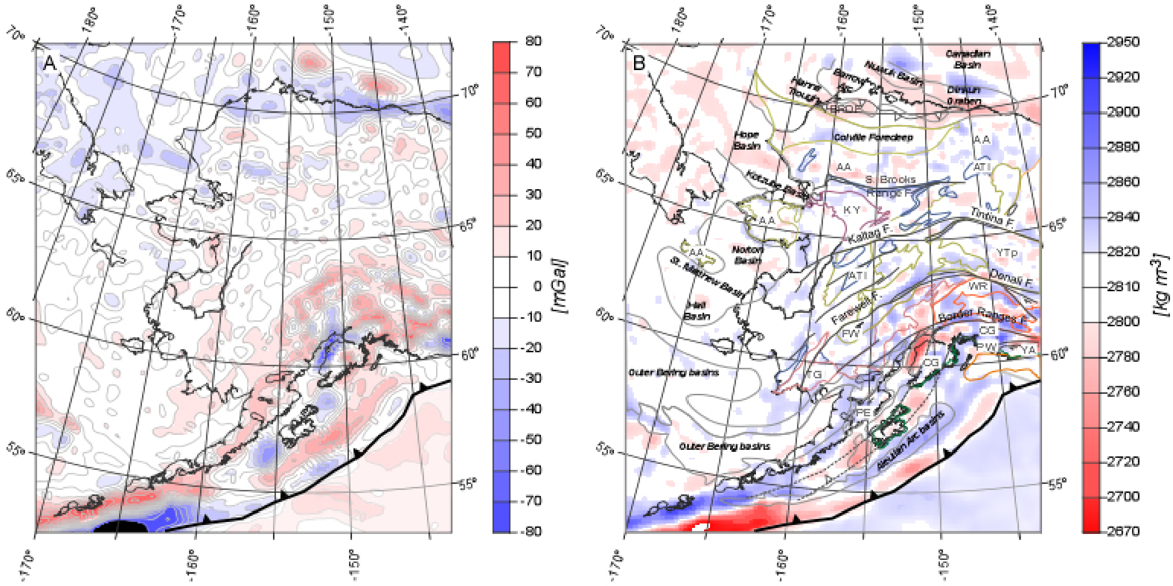


A) Bouguer anomaly derived from the Free Air anomaly satellite data compilation by Sandwell et al. (2014). Density reduction is 2670 kgm^{-3}. (https://topex.ucsd.edu/pub/global grav 1 min/).
B) Geoid anomal from GECO Global Model (Gilardoni et al., 2016). Long wavelengths have been removed up to degree and order 12. A low-pass Gaussian filter of 80 km has been applied to remove short-wave lengths effects. Details on Bouguer and Geoid reduction can be found in Torne et al. (2020).
mWm−2.

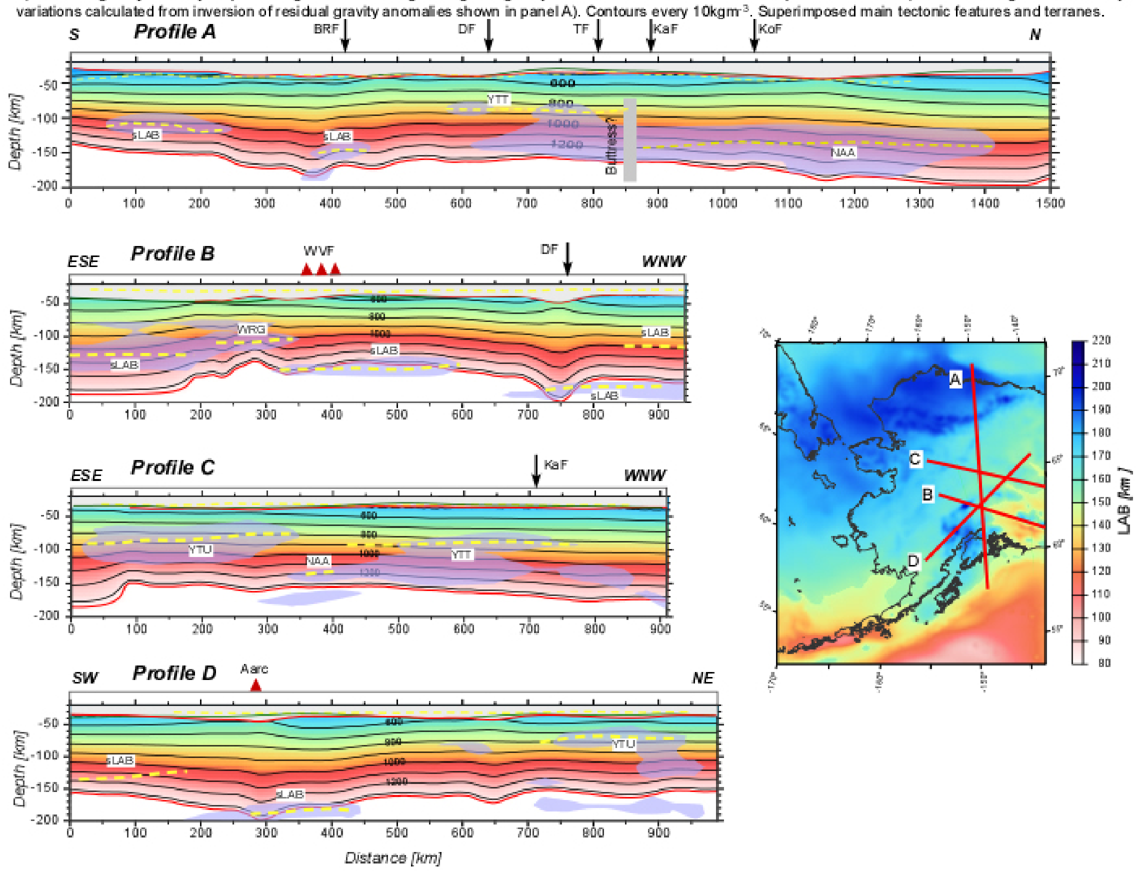
RESULTS



A) Crustal thickness from model. B) Depth to the LAB. Dashed white line shows position of the Chukotka-Artic Alaska microplate. Red lines show depth to top of the subducting plate (Model slabE115 of Jadamec & Billen, 2010)



A) Residual gravity anomaly map resulting from subtracting the regional gravity calculated from the obtained lithospheric structure. B) Lateral average crustal density variations calculated from inversion of residual gravity anomalies shown in panel A). Contours every 10kgm^{-3}. Superimposed main tectonic features and terranes.



Moho and LAB depths of this study compared to PRF & SRF. Colour palette is T. Lines: red is Moho & LAB; green PRF; yellow thin SRF; yellow thick dashed SRF LAB. Light grey areas shaded show the crust from this study. Blue light shaded show areas of SRF negative conversions. Red triangles: Quaternary volcanoes. Volcanic fields: WVF–Wrangell andArc–Aleutian. Faults: BRF–Border Ranges, DF–Denali, KaF–Kaltag, KoF–Kobuk, TF–Tintina. Terranes: YTT–Yukon–Tanana Terrane, YTU–Yukon–Tanana Upland, NAA–North Alaska Arctic. sLAB–slab LAB. See references

SOME REMARKS

- Here we present for the first time an integrated image of the crust and lithospheric mantle of Alaska and its adjacent western shelves of the Bering and Chukchi seas.

- Results show a long wavelength NW directed crustal thickening (32-36 km) superimposed over onshore Alaska with two local crustal thickening trends that broadly correlate with topography.

- Crustal thicknesses above 40 and 50 km are found in the northern Brooks Range and in the Alaska and St Elias ranges, respectively

- The sharp crustal thickness gradient along the Denali Fault agrees with the presence of a crustal tectonic buttress that would facilitate an 'escape tectonics' scenario in which the crustal curvature is guiding block motion west and south towards the subduction zone.

- Offshore, north of St Lawrence Island, we observe a slightly anomalous thick crust relative to the shallow bathymetry of the area, gently thickening towards the Chukchi Shelf.

- The denser crust, up to 2910 $kg{\cdot}m^{-3}$, is found south of the Denali Fault likely related to the oceanic nature of the Wrangellia Composite Terrane and the high P-wave velocity recorded at mid lower crustal levels below the Chugach Terrane.

- Some low-density anomalies are interspersed, highlighting the low associated with the forearc Cook Inlet Basin.

- Offshore, less dense crust (below 2780–2800 $kg{\cdot}m^{-3}$) is found along the Chukchi and Beaufort shelves, which relates to the sedimentary infill of the South Chukchi (Hope) and Nuwuk–Dinkum–Kaktovik basins, respectively.

- The two high density anomalies (above 2860 $kg{\cdot}m^{-3}$) following the trend of the Beaufort continental shelf break are likely related to the presence of a basement ridge on the outer shelf. However, we cannot rule out that the presence of high density rocks at mid-to-lower crust levels (e.g. uppermost mantle rocks).

- At LAB levels, there is a regional SE–NW trend that coincides with the current motion of the subducting Pacific Plate.

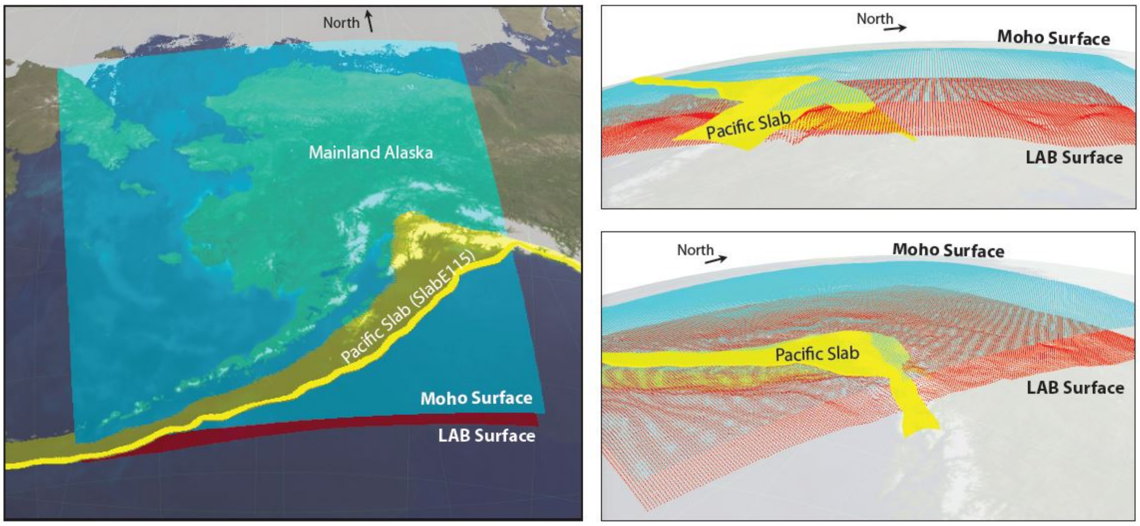
- A lithospheric root (above 180 km) is observed underneath the Brooks Range, Northern Slope and Chuckchi Sea, that may correspond to a relic of the Chukotka-Artic Alaska microplate.

- The lithospheric root agrees with the presence of a boundary of cold, strong lithosphere that deflects the strain towards the South, thus influencing the current geometry of the Brooks Range belt and the southern regions.

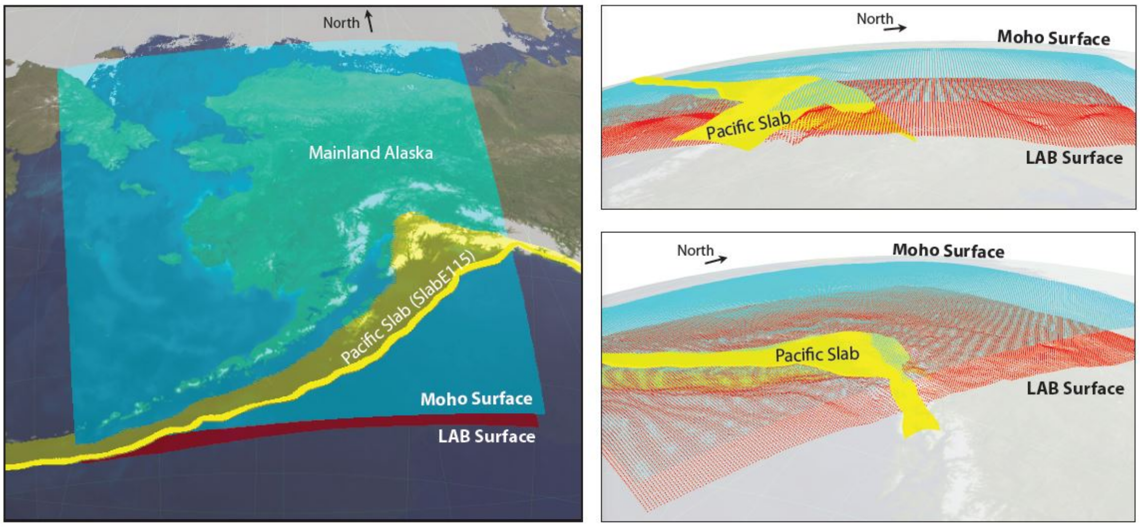
- South of the Denali Fault the LAB topography is quite complex. East of 150W, below Wrangellia and the eastern side of Chugach terranes the LAB is much shallower than it is west of this meridian.

- The NW trending limit separating the thinner lithosphere in the east and thick lithosphere in the west agrees with the two-tiered slab shape of the subducting Pacific Plate and with tomographic data.

SUPLEMENTARY MATERIAL



Supporting Information Figure: Three-dimensional view of data in supplementary data file containing predicted continous moho surface (shown in blue) and predicted continous LAB surface (shown in red) from this study. The SlabE115 Pacific slab surface (yellow) is shown for reference (Jadamec and Billen, 2010). Predicted Moho and LAB surfaces are generated using a flat earth assumption over the model domain (see main manuscript text for details). Accompanying images here help the reader conceptualize the data in the supporting data files and provide perspective for the relative depths of the Moho and LAB, as well as where they intersect the flat slab in south central Alaska. Image rendered with ShowEarthModel (Jadamec et al., 2018).



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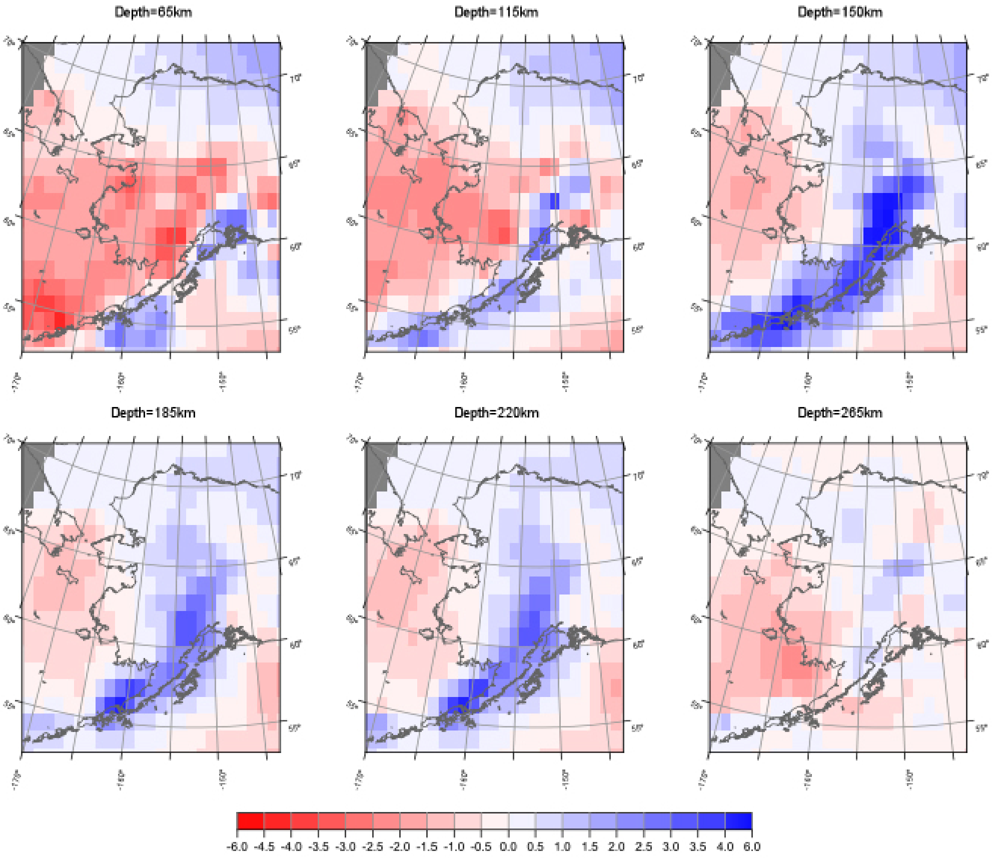

P velocity variation % from tomographic model of Simmons et al. (2012)

AUTHOR INFORMATION

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My main research interest is the study of the structure and composition of the earth's lithosphere and its interaction with the asthenosphere. In particular, most of my research activities are focused on three main objectives: 1) The study of the crustal and lithospheric structure and properties. 2) The study of the long-term evolution of the lithosphere coupling surface and deep processes. 3) The development of 2D and 3D models using gravity, geoid, elevation and thermal data. I have worked at different scales, depths and tectonic scenarios. The study areas include: the Iberian Peninsula and its sorrounding margins (Atlantic and Mediterranean); Africa; Norwegian margin; SE and SW Pacific active margins (Chile and Tonga and Kermadec trenches).

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ABSTRACT

We present an integrated image of the lithosphere of Alaska and its western Chukchi and Bering seas shelves based on joint modeling of potential field data constrained by thermal analysis and seismic data. We also perform 3D forward modelling and inversion of Bouguer anomalies to analyze crustal density heterogeneities. The obtained crustal model shows NW regional thickening (32 to 36 km), with localized trends of thicker crust in the Brooks Range (40 km) and in the Alaska and St. Elias ranges (50 km). Offshore, 28–30 km thick crust is obtained near the Bearing slope break and 36–38 km in the northern Chukchi Shelf. In interior Alaska, the crustal thickness changes abruptly across the Denali fault, from 34-36 to the N to above 30 km to the S, that agrees with the presence of a crustal tectonic buttress guiding block motion W and S to the subduction zone. The average crustal density is 2810 $kg{\cdot}m^{-3}$. Denser crust (2910 $kg{\cdot}m^{-3}$) is found S of the Denali Fault related to the oceanic nature of the Wrangellia Composite Terrane rocks. Offshore, less dense crust (< 2800 $kg{\cdot}m^{-3}$) is found along the basins of the Chukchi and Beaufort shelves. At LAB levels, there is a regional SE–NW trend that coincides with the Pacific plate motion, with a lithospheric root beneath the Brooks Range, Northern Slope, and Chuckchi Sea, that may be a relic of the Chukotka-Artic Alaska microplate. The lithospheric root (> 180 km) agrees with the presence of a boundary of cold, strong lithosphere that deflects the strain to the south. South of the Denali Fault the LAB topography is quite complex. East of 150 °W, below Wrangellia and the eastern side of Chugach terranes, the LAB is much shallower than it is west of this meridian. The NW trending limit separating thinner lithosphere in the East and thicker in the West agrees with the two–tiered slab shape of the subducting Pacific Plate.

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