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P.R.K. Brennan
Purdue University

H. Gilbert
Purdue University

K. D. Ridgway
Purdue

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Crustal structure across the central Alaska Range: Anatomy of a Mesozoic collisional zone

Patrick R. K. Brennan, Hersh Gilbert, and Kenneth D. Ridgway

Department of Earth and Atmospheric Sciences, Purdue University, 550 Stadium Mall Drive,
West Lafayette, Indiana 47907, USA (prbrenna@purdue.edu)

[1] A first-order process in the growth of continents is the collision and accretion of terranes against continental margins. Collision leads to the formation of a suture zone between the accreted terrane and the former continental margin. New insights on the suturing process are observed from two receiver function transects across the Mesozoic Alaska Range suture zone. Three distinct crustal sections are identified from observations of crustal thickness, intracrustal discontinuities, and Vp/Vs: a northern section with ~27 km thick crust of felsic to intermediate composition, a central section that is ~37 km thick that exhibits intracrustal discontinuities and has felsic to intermediate composition, and a southern section that is ~30 km thick and has a more mafic composition. We interpret these sections to correspond with the former continental margin (Yukon composite terrane), the suture zone proper, and the allochthonous oceanic terrane (Wrangellia composite terrane). The boundary between the Yukon composite terrane and the suture zone appears to be a subhorizontal discontinuity that accommodated underthrusting of crust from the suture zone beneath the former continental margin. The boundary between the suture zone and the Wrangellia composite terrane, in contrast, appears to be a relatively discrete, vertical boundary. The observed variability in the crust across the Alaska Range suture zone is likely controlled by the differing compositions of the terranes involved, which influences how each section responds to precollisional, syncollisional, and postcollisional deformation.

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1. Introduction

[2] The collision of oceanic island arcs and plateaus, slivers of rifted continental margins, and other allochthonous terranes with continental margins is one of the primary ways that continents increase in size. The process of terrane accretion results in the development of a suture zone between the former continental margin and the colliding rock

mass. The pivotal work of Coney *et al.* [1980] and Jones *et al.* [1983] highlighted the importance of this process along the Cordilleran margin. Since its recognition, terrane accretion has been shown to be an important process in numerous locations and times throughout geologic history [e.g., Ramos *et al.*, 1986; Metcalfe, 1996; Isozaki, 1997; Pharaoh, 1999; Xiao *et al.*, 2004]. The upper crustal configuration of suture zones can be delineated

through geologic mapping and field studies [e.g., Jones *et al.*, 1982; Moores, 1981; Ridgway *et al.*, 1997; Trop and Ridgway, 1997; Cole *et al.*, 1999; Ridgway *et al.*, 2002]. Suture zones, however, as a result of the collisional processes that form them are inherently crustal if not lithospheric in scale. To fully image a suture zone it is necessary to incorporate geophysical techniques that provide observations of the structures in the subsurface of a suture zone.

[3] Suture zones are not only syncollisional features but also serve as potential postcollisional zones of reactivation. The long-term growth of continents through collision effectively seeds the crust with inherently weak zones (i.e., former suture zones) that are frequently reactivated throughout the geologic history of the continent [e.g., Hendrix *et al.*, 1992, 1996; Graham *et al.*, 1993; Ziegler *et al.*, 1995; Ranalli, 2000; Holdsworth *et al.*, 2001; Butler *et al.*, 2006].

[4] The central Alaska Range is an ideal location to examine the crustal structure of a suture zone because the well-exposed surface geology documents a clear transition from oceanic to continental crust [Ridgway *et al.*, 2002; Manuszak *et al.*, 2007]. Previous studies in the central Alaska Range have focused on the crustal thickness [Ai *et al.*, 2005; Veenstra *et al.*, 2006], the character of the mantle [Stachnik *et al.*, 2004], and the structure of the downgoing slab [Abers *et al.*, 2002]. To better understand the crustal-scale structure and geometry of the Alaska Range suture zone, we have calculated receiver function transects that traverse the suture zone and its major structures. The receiver functions help identify discontinuities within the crust and upper mantle of the suture zone. From observations of crustal thickness, intracrustal discontinuities, and Vp/Vs it becomes possible to delineate the major components of the suture zone, as it transitions from continental to oceanic affinity crust. We interpret that the distribution of deformation within the central Alaska Range is likely controlled by compositional variations in the different types of crust juxtaposed within the suture zone.

2. Background and Previous Studies

2.1. Geologic Background

[5] The North American Cordillera has a long-lived history of terranes colliding and accreting to the continental margin [Coney *et al.*, 1980; Ben-Avraham *et al.*, 1981; Nokleberg *et al.*, 1998].

One of the largest additions of juvenile crust to the Cordilleran margin is the Mesozoic accretion of the Wrangellia composite terrane (Figure 1) [Csejtey *et al.*, 1982; Nokleberg *et al.*, 1985]. Collision of the Wrangellia composite terrane occurred with the western margin of North America during middle Jurassic to late Cretaceous time [Pavlis, 1982; McClelland *et al.*, 1992a; Manuszak *et al.*, 2007]. Currently, exposures of the Wrangellia composite terrane extend from Vancouver Island, British Columbia northwestward to western Alaska (Figure 1) [Jones *et al.*, 1977; Greene *et al.*, 2010].

[6] In the Alaska Range, the suture zone between the continental margin rocks of the Yukon composite terrane and oceanic rocks of the Wrangellia composite terrane is referred to as the Alaska Range suture zone (Figures 1, 2, and 3a) [Ridgway *et al.*, 2002]. This suture zone extends from the southernmost exposures of the Yukon composite terrane in the Northern Foothills region (Figures 1, 2, and 3a) to the northernmost exposures of the Wrangellia composite terrane in the Northern Talkeetna Mountains region (Figure 2). From north to south the study area is composed of three major geologic features:

[7] 1. The northern section consists of continental affinity metamorphic and granitoid rocks of the Yukon composite terrane that are partially overlain by sedimentary strata of the Neogene Tanana basin (Figures 2 and 3a) [Dusel-Bacon, 1994; Foster *et al.*, 1994; Ridgway *et al.*, 2007; Dusel-Bacon and Williams, 2009]. The Northern Foothills and the Kantishna Hills regions represent the southernmost exposures of Yukon composite terrane rocks in our study area (Figures 1 and 3a).

[8] 2. The central section to the south, which contains both the Alaska Range and Northern Talkeetna Mountains, consists of a complex assemblage of Paleozoic to Cretaceous metamorphic, sedimentary, and igneous rocks. These rocks are overlain by sedimentary and volcanic strata of the Late Jurassic to Late Cretaceous Kahiltna basin and Late Cretaceous to Eocene Cantwell basin (Figures 2 and 3a) [Hickman *et al.*, 1990; Csejtey *et al.*, 1992; Ridgway *et al.*, 1997; Cole *et al.*, 1999; Ridgway *et al.*, 2002].

[9] 3. The southern section of our study area consists of the Wrangellia composite terrane (Figures 1 and 3a), which includes the Wrangellia terrane, an oceanic plateau with associated marine sedimentary strata; the Peninsular terrane, an assemblage of volcanic arc rocks; and the Alexander terrane, a crustal fragment of metamorphosed volcanic arc and sedimentary rocks [Csejtey *et al.*, 1992; Gehrels

Figure 1. Generalized terrane map of the northern North America Cordillera. The locations of sedimentary strata representing Mesozoic basins that formed along the suture zone between the Yukon composite and the Wrangellia composite terranes, and major fault systems are shown. See text for description. Location of Figures 2, 3a, and 3b is shown by the dashed box. Modified from *Plafker and Berg* [1994], *Gehrels and Kapp* [1998], and *Trop et al.* [2002].

and Berg, 1994; *Plafker and Berg*, 1994; *Nokleberg et al.*, 1994]; these individual terranes were juxtaposed in late Paleozoic time [*Gardner et al.*, 1988; *Plafker et al.*, 1989]. The Alaska Range suture zone contains several major faults. These faults include from north to south, the Hines Creek and McKinley strands of the Denali fault system and the Talkeetna fault (Figures 1, 2, and 3a) [*Wahrhaftig et al.*, 1975; *Lanphere*, 1978; *Sherwood*, 1979].

2.2. Previous Work

[10] Previous geophysical studies both within and adjacent to our study area provide a framework for the characterization of the crust and upper mantle of the Alaska Range suture zone. Additionally, these studies provide an opportunity for direct and along-strike comparison to our observations.

[11] At the scale of the suture zone and the adjoining terranes, two distinct geophysical domains have been identified through aeromagnetic and gravity surveys of south-central Alaska (Figure 3b) [*Saltus et al.*, 1997, 1999; *Brunstein*, 2002; *Glen et al.*, 2007; *Saltus et al.*, 2007]. These domains include the southern Alaska magnetic trough and the southern

Alaska magnetic high (terminology of *Saltus et al.* [2007], and used herein), or the north Talkeetna and Kahiltina Flysch basins, respectively, and Wrangellia domains (terminology of *Glen et al.* [2007]). The southern Alaska magnetic trough has a low magnetic and gravity signature over both the Alaska Range and Northern Talkeetna Mountains regions of our study area (Figures 2, 3a, and 3b). This magnetic domain generally coincides with the previously described region of the Alaska Range suture zone (Figures 3a and 3b). A sharp gradient in magnetic potential delineates the boundary between the two main geophysical domains (Figure 3b). The boundary between the geophysical domains is additionally observed from the Bouguer gravity signature for the same region, where lower values (~12 to 55 mGal) correlate closely with the magnetic trough domain and higher values (~55 to 95 mGal) correlate with the magnetic high domain [*Saltus et al.*, 2007]. The southern Alaska magnetic high represents a regional high in both gravity and magnetic potential that correlates to the Wrangellia composite terrane (Figures 2, 3a, and 3b). This magnetic and gravity high is attributed to thick, dense, mafic rocks of the Wrangellia composite

Figure 2. Shaded relief map of the study area showing receiver function transect lines, seismic station locations, and major fault systems. Colored triangles indicate stations used in this study and are colored to match the transect line to which they are projected. Upright triangles indicate stations from the BEAAR temporary deployment, and upside-down triangles indicate permanent seismic stations of the AEIC. The location of the TACT transect is shown by the white lines. Major faults are outlined by heavy black lines: DF (M), McKinley fault; HCF, Hines Creek fault; TF, Talcote fault; DF (E), Eastern Denali fault; CMF, Castle Mountain fault; BRF, Border Ranges fault. Yellow star shows the location of the *M* 7.9 2002 Denali earthquake. The black star shows the location of Mt. McKinley (Denali), which has an elevation of 6194 m. Major towns are shown by black polygons.

terrane [Saltus *et al.*, 2007; Glen *et al.*, 2007]. Although not identified as a separate geophysical domain in previous studies, a smaller gradient in magnetic potential delineates a distinct region of increased magnetic potential (~ 300 nT/m) north of the Southern Alaska magnetic trough, which closely follows the outline of the Yukon composite terrane (Figures 3a and 3b).

[12] In addition to gravity and aeromagnetic surveys, seismic refraction and wide-angle reflection studies of the Trans Alaska Crustal Transect (TACT) provide detailed images of the crust and seismic velocity models for the region directly east

of the Alaska Range suture zone (Figure 2) [Fuis *et al.*, 1987, 1991, 2008; Goodwin *et al.*, 1989; Beaudoin *et al.*, 1992, 1994; Brocher *et al.*, 2004]. These studies provide valuable along-strike constraints on both the crustal structure and composition of the Yukon and Wrangellia composite terranes, and can be used for comparison to the crustal structure and geometry of the suture zone.

[13] More recent seismic investigations of south-central Alaska include studies using data from the Broadband Experiment Across the Alaska Range (BEAAR), which was used to identify crustal thickness from receiver function analysis [Ai *et al.*, 2005; Veenstra *et al.*, 2006] and to provide crustal and upper mantle V_p and V_p/V_s measurements from tomographic analysis [Eberhart-Phillips *et al.*, 2006]. Our investigation builds on these previous studies by using seismic records from both the temporary BEAAR deployment and permanent broadband stations in the central Alaska Range. These previous studies have focused mainly on delineating the downgoing (Yakutat) slab beneath south-central Alaska and on providing estimates of crustal thickness. Our study, in contrast, focuses on the crustal structure and composition of the upper plate from the Moho to the surface.

3. Data and Analysis

3.1. Receiver Functions

[14] This study uses teleseismic recordings from three-component broadband stations to calculate receiver functions that isolate the receiver side converted S waves from incident P waves. Receiver functions, which are sensitive to changes in S wave velocities, have been widely used to study the crust and upper mantle [e.g., Phinney, 1964; Langston, 1977; Owens *et al.*, 1987; Sheehan *et al.*, 1995; Gilbert *et al.*, 2006].

[15] A total of 35 seismic stations are used in this study, these include three-component broadband stations from both permanent stations of the Alaska Earthquake Information Center (AEIC) and temporary stations from BEAAR (Figure 2) (see Abers *et al.* [2002] for a description of the BEAAR deployment) [Ferris *et al.*, 2003; Stachnik *et al.*, 2004; Veenstra *et al.*, 2006]. P waves from 505 events recorded by these stations were visually inspected, and only those with a minimum signal-to-noise ratio of three to one for a time window of 50 s before the P wave arrival on the vertical and radial components were further processed. The horizontal

Figure 3. (a) Simplified geologic map of south-central Alaska. This map is at the same scale as Figure 3b to allow comparison of geologic features to the regional magnetic potential map. Modified from *Trop and Ridgway* [2007]. (b) Magnetic potential map of southern Alaska. Southern Alaska magnetic trough and high are geophysical domains defined by *Saltus et al.* [2007]. A steep gradient in magnetic potential separates the magnetic high from the trough. Also note that a similar, though smaller magnitude, gradient in magnetic potential bounds the northern side of the magnetic trough. The magnetic trough roughly correlates to the Kahiltna basin and the high to the Wrangellia composite terrane (both shown in Figure 3a). Major fault systems are shown by white lines. Modified from *Saltus et al.* [1999] and *Brunstein* [2002].

components of these records were rotated into the radial and tangential coordinate system defined by the station and event locations. To isolate the signal of the Earth structure, we deconvolve the vertical signal from the radial, using an iterative procedure in the time domain [*Ligorria and Ammon*, 1999], which produces the receiver functions that contain the converted S waves. This procedure yielded 2,283 receiver functions for the study area. The receiver functions were filtered using Gaussian pulse width of 2.5 which corresponds to an approximate frequency content of 1.2 Hz. Prior to stacking, the receiver functions are migrated from time to depth using the three-dimensional tomographic model of *Eberhart-Phillips et al.* [2006], this accounts for lateral variations in V_p and V_p/V_s along our transects. The tomographic model of *Eberhart-Phillips et al.* [2006] uses many of the same stations as our receiver function study. In tomographic studies, the area where the raypaths of seismic waves cross represents the most well resolved portion of the model, which occurs at depths from the midcrust to the shallow portion of

the upper mantle in the data set used by *Eberhart-Phillips et al.* [2006].

3.2. Receiver Function Stacking

[16] Stacking the depth-migrated receiver functions recorded by each station provides an estimate of the average structure beneath that station by enhancing the signal within the receiver functions and suppressing noise. The averaged stacks for each station are then compared to one another in order to examine variations between stations. Common conversion point (CCP) stacked receiver function transects are then constructed to explore the lateral extent of features identified in the single station analysis [*Dueker and Sheehan*, 1997, 1998; *Gilbert and Sheehan*, 2004]. Two, roughly perpendicular transects have been created that optimize the geometry of the stations used in the study (Figures 2 and 4a–4d). The stations that contribute data to each CCP transect were chosen based on their proximity to the profile of interest. The stations used in our CCP stacking were orthogonally pro-

Figure 4. CCP stacked receiver function (1.2 Hz frequency) transects along cross sections A–A' and B–B' (locations of transects shown in Figure 2). Simplified interpretations of the stacked receiver function transects are shown below the transects. (a) CCP stacked receiver function transect along transect A–A'. Positive arrivals are shown as red, whereas negative appear as blue. Stacked receiver functions for each column of CCP bins are shown by solid black lines. The topographic profile is averaged for a 10 km swath parallel to the line of transect and is shown 10 times vertically exaggerated. Regions discussed within the text are shown above the cross sections, as are major fault crossings. TF, Talkeetna fault; DF, Denali fault; HCF, Hines Creek fault. Distance along the transect is shown by x offset from the southern endpoint of the transect (A–A'). See text for discussion. (b) Interpreted CCP stacked receiver function for transect A–A'. The interpreted transect is presented below the CCP stacked transect for comparison to the data. The major arrivals are shown by colored polygons, which emphasize the geometry, extent, and depth of the arrivals. The Moho conversions are shown by brown polygons and are labeled with m followed by a number. Intracrustal discontinuities are red (corresponding to positive arrivals) or blue (corresponding to negative arrivals) and are labeled with i followed by a number. The steps in the Moho are labeled with s followed by a number. The individual interpretations are discussed in the text. The simplified profile of the subducting Yakutat slab is shown by the gray polygon; this polygon was determined from the tomography model of Eberhart-Phillips *et al.* [2006]. See Figure 5 for more information on location of Yakutat slab. (c) CCP stacked receiver function transect along cross section B–B'. (d) Interpreted CCP stacked receiver function transect along cross section B–B'.

Figure 4. (continued)

jected to the line of transect. Because projection results in the averaging of the subsurface region between the station and the profile line, which reaches a maximum distance of ~40 km along the southern portion of A–A'. We took care not to include stations that would average across major faults or terrane boundaries (Figure 2). We then calculated piercing points for the receiver functions at 2 km depth intervals to 100 km depth by tracing the raypaths using the velocity model of *Eberhart-Phillips et al.* [2006]. A series of circular common conversion bins with a radius of 25 km and a lateral spacing of 25 km were defined along each line of transect. Rays sampling areas outside of the common conversion point bins are not included in the

stacks. The receiver functions were then assigned to bins at each of the 2 km depth intervals to account for the horizontal offset of the raypath with depth.

[17] From the CCP transects, we present observations of variability in crustal thickness, intracrustal discontinuities, and V_p/V_s . The Moho is identified on receiver functions as a positive, high-amplitude phase that varies in depth from ~24 to 40 km in this area (Figures 4a–4d). The amplitudes of arrivals on receiver functions are proportional to the size of the velocity discontinuity that produced them. The Moho usually produces the highest-amplitude arrival within the lithosphere due to the large change

in seismic wave velocities between the crust and upper mantle.

3.3. Resolution of Receiver Function Analysis

[18] The vertical resolution of our receiver function analysis is dependent on the frequency content of the receiver functions and the velocity model used for time to depth migration. For the stacks presented here, with a frequency of 1.2 Hz and a S wave velocity of 4 km/s, the vertical resolution of the receiver functions is ~ 2 km, or one half the wavelength. Errors in the depth estimates of the receiver function arrivals could also arise from noisy data or from the velocity model that is used to migrate from time to depth. Errors resulting from noise, or other spurious signal that could degrade the receiver function peaks can be assessed using bootstrap resampling. This analysis indicates that noise is not leading to errors in our picked Moho depths by more than 2 km. As the tomographic model of *Eberhart-Phillips et al.* [2006] used data from the same stations as those used here, it provides the best possible estimates of crust and upper mantle seismic velocities of the central Alaska Range.

[19] The lateral resolution of the analysis is related to the station and bin spacing for a given transect; in our study the average stations spacing is ~ 15 km and center points of the bins are spaced every 25 km with each bin having a radius of 25 km. Because data within a bin is averaged together, we are not able to determine the extent of structures over distances less than the radius of a bin. The lateral smoothing of receiver function signals is a function of the spacing and radius of the stacking bins and the station spacing. The receiver function arrivals are weighted as a function of their distance from the bin center point. The full amplitude of traces sampling the center of a bin is stacked with a weight of one. Weighting linearly decreases to 1/2 at the bin edges.

3.4. Intracrustal Discontinuities

[20] Similar to the Moho arrival, receiver functions may also possess earlier arrivals resulting from intracrustal discontinuities. Care must be taken, however, while interpreting these signals as they could be influenced by scattering and multiples from basins or surface topography. The continuous nature of the midcrustal arrivals between multiple stations suggests that they do not originate from scattering or shallow multiples, which would not be

coherent from station to station. Instead, it appears that the arrivals correspond to intracrustal discontinuities resulting from compositional changes, anisotropic fabrics, or faults that would juxtapose rocks of differing seismic velocities [e.g., *Schulte-Pelkum et al.*, 2005; *Nábelek et al.*, 2009]. It does not appear that the observed signals result from crustal anisotropy. We analyzed the data for each station as a function of back azimuth [e.g., *Schulte-Pelkum et al.*, 2005] and found no clear anisotropic signal. This is corroborated by shear wave splitting observations that identified the presence of little crustal anisotropy in the study region [*Christensen and Abers*, 2010]. As discussed below we examined the transects for reverberations in order to identify multiples from the Moho to calculate Vp/Vs and avoid interpreting any of the intracrustal arrivals generated from multiples. Both positive and negative converted phases occur within the crustal transects presented here; these phases correspond to a sharp increase or decrease in velocity with depth, respectively. We therefore interpret the intracrustal discontinuities to result from changes in seismic velocities within the crust (e.g., compositional layering or faults), these interpretations are discussed in section 5. The geometry, lateral and vertical extent, offsets, and truncations of these features serve as markers that are used to identify lateral and vertical variations in crustal structure.

3.5. Moveout Analysis

[21] Additional phases present on the receiver functions include the reverberation of the incident wave between the converter and the surface, which results in multiples. An example of a multiple from the Moho is the 2P1s phase, which occurs when the transmitted P wave reflects off of the surface and then reflects back from the seismic discontinuity as a converted S wave from the Moho to the station. While multiples can produce artifacts within receiver function images, they can also be used to verify discontinuities by determining if both the direct and reverberation signals originated from the same depth. Where necessary our Moho picks were verified by comparing the moveout of the arrival time of the phase identified as the Moho with ray parameter [e.g., *Gurrola et al.*, 1994]. To ensure we correctly identified direct phases, we checked that their arrival times increase as a function of ray parameter, resulting in a positive moveout, and that the arrival times decrease as a function of the ray parameter for reverberations, resulting in a negative moveout [*Gurrola et al.*, 1994].

Figure 5. Profile of V_p along the lines A–A' and B–B' from the tomographic model of Eberhart-Phillips *et al.* [2006]. See Figure 2 for location of each line. Faster P wave velocities are shown in cooler colors, while slower velocities appear as warmer colors. White contours of P wave velocities are given for 6.5–8 km/s in 0.5 km/s increments. Overlain on the P wave velocities are our stacked receiver functions (black lines) for each column of CCP bins. Our Moho pick is shown by a blue tick mark on the corresponding arrival. The translucent white polygon labeled Y shows the approximate geometry of the subducting Yakutat slab determined from this tomographic model. The approximate location of the high-attenuation mantle wedge of Stachnik *et al.* [2004] is shown by the white dashed line labeled W. Regions discussed within the text are shown above the cross sections, as are major fault crossings. TF, Talkeetna fault; DF, Denali fault; HCF, Hines Creek fault. Distances along the transects are shown in x offset from the southern (A–A') and western (B–B') endpoints of the transects.

3.6. V_p/V_s Analysis

[22] Calculating V_p/V_s from the arrival times of the Pds and 2P1s Moho phases, which are sensitive to the V_p/V_s of the entire crust, provides observations that can be used to gain insight into the composition of the crust. Poisson's ratio, which is proportional to V_p/V_s , is sensitive to variations in rock composition and can be used to determine changes in the amount of quartz, iron, and magnesium in crustal rocks. Lower values of V_p/V_s (<1.71) tend to characterize more quartz-rich, felsic rocks, whereas higher values (>1.74) are associated with more iron

and magnesium-rich, mafic rocks [Christensen, 1996]. The arrival times of the direct Pds and the 2P1s reverberation phases from the Moho are used to calculate the V_p/V_s for the crust [e.g., Zandt and Ammon, 1995; Zandt *et al.*, 1995; Zhu and Kanamori, 2000; Kind *et al.*, 2002]. To determine V_p/V_s along each transect, the average crustal V_p and V_p/V_s of the 3-D tomographic model used to convert from time to depth [Eberhart-Phillips *et al.*, 2006] is first found for each column of bins used for stacking the receiver functions (Figure 5 and Table 1). The averaged values of the crust for each

Table 1. Velocity Model Parameters (Vp and Vp/Vs) Used for Depth Conversion From *Eberhart-Phillips et al.* [2006], Moho (Pds) and Moho Reverberation (2p1s) Depth Picks, and Calculated Vp/Vs Along Transects A-A' and B-B^a

	Bin													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
<i>North-South</i>														
Bin center latitude	N62.00°	N62.21°	N62.43°	N62.65°	N62.87°	N63.08°	N63.30°	N63.52°	N63.73°	N63.95°	N64.17°	N64.39°	N64.60°	
Bin center longitude	W150.18°	W150.05°	W149.92°	W149.79°	W149.66°	W149.53°	W149.40°	W149.27°	W149.14°	W149.01°	W148.88°	W148.75°	W148.62°	
Traces per bin	118	182	191	195	180	180	124	333	540	347	107	113	91	
Model Vp (km/s)	6.3	6.3	6.2	6.2	6.3	6.3	6.3	6.3	6.4	6.3	6.2	6.2	6.2	
Model Vp/Vs	1.76	1.75	1.72	1.70	1.70	1.70	1.70	1.69	1.69	1.69	1.70	1.70	1.70	
Moho depth (km)	26	27	35.5	36.5	33	34	35	35	35.5	23.5	24.5	24.5	23	
Moho Reverberation	23	24	32.5	33	32	31	32	32	30.5	26.5	24	22	21	
depth (km)														
Calculated Vp/Vs	1.90 ± 0.06	1.89 ± 0.04	1.81 ± 0.02	1.80 ± 0.03	1.73 ± 0.03	1.80 ± 0.04	1.80 ± 0.03	1.78 ± 0.02	1.85 ± 0.03	1.59 ± 0.01	1.72 ± 0.02	1.82 ± 0.04	1.80 ± 0.02	
<i>East-West</i>														
Bin center latitude	N63.50°	N63.46°	N63.42°	N63.38°	N63.34°	N63.30°	N63.26°	N63.22°	N63.18°	N63.14°	N63.10°	N63.07°	N63.03°	N62.99°
Bin center longitude	W151.87°	W151.37°	W150.88°	W150.39°	W149.89°	W149.40°	W148.91°	W148.41°	W147.92°	W147.43°	W146.93°	W146.44°	W145.95°	W145.46°
Traces per bin	67	117	372	471	249	112	162	84	26	42	71	33	80	93
Model Vp (km/s)	6.3	6.3	6.4	6.4	6.4	6.4	6.4	6.5	6.6	6.7	6.6	6.5	6.5	6.5
Model Vp/Vs	1.71	1.70	1.70	1.70	1.70	1.70	1.70	1.71	1.74	1.75	1.74	1.73	1.73	1.73
Moho depth (km)	28	27.5	26	27.5	32.5	35	35.5	37	39.5	40	31.5	31.5	32	36
Moho Reverberation	27.5	27	27.5	28	32	31	31.5	35	35	36	—	—	—	36
depth (km)														
Calculated Vp/Vs	1.73 ± 0.02	1.72 ± 0.02	1.65 ± 0.01	1.68 ± 0.02	1.72 ± 0.02	1.84 ± 0.04	1.83 ± 0.03	1.77 ± 0.02	1.88 ± 0.03	1.88 ± 0.03	—	—	—	1.73 ± 0.02

^aLocations of transects are shown in Figure 2. Values are given for bins shown in Figure 6; the bin width is 25 km.

bin, along with the arrival times of the Pds and 2P1s phases are used to calculate crustal Vp/Vs values following the method of *Zandt and Ammon* [1995] (Table 1). These Vp/Vs values represent an average value for a column of the crust from the Moho to the surface.

4. Observations

4.1. Crustal Thickness

[23] Our observations across the two receiver function transects are presented in Figures 4a–4d. The features discussed are labeled in Figures 4a–4d with an m (Moho), i (intracrustal discontinuity) or s (Moho step) followed by a number to differentiate between features. Along both transects the crustal thickness is greatest in the Alaska Range and Northern Talkeetna Mountains regions (m1 and m2 in Figures 4a–4d). Beneath the Alaska Range, crustal thicknesses range between 35 and 37 km (m1 in Figures 4a–4d). From the Alaska Range, the Moho dips shallowly to the south beneath the Northern Talkeetna Mountains, where the crust reaches a maximum thickness of 40 km (m2 in Figures 4a–4d). The Moho arrival (m2) beneath this region has the highest and broadest amplitude observed across both cross sections (Figures 4a–4d). Both *Ai et al.* [2005] and *Veenstra et al.* [2006] found crustal thicknesses ranging from ~35–45 km in this region. The study of *Veenstra et al.* [2006] observed some variability in crustal thickness across this region, in contrast to the relatively flat Moho presented here. Figures 5a and 5b show a profile of the P wave tomography model of *Eberhart-Phillips et al.* [2006] along our transects overlain by our stacked receiver functions. The Moho arrival on the receiver functions correlates well with the depth of the steep gradient in P wave velocities between lower crustal (6.5 km/s or less) and upper mantle P wave velocities (~8 km/s or more) identified for the region [*Eberhart-Phillips et al.*, 2006].

[24] North of the Alaska Range, the crust is 24–28 km thick in the Northern Foothills region (m3 in Figures 4a–4d). The Moho (m3) dips steeply to the south (s1) along cross section B–B' where it continues beneath the Alaska Range (m1 in Figures 4c and 4d). The crust thickens to ~28 km as the Moho dips gradually from the Northern Foothills (m3) to the Kantishna Hills region (m4 in Figures 4b and 4d). The converted phases of the Moho in the Kantishna Hills (m4) have higher amplitudes but

exhibit narrower pulse widths than the Moho phase from either the Alaska Range (m1) or the Northern Talkeetna Mountains (m2) (Figures 4a–4d). Narrowing of the pulse width can correspond to a sharper change in seismic wave velocities between the crust and mantle.

[25] Cross section A–A' shows a ~7 km step (s2) in the Moho between the Northern Foothills (m3) and the Alaska Range (m1 in Figures 4a and 4b). This offset in the Moho is dissimilar to the steeply dipping Moho (s1) observed along section B–B' at the boundary between the Alaska Range and Northern Foothills, where the Moho may be continuous across the step (Figures 4c and 4d). The Moho beneath the Northern Foothills (m3) appears to be continuous with a smaller amplitude intracrustal discontinuity (i1) at ~29 km depth that gently shallows southward within the Alaska Range region (Figures 4a and 4b).

[26] The Moho is not clearly defined between the Northern Foothills and Tanana basin regions suggesting either a weak or broad Moho signal (Figures 4a and 4b). Using moveout analysis, we interpret the arrival at 23 km depth (m5) within the Tanana basin region to result from a lower-amplitude discontinuity at the Moho (Figures 4a and 4b). The anomalously thin crust of the Northern Foothills (m3) and Tanana Basin (m5) regions was observed by other geophysical studies both in the area of our investigation and eastward along the TACT line [*Beaudoin et al.*, 1992; *Brocher et al.*, 2004; *Ai et al.*, 2005; *Eberhart-Phillips et al.*, 2006; *Veenstra et al.*, 2006; *Fuis et al.*, 2008].

[27] South of the thick crust of the Northern Talkeetna Mountains (m2) and Alaska Range (m1), the crust thins to 28 km thick (m6) beneath the Susitna basin (Figures 4a and 4b) and to 31 km thick (m7) beneath the Tangle Lakes region (Figures 4c and 4d). The transition from thick to thin crust occurs across a shallowing step (s3) from the ~36–40 km thick crust of the Northern Talkeetna Mountains to the Susitna basin and the Tangle Lakes areas (Figures 4a–4d). The Moho is weakly defined at the step (s3) from the Northern Talkeetna Mountains to the Tangle Lakes area, possibly as a result of the large station spacing at the surface (Figures 2, 4c, and 4d) or the Moho here may have a small impedance contrast. At the southeastern end of transect B–B' the Moho signal has a comparatively low amplitude, but demonstrates that the crust thickens to ~37 km (m8) (Figures 4b and 4d).

[28] Overall, our crustal thickness measurements from receiver functions closely follow the transi-

tion from lower crustal to upper mantle velocities in the tomography model of *Eberhart-Phillips et al.* [2006] (Figures 5a and 5b). It is, however, difficult to identify the base of the crust beneath the Susitna basin and Tangle Lakes regions from the tomography model due to the presence of the shallowly subducting Yakutat microplate directly beneath the crust (Figures 4a–4d, 5a, and 5b). The slab dips to the north and west beneath these regions [*Ferris et al.*, 2003; *Eberhart-Phillips et al.*, 2006]. No clear receiver function arrival, due to the lack of a large seismic velocity contrast, is observed to mark the base of the crust where it may be in contact with the subducting slab (Figures 4a–4d, 5a, and 5b).

[29] In summary, our receiver function observations broadly define three areas of distinct crustal thickness and comparable Moho signature. The northern section, which includes the Northern Foothills, Tanana Basin and Kantishna Hills regions, has comparatively thin crust and a rather complicated Moho signature. The observations within the northern section are similar to findings from other studies which have identified relatively thin crustal thickness estimates in this and adjacent regions [*Beaudoin et al.*, 1992, 1994; *Brocher et al.*, 2004; *Eberhart-Phillips et al.*, 2006; *Veenstra et al.*, 2006; *Fuis et al.*, 2008]. Our observations, however, show that the region of shallow crust extends westward to the Kantishna Hills region, and additionally that the geometry of the transition from thin crust of the northern section to thicker crust of the central section changes from an overlapping relationship on transect A–A' to that of a more discrete step on transect B–B' (Figures 4a–4d).

[30] The Moho arrival in the central section, which includes the Alaska Range and Northern Talkeetna Mountains regions, exhibits the highest average amplitudes and marks the thickest crust of the study area. Steps in the depth of the Moho occur at both boundaries of the central section (Figures 4a–4d). Whereas our crustal thickness estimates are similar to previous investigations [*Eberhart-Phillips et al.*, 2006; *Veenstra et al.*, 2006], the abruptness of the shallowing steps is more similar to features identified through aeromagnetic and gravity studies [*Glen et al.*, 2007; *Saltus et al.*, 2007]. These boundaries have not been previously shown, however, to extend to the base of the crust.

[31] The southern section includes the Tangle Lakes and Susitna Basin regions. This section has intermediate crustal thickness compared to the other sections, and correlates to the southern Alaska

magnetic high geophysical domain of *Saltus et al.* [2007]. The tomography study of *Eberhart-Phillips et al.* [2006] samples a similar area, but shows a more gradual decrease in crustal thickness between the central and southern sections (Figures 5a and 5b).

4.2. Intracrustal Discontinuities

[32] The presence, geometry, truncation, and offset of discontinuities within the crust as identified by our receiver function observations provide insight into the configuration and structure of the crust. Similar to the observed changes in the character of the Moho between the southern, northern, and central sections, we find variability in intracrustal discontinuities between sections and commonalities within the sections.

[33] Midcrustal discontinuities (i2 and i3) are present in the northern section along transect A–A' (Figures 4a and 4b), with a negative arrival (i2) being truncated at the boundary between the northern and central sections. In the upper crust, however, a broad positive arrival (i6) is continuous across the sections (Figures 4a and 4b). The lower crustal arrival (i1) in the central section may mark the continuation of the Moho (m3) beneath the Northern Foothills (discussed below (Figures 4a and 4b)).

[34] Within the midcrust of the central section, a negative arrival (i4) is continuous across the boundary between the Alaska Range and Northern Talkeetna Mountains regions on transect A–A' (Figures 4a and 4b). In the upper ~10 km of the crust, however, there is a discrete transition from a negative arrival (i5) in the Northern Talkeetna Mountains to a broad positive arrival (i6) in the Alaska Range (Figures 4a and 4b). At the southern end of the central section, a negative arrival (i7) in the upper crust is offset from a similar amplitude feature (i8) in the midcrust of the southern section (Figures 4a and 4b). A similar offset relationship is observed higher in the crust as two positive arrivals (i9 and i10) are offset across the boundary between the central and southern sections (Figures 4a and 4b).

[35] Along transect B–B' there are few intracrustal signals in the northern section; suggesting a lack of sharp discontinuities in S wave speed in this portion of the crust (Figures 4c and 4d). The central section along this transect has a negative arrival (i11) in the lower crust that is limited to the Alaska Range region (Figures 4c and 4d). Abundant signals (i12–i16) are present in the Northern Talkeetna Mountains region of the central section (Figures 4c

Figure 6. The calculated Vp/Vs across the transects and the data used to make these calculations. See text for discussion and Figure 2 for location of the lines. The receiver function CCP transects are migrated from time to depth using both Pds (red) and 2P1s reverberation (blue) moveout. The Moho picks for the Pds are shown by the thick red line, while the Moho reverberation picks for the 2P1s are shown by the thick blue line. Where the Pds pick is deeper than the 2P1s reverberation pick, the Vp/Vs is higher than the model's that was used to migrate from time to depth. Below the transects the Vp/Vs required to collapse the 2P1s and the Pds arrivals to the same depth are calculated (solid black line) along the transect and compared to the average Vp/Vs for the crust from the tomographic model of *Eberhart-Phillips et al.* [2006] (shown as the dashed black line). The gray polygon represents ± 1 standard deviation in Vp/Vs calculated from bootstrapping estimation. The bin numbers shown correspond to Table 1, which lists the values used in this calculation. Regions discussed within the text are shown above the cross sections, as are major fault crossings. TF, Talkeetna fault; DF, Denali fault; HCF, Hines Creek fault. Distances along the transects are shown in x offset from the southern (A–A') and western (B–B') endpoints of the transects.

Figure 7. Profile of V_p/V_s along the receiver function transects from the tomographic model of *Eberhart-Phillips et al.* [2006]. See Figure 2 for location of the lines. This model represents the V_p/V_s used to migrate from time to depth along with V_p shown in Figure 5. V_p/V_s values range from 1.65 to 1.85; lower values are white, while higher values are black. Overlain on the V_p/V_s values are our stacked receiver functions (black lines) for each column of CCP bins. Our Moho picks are shown by the blue tick marks on the corresponding arrival. The translucent white polygon labeled Y shows the approximate geometry of the subducting Yakutat slab determined from this tomographic model. The approximate location of the high-attenuation mantle wedge of *Stachnik et al.* [2004] is shown by the white dashed line labeled W. Regions discussed within the text are shown above the cross sections, as are major fault crossings. TF, Talkeetna fault; DF, Denali fault; HCF, Hines Creek fault. Distances along the transects are shown in x offset from the southern (A–A') and western (B–B') endpoints of the transects.

and 4d). The majority of these features (i12–i15) extend only short distances (~ 5 km) into the Alaska Range region (Figures 4c and 4d). In the upper crust of the central section, two discrete reversals in polarity of arrivals i17, i16, and i15 occur, one near the Alaska Range/Northern Talkeetna Mountains

boundary and one within the Northern Talkeetna Mountains (Figures 4c and 4d). The intracrustal signals in the central section do not continue into the southern section, which lacks any significant arrivals (Figures 4c and 4d).

4.3. Vp/Vs Variations

[36] Our Vp/Vs measurements provide a bulk compositional estimate for the crust at each bin along the transects, these estimates are compared to compositional data from tomographic and geologic studies. The northern section shows the lowest calculated Vp/Vs values (1.59–1.72 along transect A–A' bins 10–11 (Figure 6a and Table 1)), which are found at the boundary between the central and northern sections. The low values transition northward to more intermediate to high Vp/Vs values (1.80–1.83 along transect A–A' bins 12–13 (Figure 6a and Table 1)) in the Tanana basin region. We were only able to calculate a Vp/Vs value for one station in the northern section along transect B–B' (Figure 6b and Table 1) due to weakly developed 2P1s Moho reverberations at the other stations. The lower values calculated for the Northern Foothills region along transect A–A' and the single station along B–B' are similar to those found in the tomography model of *Eberhart-Phillips et al.* [2006], which shows low Vp/Vs values (~1.67–1.72 (Figures 7a and 7b)). The low values found in the northern section correlate with estimates of a relatively felsic crustal composition [e.g., *Christensen*, 1996]. The few high Vp/Vs values may be a result of fluids present at some depth within the crust, which would act to increase the overall Vp/Vs [e.g., *Eberhart-Phillips et al.*, 1995].

[37] Vp/Vs values within the central section are comparatively higher than the northern section and range between values of 1.75 and 1.85 (Figures 6a and 6b and Table 1). Our values are on average greater than those predicted by the tomography model of *Eberhart-Phillips et al.* [2006], where observed values average ~1.74 (Figures 7a and 7b). The Vp/Vs values of the central section indicate an intermediate crustal composition [e.g., *Christensen*, 1996]. The higher Vp/Vs values in portions of the central section may reflect the presence of fluids in the crustal column. Magnetotelluric observations of *Glen et al.* [2007] suggested that fluids in the middle and lower crust could be responsible for producing the low-resistivity values observed at depths greater than 5 km for the Northern Talkeetna Mountains region (Figures 2, 6a, and 6b). The presence of fluids in this part of the study area helps explain the high Vp/Vs values observed in portions of the central section and agrees with an overall felsic to intermediate composition for the region.

[38] The southern section and the Northern Talkeetna Mountains region represent the highest aver-

age Vp/Vs values in our study (Figures 6a and 6b and Table 1). These values generally range between 1.78 and 1.82. Due to the low amplitudes of the 2P1s reverberation phase arrivals, we were only able to calculate a Vp/Vs value for a single bin in the Tangle Lakes region (Figure 6b and bin 14 in Table 1). High-resistivity values observed from magnetotelluric analysis of part of the southern section suggest the absence of fluids in this portion of the crust [*Glen et al.*, 2007]. Our calculated values are consistently higher for the southern section than are indicated by the tomography model of *Eberhart-Phillips et al.* [2006] (Figures 7a and 7b and Table 1). The higher Vp/Vs values observed for this region are more typical of mafic rocks, especially those of oceanic affinity [e.g., *Christensen*, 1996].

5. Interpretation

5.1. Northern Section

[39] The northern section includes the thinnest crust observed in the study area (Figures 4a–4d), the lowest observed Vp/Vs (Figures 6a and 6b and Table 1), and several intracrustal discontinuities (Figures 4a and 4b). We interpret the northern section as most representative of the Yukon composite terrane based on those characteristics. As discussed earlier, the Yukon composite terrane represents the former Mesozoic continental margin of southern Alaska. Along-strike comparison of the character of the Yukon composite terrane is possible by comparing observations presented here to those of the TACT study (see location in Figure 2). Using TACT data, *Beaudoin et al.* [1992] showed that the Yukon composite terrane has a relatively low seismic velocity ($V_p \leq 6.4$ km/s) and a Poisson's ratio of 0.23, corresponding to a Vp/Vs of 1.69. These observations are consistent with both our observations of low Vp/Vs in the Yukon composite terrane and previous geologic studies that document an abundance of felsic-rich metamorphic rocks in this terrane [e.g., *Dusel-Bacon*, 1994; *Foster et al.*, 1994].

[40] The observation of thin crust along the southern margin of the Yukon composite terrane was first made during the refraction/reflection study of TACT [*Beaudoin et al.*, 1992, 1994; *Pavlis et al.*, 1993; *Fuis et al.*, 2008]. Subsequent studies found that the region of thin crust extends westward to the Tanana basin region [*Eberhart-Phillips et al.*, 2006; *Veenstra et al.*, 2006]. We find that although the character of the Moho changes significantly, the crust is consistently thin westward to

the Kantishna Hills region (Figure 4c). *Pavlis et al.* [1993] suggested that the thin crust of the Yukon composite terrane was developed during a mid-Cretaceous regional extension event. Regional extension resulted in the juxtaposition of inverted metamorphic grades, which require the elimination of ~10 km of the crustal column [*Pavlis et al.*, 1993]. The negative polarity intracrustal discontinuity observed in the northern section (i2 in Figures 4a and 4b) may represent these inversely juxtaposed metamorphic grades described from previous geologic studies.

[41] The transition from the northern to central sections is gradational along transect A–A' (Figures 2 and 4a–4d). Although there is a discrete step across the Moho (s2), intracrustal discontinuities (i1 and i6) suggest a similar crustal structure across the boundary, and possibly a common Mesozoic deformational history (Figures 4a and 4c). We infer that the transition between these sections occurs at a more discrete boundary along transect B–B' (Figures 4c and 4d). This interpretation is based on the observation of a step in the Moho (s1) and the truncation of the lower crustal discontinuity (i11) at this boundary, there is also a notable decrease in the amplitude of the upper crustal discontinuity (i17) at the same location (Figures 4c and 4d). The topography of the Moho and lower crustal discontinuity truncation show that this feature is present in the lower crust, and that it may extend throughout the crust as evidenced by the change in amplitude of the upper crustal discontinuity across the boundary.

[42] Observations of an offset Moho (s1) and the continuation of an arrival (i1) at the same depth as the Northern Foothills Moho (m3) may be a result of tectonic underthrusting (Figures 4a and 4b). In this interpretation, lower crustal rocks of the suture zone (i.e., the central section) are thrust beneath the thin crust of the Yukon composite terrane. Underthrusting has been proposed as a potential mechanism to explain changes in crustal thickness and magnetic character across the suture zone from observations made during the TACT survey [e.g., *Beaudoin et al.*, 1992; *Stanley et al.*, 1990]. In addition, geologic studies along this contact in along-strike parts of the suture zone have reached similar conclusions [*McClelland et al.*, 1992a, 1992b, 1992c; *McClelland and Mattinson*, 2000; *Manuszak et al.*, 2007]. The complex configuration of the Moho and the Moho step (s2) between the northern and central sections along transect A–A' (Figures 4a and 4b) may therefore be a product of underthrusting. If our interpretation is correct, the boundary between the northern and

central sections is a subhorizontal discontinuity where the crust of the suture zone thrusts beneath the thinned continental margin. Our receiver function transects indicate that the potentially underthrust region does not extend westward into the Kantishna Hills region (Figures 4c and 4d).

5.2. Central Section

[43] The central section includes the thickest crust observed in the study, intermediate Vp/Vs that are laterally variable across the section, and exhibits a number of intracrustal discontinuities that truncate both within and at the boundaries of the section. Our central section closely corresponds to the southern Alaska magnetic trough geophysical domain of *Saltus et al.* [2007] (Figure 3b). Based on the distinct correlation of geophysical properties from both our study and previously published data, we interpret the central section to generally coincide with the suture zone proper.

[44] Although we find some Vp/Vs values comparable to the more mafic values found in the southern section (Figures 6a and 7b and Table 1), we interpret the central section to have an overall felsic to intermediate composition based on the likely presence of fluids in the middle and lower crust of this region as observed from magnetotelluric analysis [*Glen et al.*, 2007]. Additional magnetotelluric studies adjacent to the suture zone, which follow the same profile as the TACT study (Figure 2) find a low-resistivity body in the middle to lower crust beneath the trace of the Denali fault [*Fisher et al.*, 2004a, 2004b, 2007]. This low-resistivity body may be extrapolated into the central section of our study region providing further support for the presence of fluids in this section.

[45] The central section has a comparable crustal character across the region interpreted as the suture zone proper. Although the Moho is relatively flat across the suture zone proper, the crustal thicknesses increase slightly near the boundary with the southern section (Figures 4c and 4d). The transition from the central section (suture zone) to the southern section occurs across another significant step in the Moho (s3; Figures 4c and 4d). The pervasiveness and abruptness of this step is shown by the truncation of all the intracrustal discontinuities (i12–i16) on transect B–B' and the offset discontinuities (i9–i10 and i8–i7) on transect A–A' (Figures 4a–4d). The intracrustal discontinuities within the central section (Figures 4a–4d) may result from compositional layering within the crust or possibly from low-angle shearing

within the crust along a detachment surface that has accommodated crustal shortening within this region, similar structures have been observed using receiver function analysis in the Betic Cordillera of Spain [Pedrera *et al.*, 2010]. Overall, it appears that the boundary between the southern and central sections is more of a discrete feature, with a definable transition in crustal thickness, truncation or offset of intracrustal discontinuities and composition (Figures 6a and 6b and Table 1).

5.3. Southern Section

[46] The southern section has an average crustal thicknesses of ~30 km, the highest Vp/Vs observed in the study, and intracrustal discontinuities that are present only along transect A–A'. We interpret the southern section as the portion of the crust most representative of the Wrangellia composite terrane based on our observations and their similarity to other geophysical properties of the crust including both gravity and aeromagnetic data [e.g., Glen *et al.*, 2007; Saltus *et al.*, 2007]. Of particular note are the high Vp/Vs values observed in the southern section (Figures 6a, 6b, 7a, and 7b and Table 1). These values are similar to other measurements of the Wrangellia composite terrane where the crust has generally been found to be of intermediate to mafic composition (including abundant tholeiitic and volcanic basalts and marine sedimentary rocks), and includes some silica-rich plutonic rocks likely related to the long-lived granitoid magmatic arcs that intruded the terrane [Berg *et al.*, 1972; Richter *et al.*, 1975; Plafker *et al.*, 1989; McClelland *et al.*, 1992a; Plafker and Berg, 1994; Nokleberg *et al.*, 1994; Saltus *et al.*, 1999, 2007; Morozov *et al.*, 2003; Hollister and Andronicos, 2006; Glen *et al.*, 2007; Rioux *et al.*, 2007; Snyder and Hart, 2007; Calkins *et al.*, 2010]. Intracrustal discontinuities within the southern section likely result from compositional layering within the overthickened oceanic crust of the Wrangellia composite terrane and are similar to intracrustal features noted along strike of the suture zone near the Coast Range Batholith [Calkins *et al.*, 2010]. In summary, the southern section represents crust characteristic of the allochthonous oceanic terrane, the Wrangellia composite terrane, which collided with the Mesozoic continental margin.

6. Discussion

[47] The division of our study area into northern, central, and southern sections effectively groups

similarities in both our observations of crustal thickness and crustal Vp/Vs. Additionally, intracrustal discontinuities observed in our data set are either truncated or offset at the boundaries between the three sections whereas other discontinuities terminate within the sections (Figures 4a–4d). We infer these observations to result from the different manner in which the individual sections have responded to similar tectonic stresses as a result of Mesozoic collision. The variable character of the crust (e.g., thickness, intracrustal discontinuities and composition) between the individual elements (i.e., former continental margin, suture zone proper, and accreted terrane) of the suture zone and allows for the discrimination between the sections through the entire crust. These observations suggest that the individual sections have responded differently to similar stresses. One possible control of this response may be the varying compositions between the sections of the suture zone. Variability in composition across the sections of the Alaska Range suture zone is supported by our estimates of Vp/Vs (Figures 6a and 6b) Vp/Vs calculations of Eberhart-Phillips *et al.* [2006] (Figures 7a and 7b), the overall pattern of magnetic potential (Figure 3b) [Saltus *et al.*, 1997, 1999; Brunstein, 2002; Glen *et al.*, 2007; Saltus *et al.*, 2007], and regional geologic mapping (Figure 3a) [e.g., Jones *et al.*, 1982; Csejtey *et al.*, 1992; Ridgway *et al.*, 1997; Trop and Ridgway, 1997; Ridgway *et al.*, 2002]. The observed variability in crustal structure across the Alaska Range suture zone is likely controlled by the differing compositions of the terranes involved, which have influenced how each section has responded to precollisional, syncollisional, and postcollisional deformation.

[48] Of particular note is the development of significant steps in the Moho at the boundaries of the suture zone. The suture zone proper, originally identified from rock types and deformation patterns at the surface [Jones *et al.*, 1982; Ridgway *et al.*, 2002], is shown to be a crustal-scale feature from our receiver function analysis. The surface geometry of the suture zone proper closely mimics the subsurface geometry suggesting limited vertical modification of the collisional zone in roughly 100 Myr. In general, this observation suggests that the original configuration of a collisional zone sets the long-term boundary conditions for deformation along a collisional plate margin.

[49] The observed compositional change from more oceanic to continental affinity crust from south to north across the central Alaska Range, have likely played a significant role in where deformation

occurred during Mesozoic suturing. The suture zone proper for example, has been interpreted to have undergone significant internal deformation as a result of crustal shortening and thickening to reach a present average crustal thickness of 37 km. It is unlikely that the original crustal thicknesses of the suture zone, prior to suturing, were similar to the present ones based on geologic data. Much of the syncollisional marine sedimentary strata that overlie this region (the Kahiltna basin in Figures 1 and 3a) were likely deposited on both relatively thin transitional to oceanic crust and on numerous small terranes of oceanic affinity [Jones *et al.*, 1982; Csejty *et al.*, 1992; Nokleberg and Richter, 2007]. Submarine fan strata of the Kahiltna basin, for example, were deposited on oceanic pillow basalts [Hampton *et al.*, 2007; Kalbas *et al.*, 2007].

[50] The crustal thickness and character of the suture zone proper (i.e., central section) does not vary greatly across the transects (Figures 4a–4d), suggesting that this region which broadens westward has experienced distributed deformation during Mesozoic collision and that deformation was likely not localized along a major discrete structure. This interpretation is consistent with geologic studies within the central section that document highly deformed, often isoclinally folded strata [Reed and Nelson, 1980; Csejty *et al.*, 1992; Clautice *et al.*, 2001; Eastham and Ridgway, 2002]. The presence of intracrustal discontinuities within the central section, the current crustal thickness, and geometry and relationship of the boundaries of this section with the former continental margin and allochthonous terrane, suggests that deformation was also accommodated within the middle and lower crust (Figures 4a–4d). Continued thickening and internal deformation within the suture zone appears to have lead to the development of steps in the Moho as the crust thickened beyond the base of the crust of both the adjacent Yukon and Wrangellia composite terranes. The mafic composition of the Wrangellia composite terrane seems to have provided increased strength and rigidity, allowing it to resist the extent of internal deformation found in the suture zone proper and along the southern margin of the Yukon composite terrane. Similarly, the felsic-rich composition along the southern boundary of the Yukon composite terrane suggests it may be relatively weaker and thereby more readily deformable than the more rigid oceanic plateau crust of the Wrangellia composite terrane.

[51] The character of the boundaries between the individual sections is additionally consistent with the relative strength interpretations for each section.

The boundary between the suture zone (central section) and the Yukon composite terrane (northern section), for example, appears more gradational with intracrustal discontinuities extending across both sections. Additionally, the boundary between these sections appears to be a subhorizontal discontinuity where the suture zone crust underthrusts the former continental margin. The boundary between the suture zone (central section) and the Wrangellia composite terrane (southern section), in contrast, appears to be a relatively discrete, subvertical boundary as both the Moho and intracrustal discontinuities abruptly truncate or are offset across the boundary (Figures 4a–4d).

[52] Our analysis shows that the compositional contrasts between the colliding oceanic terrane, the suture zone proper, and the former continental margin will likely control, on a first order, where deformation is distributed across a collisional zone. As shown by the crustal configuration of the central Alaska Range, the suture zone proper and continental margin are more readily deformed during syncollisional stages compared to the relatively strong, often overthickened, oceanic affinity crust of the accreting terrane. This difference may especially be the case for larger, buoyant terranes such as oceanic plateaus similar to the Wrangellia composite terrane.

[53] The apparent strength contrast across the suture zone also has implications for postcollisional reactivation of weaker region(s) [e.g., Moores, 1981; Ranalli, 2000; Holdsworth *et al.*, 2001]. For example, the region defined as the suture zone proper is currently the location of the highest topography in North America, and is bisected by the active McKinley strand of the Denali fault (Figures 1, 2, and 3a). The 2002, M7.9 Denali earthquake occurred on a portion of the Denali fault that is located within the suture zone proper (Figure 2) [Eberhart-Phillips *et al.*, 2003]. The location of continued postcollisional deformation within the suture zone proper is likely a consequence of the inherent weakness of this region relative to the adjacent accreted oceanic plateau and the continentalized interior of central Alaska. In general, the collision of oceanic terranes along continental margins both increases the size of the continent as well as seeds the crust with zones of weakness (i.e., former suture zones). These zones of weakness are a locus for postcollisional deformation and may control the long-term distribution of deformation along a convergent margin.

[54] The role of the major fault systems in the development of the central Alaska Range is unclear

from the present study. The conspicuous location of the Hines Creek and Talkeetna faults near the boundaries between the identified sections suggests a possible genetic relationship to the collisional zone, a direct link, however, cannot be inferred with the currently available data. Whether these faults developed congruently with Mesozoic collision of the Wrangellia composite terrane and formation of the Alaska Range suture zone or are younger reactivated Cenozoic features that are exploiting zones of weakness within the Mesozoic suture zone, or some combination of these two end-member processes, is not clear. While the Hines Creek and Talkeetna faults appear to continue through the crust and extend into the mantle, the Denali fault does not appear to offset the Moho (Figures 4a–4d). Several truncated intracrustal discontinuities in the upper to middle crust and the continuation of other discontinuities at greater depths suggests that the Denali fault is confined to the upper and middle crust in this portion of the Alaska Range suture zone (Figures 4a–4d). Clearly understanding the role of these fault systems will require further analysis to determine their timing and displacement relative to syncollisional and postcollisional deformation in the central Alaska Range.

7. Conclusions

[55] The collision of terranes, such as oceanic plateaus and volcanic arcs, has been recognized as a fundamental process in collisional orogenesis and the tectonic growth of continents [e.g., Cloos, 1993]. The central Alaska Range is an ideal location to study the crustal structure of a collisional zone because it is part of a regional suture that extends from British Columbia to southwestern Alaska, and because there is a clear transition from oceanic to continental crust. Receiver function analysis shows that many of the key components of this Mesozoic suture zone are both preserved and identifiable throughout the lithosphere. We have identified three sections with disparate crustal character as observed from estimates of crustal thickness, intracrustal discontinuities and compositional differences. These regions are interpreted to represent the juxtaposition of different types of continental and oceanic crust within the collisional zone. Our observations from the central Alaska Range suggest that allochthonous oceanic crust will likely act as stable, rigid blocks during both syncollision and postcollision processes. In contrast, deformation is preferentially transmitted to the comparatively weak

and deformable suture zone as well as the leading edge of the former continental margin. Our analysis shows that the differences in crustal types juxtaposed within a collisional zone guides the distribution of deformation along a convergent margin over geologic timescales.

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