Geophysical Research Letters

RESEARCH LETTER
10.1029/2020GL091654

New Insights Into the Heterogeneity of the Lithosphere-Asthenosphere System Beneath South China From Teleseismic Body-Wave Attenuation

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Abstract Teleseismic body-wave attenuation provides an independent constraint on the architecture of the lithosphere-asthenosphere system. We obtain the first map of teleseismic attenuation across South China, which correlates well with previous estimates of lithospheric thickness. The weakest attenuation occurs in the Sichuan Basin, where continental lithosphere is thick, and in the adjacent Chuanbian region, which we attribute to delaminated lithosphere, or lithosphere strengthened by an ancient plume based on comparison with previous studies. Smaller batches of remnant or delaminated lithosphere may cause local minima along the eastern coast. Pronounced negative anomalies occur in the Hengyang, Jianghan and Nanchang basins, motivating the hypothesis that the basins occur where locally strong blocks within the lithosphere resisted the pervasive deformation of South China. The strongest attenuation occurs in a broad region in the vicinity of the Hainan plume, which is consistent with high temperatures and possibly partial melt in the upper mantle.

Plain Language Summary As a classical intracontinental orogen, the detailed deformation of South China is a topic of broad interest. In this study, we present a teleseismic attenuation map based on 9,160 first-arriving P phases from 82 deep teleseismic events that were recorded by the permanent seismic stations in South China. The attenuation is consistent with the lithospheric thickness revealed by previous results from seismic imaging, flexure modeling, and heat flow. In addition, the low attenuation in the Sichuan basin, Chuanbian fragment and other basins, as well as high attenuation in Hainan Island are observed. Several other weaker local maxima require Qp values in the asthenosphere sufficiently low so as to be consistent with upwelling mantle, suggesting that small-scale convection is pervasive across the region without causing significant volcanism at the surface. Combined with previous studies, the results support the occurrence of lithospheric dismemberment in Eastern China and provide an additional perspective on lithospheric strength and hot spot activity.

1. Introduction

The long tectonic history of South China includes Precambrian amalgamation and several Phanerozoic episodes of lithospheric modification. It formed via the collision of the Yangtze and Cathaysia blocks (Figure 1a) along the Jiangshan-Shaoxing fault in the Neoproterozoic (e.g. Z. X. Li et al., 2002). After amalgamation, three important tectonothermal events occurred in South China, namely the Wuyi-Yunkai (Early Paleozoic), Indosinian (Triassic), and Yanshanian (Jurassic-Cretaceous) events (Y. Wang et al., 2013b), often called “movements” in Chinese literature. Each event led to extensive deformation and magmatism across South China.

The lingering effects of these events on lithospheric structure have been investigated by many geophysical studies, including models of P wave velocity structure from active seismic profiles (Y. Deng et al., 2011) and teleseismic travel-time tomography (He & Santosh, 2016), S-wave velocity from surface wave tomography (Shen et al., 2016; Shan et al., 2017; M. L. Wang et al., 2015; L. Zhou et al., 2012), crustal attenuation from Lg waves (Zhao, Xie, et al., 2013; X. Y. Zhu, 2014), density structure from gravity (Y. Deng et al., 2014a; Gao et al., 2020); Vp/Vs ratios from receiver functions (Song et al., 2017; Guo et al., 2018, 2019), temperature from joint inversion of dispersion data, geoid height, topography, and heat flow (Shan et al., 2014); seismic anisotropy from SKS splitting (H. Li et al., 2018; Zhao, Zheng, & Lu, 2013), and resistivity from magnetotelluric imaging (Y. Liu et al., 2013; L. Zhang et al., 2015).
However, seismic attenuation in the upper mantle remains unconstrained in South China. Teleseismic body-wave attenuation provides useful information on the structure of the lithosphere-asthenosphere system, which is independent from and complementary to that gained from other geophysical information. Previous studies have shown that variations in the attenuation of teleseismic $P$ phases can correlate with variations in lithospheric thickness (Cafferky and Schmandt, 2017; Hwang et al., 2009), the distribution of seismicity (M. J. Bezada and Smale, 2019), the locations of undeformed basins (M. J. Bezada, 2017), and mantle upwellings (J. S. Byrnes et al., 2019; J. S. Byrnes and Bezada, 2020; Dong & Menke, 2017; Eilon & Abers, 2017) as or more clearly than other geophysical constraints, and hence may shed light on the role of upper mantle structure in the evolution of South China.

This study takes advantage of the extensive network of permanent stations across South China to investigate variations in the lithosphere-asthenosphere system. Lateral variations in the attenuation of teleseismic $P$ waves are obtained using a time-domain approach and mapped across the study area in two-dimensions (M. J. Bezada, 2017; J. S. Byrnes et al., 2019). We find an overall pattern of increasing attenuation from northwest to southeast, consistent with previous estimations for lithospheric thickness, as well as other locally important anomalies. Implications for lithospheric deformation, small-scale convection, and delamination in South China are discussed based on these results.

2. Data and Method

A network of more than 350 permanent broad-band seismometers archived by the Data Management Center of the China National Seismic Network (X. Zheng et al. 2010), with a typical station spacing of about 50 km, provides excellent coverage (Figure 1a). We use first-arriving $P$ phases from earthquakes in USGS earthquake catalog with focal depths greater than 200 km, epicentral distances between 30 and 90°, and magnitudes greater than 5.5 (Figure 1b). The restriction to deep events greatly reduces the number of usable events, but energy from these events does not traverse the attenuating asthenosphere on the source side. The instrument response is removed with a causal filter (Haney et al., 2012), but the records are otherwise unfiltered. Seismograms with low signal-to-noise ratios (SNR<10) are removed after inspection, and only events with high quality recordings on more than 70 stations are kept.

Once seismograms have been selected, we measure the relative attenuation between records with the method of M. J. Bezada (2017). For a given event, an estimate of the source-time function is found by stacking the apparently least-attenuated waveforms in the time-domain. This estimate is then numerically attenuated...
with the operator of Azimi et al. (1968) to make attenuated versions of the source. The degree of attenuation is quantified by the metric $\Delta t_P^*$, or relative $t_P^*$, where $t_P^*$ is defined by

$$t_P^* = \frac{1}{Q_p} \int V_p^{-1}(r) dr$$

(1)

where $Q_p$ is the quality factor for $P$ phases, $V_p$ is the $P$ wave velocity, and $r$ is distance along the ray path. Since $Q_p$ is unitless, $t_P^*$ has units of seconds. More positive values of $\Delta t_P^*$ indicate a greater degree of attenuation.

Once a set of $\Delta t_P^*$ measurements has been made, smoothed maps are constructed with a linear (M. J. Bezada, 2017) and a Bayesian approach (J. S. Byrnes et al., 2019). We present both results with error assessments to understand what aspects of the results depend on the methodology. For the linear approach we parameterize $\Delta t_P^*$ in the area over a regular grid and assume a forward formulation where the measured value at each station is the average of the $\Delta t_P^*$ at the nearest grid nodes weighted by the inverse of the distance to the station plus a station term and an event term. We then solve the linear inverse problem to find the values of $\Delta t_P^*$ on the grid given the measured values at the stations by minimizing the objective function (M. J. Bezada, 2017) as

$$E = \| G \cdot m - d \|_2 + K_1 \| m \|_2 + K_2 \| L \cdot m \|_2 + K_3 \| s \|_2$$

(2)

where $G$ contains the averaging weights, $m$ is the model of $\Delta t_P^*$, station and event terms, $d$ is the vector of observed $\Delta t_P^*$, $L$ is a roughness matrix, $s$ contains the station terms, and $K$ terms are free parameters that weight the regularization with respect to the data misfit. Station terms are used to reduce small undulations that occur when adjacent stations disagree (M. J. Bezada et al., 2019) and are heavily damped. Errors are estimated with a hybrid jackknife-bootstrap approach (J-B), where a set of maps are constructed from a subset of the events, and the standard deviation of the subsets is taken as an estimate of the standard error.

In the Bayesian approach, models are generated using a Markov Chain Monte Carlo procedure. Each model is defined by nodes unevenly distributed in space, with attenuation found by nearest-neighbor interpolation from the nodes. The inversion is “trans-dimensional”, meaning the number of nodes is allowed to change. The reader is referred to J. S. Byrnes et al. (2019) for details. Since $\Delta t_P^*$ measurements typically have high uncertainties, the Bayesian approach has the advantage of determining the appropriate smoothness of the solution for the variance of the data set. Uncertainties can be estimated, since many maps that explain the data are constructed. The result constrains the accumulated attenuation along the ray path, and in most cases the data are insufficient to construct a three-dimensional tomography model. Lateral variations are constrained without placing direct constraints on the depths at which the signal arises, similar to the case of SKS splitting analysis.

### 3. Results

We measure $\Delta t_P^*$ on 9160 $P$ records from 82 teleseismic events occurring between January 2010 and December 2019. The earthquakes primarily occurred in the Western Pacific (Figure 1b) since only deep events are used. Figure 2a shows the $\Delta t_P^*$ map from the linear inversion of the entire quality-checked data set. The station terms have a standard deviation of 0.038 s, significantly less than the range shown in the map. The largest negative $\Delta t_P^*$ is up to $-0.15$, which is located in the Sichuan Basin and extends to the southwest (the Chuandian fragment, CD). More positive $\Delta t_P^*$ occurs further east, with a maximum at Hainan Island.

In order to validate the robustness of the results, we apply the J-B approach by randomly choosing 66 out of 82 events to generate the subsets. Figure S1 shows four examples of $\Delta t_P^*$ map inverted from 4 groups of 66 randomly chosen events. Figure S2 shows the mean and standard deviation of $\Delta t_P^*$ inverted from 80 groups of 66 randomly chosen events. Even though small variations between the models exist, the main features are consistent between the inversions of different subsets of events.
In addition, we focus on three regions and review the observed and synthetic seismograms for one high-quality event in order to confirm the presence of several peculiar features. For more negative values of $\Delta t_p^*$, the waveform should be narrower in the time domain and contains more high frequency energy. As $\Delta t_p^*$ increases, the high frequencies are damped and the waveform broadens (e.g., J. S. Byrnes et al., 2019, Figure 2). In region A spanning the Sichuan Basin and the Chuandian fragment, the seismograms in the north have the same width and general character as those in the south, consistent with similar $\Delta t_p^*$ across the region. However, in region B, the seismograms in the north are narrower and less smooth than those in the south, and in region C the opposite is true. Inspection of the observed and synthetic waveforms confirms the low attenuation across region A and the abrupt transitions from low to high and low to attenuation from north to south in regions B and C, respectively (Figure 3). This provides confidence in the $\Delta t_p^*$ estimation procedure and the subsequent inversion results.

Figure 2b shows the $\Delta t_p^*$ from the Bayesian Monte Carlo inversion by taking at each point the mean of 768 models from 48 different chains. The Bayesian model shows a very similar pattern but contains more detailed structure than that from the linear inversion (Figure 2a). The Sichuan Basin and Chuandian fragment still show the most negative $\Delta t_p^*$ with identical values, and most of the eastern region shows positive $\Delta t_p^*$. Some basins are associated with negative $\Delta t_p^*$ values (see Section 4.2). We also find isolated negative anomalies along the coast. The standard deviation is less than 0.10 in places with good station coverage except in isolated patches (Figure 2c).

4. Discussion

To first order, our results show a change from low $\Delta t_p^*$ in the northwest too high $\Delta t_p^*$ in the southeast (Figure 2). Given the large difference in $Q_p$ between lithospheric and asthenospheric mantle (e.g., Romanowicz & Dziewonski, 2010), we assume that the primary cause of this signal is variations in lithospheric thickness. Indeed, our results are consistent with several independently obtained estimates of lithospheric thickness that show an overall thinning of the lithosphere from northwest ($\sim 190$ km) to southeast ($\sim 75$ km) in South China (Figure 4). In our results, $\Delta t_p^*$ decreases gradually from the Sichuan Basin to the coastal area, with some undulations beneath several basins found by the Bayesian inversion (Figure 4b). The same general pattern is found in the thermal lithospheric thickness (dashed green line in Figure 4b), flexural isostatic lithospheric thickness (dashed black line in Figure 4b), and estimates from receiver functions (dashed blue line in Figure 4b).

Several lines of evidence suggest that Mesozoic reworking of the Precambrian lithosphere is more extensive in southeastern China than in the northwest (Y. F. Zheng et al., 2013). Whole-rock and mineral geochemical data suggest the Cathaysia block had a thickened (>45 km thick) crust at the early Mesozoic (K. Y. Zhu et al., 2017). Mesozoic mantle xenoliths imply a thinner lithosphere (<80 km) at the Late Mesozoic (C. Z. Liu et al., 2012a). Moreover, the Mesozoic mantle xenoliths show that the mantle lithosphere in the
southeast is a combination of ancient and newly accreted mantle (C. Z. Liu et al., 2012b; H. Zhang et al., 2017). Our findings of high \( \Delta \rho \) provide another line of evidence to support the idea that easternmost China as a whole has undergone lithospheric dismemberment (Y. Deng & Levandowski, 2018; Q. Wang et al., 2017; T. Y. Zheng et al., 2014), not only the North China Craton (L. Chen, 2010). The lithospheric extension and thinning provide the heat and pressure conditions for melting the lower crust and thus forming the widespread granitoids in South China (Y. Deng et al., 2019).

Since our results for \( \Delta \rho \) reflect the attenuation integrated over the ray path, we cannot determine \( Q_p \) as may be done with a tomographic model. To estimate \( Q_p \), we assume a two-layer lithosphere-asthenosphere model and further assume that the lowest and highest attenuation correspond to rays crossing the thickest and thinnest lithosphere. In this two-layer case, Equation 1 becomes

\[
\Delta \rho^* = \frac{r_{\text{asth}}}{Q_{\rho,\text{asth}} V_{\rho,\text{asth}}} - \frac{r_{\text{lithos}}}{Q_{\rho,\text{lithos}} V_{\rho,\text{lithos}}}
\]  

(3)

where \( r_{\text{lithos}} \) and \( r_{\text{asth}} \) are the path lengths through the lithosphere and asthenosphere, respectively. Using the range in lithospheric thickness defined in Figure 4b (Y. Y. Zhang et al., 2018a) and assuming values for \( Q_{\rho,\text{lithos}} \) and \( V_{\rho,\text{lithos}} \) (for simplicity we use 8 km/s for both the lithosphere and asthenosphere) and an incidence angle of 20°, we obtain the \( Q_{\rho,\text{asth}} \) that produces the observed range in \( \Delta \rho^* \). Assuming an infinite \( Q_p \) for the lithosphere, possible if the temperature is below \( \sim 900^\circ \text{C} \) (Faul & Jackson, 2005), gives an upper bound for \( Q_{\rho,\text{asth}} \) of 83; with the typical error of 0.06 s (Figure 2c) allowing a \( Q_p \) as large as 119. Assuming a finite \( Q_p \) in the lithosphere of 600 (approximately half the \( Q_p \) in PREM, Dziewonski & Anderson, 1981) reduces this estimate to 73, which the uncertainty allows to be as large as 99. In both cases the estimates for \( Q_{\rho,\text{asth}} \) fall below the global average of 150–250 (Dalton et al., 2009; Dalton & Faul, 2010; Dziewonski & Anderson, 1981; Ma et al., 2020) assuming a \( Q_p/Q_s \) value of 2.25 (Karato & Spetzler, 1990).

However, the attenuation in Figure 2a and 2b is not uniform across the study area. Instead, regions where the lithosphere has thinned significantly (such as 113°, Figure 4b) are associated with \( \Delta \rho^* \) of only 0.1 s, which can be explained by a \( Q_p \) of 166, an estimate consistent with the global mean. The \( \Delta \rho^* \) from minima to local maxima in Figure 2 breach 0.25 s–0.35 s, which give \( Q_p \) values of 66 to 47, respectively. Such values are typically associated with mantle melting or upwelling (Abers et al., 2014; J. S. Byrnes and Bezada, 2020; J. S. Byrnes et al., 2019; Debyale et al., 2020; S. S. Wei and Wiens, 2020) and are significantly more attenuating than expected for globally typical asthenosphere (Dalton et al., 2009; Dalton & Faul, 2010; Dziewonski & Anderson, 1981; Ma et al., 2020). Thus, we summarize the state of the lithosphere-asthenosphere system in South China as intact thick lithosphere beneath the Sichuan Basin thinning toward the southeast, where it is underlain by globally typical asthenosphere that hosts localized upwellings.

### 4.1. The Sichuan Basin and Chuandian Fragment

No matter the inverse approach, a pronounced negative \( \Delta \rho^* \) in the northwest of the study area spans the Sichuan Basin and the Chuandian fragment. Weak attenuation in the Sichuan Basin is expected, since low rates
of seismicity within the basin and low heat flow (Figure S3) indicate that it is composed of strong lithosphere that is not deforming. Other geophysical investigations have found high velocities at depths greater than 150 km (F. Zhang et al., 2018b; Xin et al., 2019), high \( P_n \) velocities (Lü et al., 2017), high elastic thickness (Y. Deng et al., 2014b), low temperature and high strength within the lithosphere (Y. Deng & Tesauro, 2016), and thick flexural lithosphere (Y. Deng & Levandowski, 2018). Hence we attribute the weak attenuation to a thick cratonic nucleus. The absence of seismicity within the negative \( \Delta \rho \) region in the Sichuan Basin, and the abundance of seismicity in its periphery (Figure 4c), are consistent with results from Australia (M. J. Bezada & Smale, 2019) that suggest that variations in lithospheric strength localize intraplate seismicity. However, we do not infer a general correlation between \( \Delta \rho \) and seismicity rates across South China because an increase in seismicity and deformation southwest of the Sichuan Basin occurs with low attenuation.

Interestingly, the negative \( \Delta \rho \) anomaly in the Chuandian fragment is as strong as the one observed in the Sichuan Basin. Previous seismic results conflict as to upper mantle structure in this region. Bao et al., (2015) found high S-wave velocities from the Moho to a depth of 150 km with surface wave tomography. Z. Huang et al. (2015), however, found low \( P \) wave velocities from 65 km to 250 km but high velocities at greater depths based on joint local and teleseismic body-wave travel-time tomography with stations deployed by the ChinArray-I project. An updated model by Z. Huang et al. (2019) found high \( P \) and \( S \) velocities from...
reflects deeper material, and the second is that there is in-place lithosphere beneath the 

As these results conflict, we consider two possibilities. The first is that the lithosphere has been lost and the negative $\Delta r_p$ reflects deeper material, and the second is that there is in-place lithosphere beneath the Chuandian fragment. Regarding the first possibility, $Pn$ tomography shows high uppermost mantle velocity beneath the Sichuan basin, but low velocity beneath Chuandian (Du et al., 2019; Lü et al., 2017; Zhou & Lei, 2016); consistent with a thick lithospheric keel beneath Sichuan but not Chuandian. We would then attribute the negative $\Delta r_p$ in this region to high-velocity material currently located below the lithosphere-asthenosphere system. A deeper body may reflect either subducted Tethys oceanic lithosphere or delaminated lithosphere. Prior to the subduction of India beneath the Burma arc (Lei et al., 2019), subduction was associated with the closure of the Paleo-Tethys and Neo-Tethys oceans, which resulted in the emplacement of several ophiolite belts (Searle et al., 2017) and the Sanjiang Tethyan metallogenic system (J. Deng et al., 2014d; Hou et al., 2007). However, tomographic imaging may place the Tethyan slab in the lower mantle (Hall & Spakman, 2015; Widiantoro & van der Hilst, 1997), making it an unlikely source of the low attenuation anomaly we observe. Consequently, delaminated/detached lithosphere, as proposed by R. Zhang et al. (2017) and Z. Huang et al. (2019), seems a plausible explanation for low $\Delta r_p$.

Second, we consider the possibility of strengthened, in-place lithosphere beneath Chuandian. The error on the results allows similar or thinner lithosphere than beneath Sichuan. In support of this possibility, we note this region is assumed to be the inner zone of a Permian mantle plume (e.g. Y. G. Xu et al., 2007). Geophysical studies suggest that plume activity resulted in crustal underplating with high $V_p$, $V_s$, density and low attenuation in the crust (Y. Chen et al., 2015; Dai et al., 2020; Y. Deng et al., 2016; T. Xu et al., 2015). The regional residual gravity (Y. Deng et al., 2014c) and high resistivity (X. Li et al., 2020) here are also consistent with a plume-modified lithosphere. The minimum in $\Delta r_p$ is colocated with a maximum in $Q_p$ at crustal depths (Dai et al., 2020) and a maximum in resistivity (X. Li et al., 2020), confirming the plume-modified lithosphere. Consequently, lithosphere strengthened by a Permian mantle plume (Y. Deng et al., 2017; X. Xu et al., 2020) could be the source of the low attenuation in this region.

4.2. Basins in South China

The results of the Bayesian inversion show negative $\Delta r_p$ anomalies beneath several basins (Figure 2b) such as the Jianghan, Henyang and Nanchang basins, which each correspond to locally low topography (Figure 1). These anomalies are not clearly identified with the linear approach (Figure 2a). Analogous results in sedimentary basins in Spain (M. J. Bezada, 2017) suggest a pattern where low-lying basins within widely deformed continents are underlain by strong lithosphere readily detectable with seismic attenuation. Rayleigh-wave tomography reveals relatively high-velocities in the middle-lower crust of the Jianghan basin and indicates it rheologically stiff (L. Zhou et al., 2012). Our method of estimating the $\Delta r_p$ measurements with teleseismic body-waves is expected to have greater lateral resolution than surface-waves and may better distinguish structure beneath smaller basins. Our results motivate further high-resolution studies of these basins to confirm if they are formed by locally strong blocks within the lithosphere.

Several negative $\Delta r_p$ anomalies distributed along the coast of South China, for example near 22°N and 113°E, are robust (Figure 2c) and we confirm that waveforms recorded within several of these regions contain excess high-frequency energy (Figure 3). By analogy with the Chuandian region, these anomalies could represent detached lithosphere (Figure 4d). The features do not correlate with the locations of major basins. The low $\Delta r_p$ near the coast is similar to the situation in the northeastern United States, where Dong
and Menke (2017) also observed fluctuated low attenuation and attributed the observation to lithospheric removal. The scale of the detached lithosphere likely controls the amplitude of $\Delta r_p$, though the uncertainties on the model allow these features to have low amplitude.

### 4.3. Volcanic Regions and the Hainan Plume

We observe the most positive $\Delta r_p$ anomalies in the study area near Hainan Island. We attribute this signal to high attenuation in the upper mantle given that geochemical and geophysical data support the presence of a deep-mantle plume beneath this island, the Hainan plume. Late Cenozoic basalts outcrop across both the Leizhou Peninsula and Hainan Island (Zou & Fan, 2010) over an area of $\sim$5,000 km$^2$. Geochemical data show that these basalts are sourced from a lower mantle reservoir (X. C. Wang et al., 2013a). The potential mantle temperature estimated from clinopyroxene phenocrysts for the Hainan basalts is about 170°C higher than that for the MORB source mantle (Gu et al., 2019). Moreover, receiver function analysis (S. S. Wei & Chen, 2016) and triplicated waveforms (Le et al., 2015) show a thin mantle transition zone beneath Hainan Island. With seismic tomography, Lei et al., (2009) found low velocities in the upper mantle, and J. Huang (2014) showed low velocities from the crust to the mantle transition zone. Thus, our high $\Delta r_p$ measurements are likely caused by a deep-sourced mantle plume in this region. The highest values are primarily restricted to Hainan Island, which is in the south of the region over which basalts outcrop on the surface, possibly indicating an inclined bottom-up channel or a tree branch of a mantle plume (H. Liu & Leng, 2020).

We find that the $\Delta r_p$ near Tengchong volcano is not as high as Hainan. We first note that station coverage is sparser near Tengchong than elsewhere. In addition, the final attenuation could be the summation of high attenuation of the upper mantle due to high temperatures or melting and low attenuation due to cold temperature in the subducting Indian plate (Lei et al., 2019; R. Zhang et al., 2017). Accounting for a subducted slab with a thickness between 60 and 100 km and a $Q_p$ in the asthenosphere of 83 brings the $\Delta r_p$ predicted by Equation 3 to $\sim$0.1 s relative to the Sichuan Basin (Figure S4, Supporting information). In fact, peaks in attenuation beneath western Guangxi ($\sim$24°N and 106°E) and southern Guangxi ($\sim$23°N and 109.5°E) reach their maximum amplitudes without any known volcanic activity on the surface. These features may suggest small-scale convection therefore does not produce a one-to-one relationship between mantle upwelling and surficial volcanism.

### 5. Conclusions

In order to better understand lithosphere-asthenosphere system in South China, we estimate relative attenuation of $P$ phases from deep earthquakes recorded at teleseismic distances as quantified by $\Delta r_p$ and mapped with linear and Bayesian inversions. The results are consistent with previous estimates of lithospheric thickness, which illustrates a thick and strong lithospheric root in the Sichuan basin and thinning of the lithosphere from there to the Cathaysia block. In addition, the use of teleseismic body waves provides higher lateral resolution than available in many previous studies. Small-scale features include low attenuation in the Chuandian region, major sedimentary basins, and in isolated regions along the coast, with local peaks in attenuation distributed across the region and a maximum in Hainan Island, suggesting a heterogeneous lithosphere-asthenosphere system. The low attenuation in the Chuandian region likely indicates delaminated lithosphere or a strengthened lithosphere, while the low attenuation in sedimentary basins suggests that basins form where the lithosphere is locally strong and resistant to deformation. The high attenuation regions are sufficiently attenuating to require mantle upwelling or melting, and such activity occurs over a broad region near the Hainan mantle plume and in several locations not associated with surficial volcanism.

### Data Availability Statement

The method in this study is available at https://github.com/jsbyrnes/tSToolbox (https://doi.org/10.5281/zenodo.4277716). The obtained $\Delta r_p$ are provided at https://figshare.com/articles/dataset/attenuation_results_in_South_China/12820460.
Acknowledgments
Constructive comments from editor Lucy Flesch and three anonymous reviewers have greatly improved the manuscript. This work was funded by the Strategic Priority Research Program (B) of the Chinese Academy of Sciences (XDB18000000), National Natural Science Foundation of China (grant 41874106, 42021002), Youth Innovation Promotion Association CAS (YIPA2018385)), and by the National Science Foundation of the United States (grant EAR-1827277).

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