RECEIVER FUNCTION ANALYSIS FOR CRUSTAL VELOCITY STRUCTURE BENEATH SALT RANGE, PAKISTAN

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ABSTRACT

We applied a receiver function technique to investigate the crustal structure beneath the KTAS seismic station in the Salt Range area of Pakistan. The station was installed in 2010 and is a constituent station of the Pak-China Seismic Network of Pakistan Meteorological Department. The teleseismic broadband waveform data recorded by this seismic station were used for this research. We calculated receiver functions using the source equalization technique to obtain good receiver functions for three events. Then, we compared the observed receiver functions to synthetic receiver functions computed for the four crust models taken from the global crust model CRUST 2.0 to find significant differences.

Since in the study area, the Salt Range, there exist salt reservoirs (halite i.e. rock salt), and since such a halite layer is not included in these four models, we modified one of the four models so that the modified models have the shallowest layer with physical properties (density, and shear wave velocity etc.) with halite beds. Then, we calculated synthetic receiver functions for these modified models. Comparison between the synthetic and observed receiver functions suggested the existence of a possible halite layer.

We carried out inversion of the observed receiver functions for crust structure using genetic algorithm including a parameter range of a halite layer. Two selected teleseismic events were stacked for inversion. The obtained model contains a top layer whose physical property is consistent with halite, and the synthetic receiver function computed for this model explained the earlier part of the receiver functions. This result suggested the existence of halite in the study region. The depth of Moho was estimated to be about 55 km, which is consistent with previous studies.

Keywords: Receiver function, crust model, Salt Range, Genetic Algorithm.

1. INTRODUCTION

The Salt Range, with a latitude of 32.67 (32° 40' 0 N) and a longitude of 72.58 (72°34' E), is a hypsographic (mountains) located in the area / state of Punjab in Pakistan (Figure 1). The Salt Range is the surface expression of the leading edge of decollement thrusts over northward offsets of the crystalline basement (Crawford, 1974; Seeber and Armbruster, 1979; Yeats and Lawrence, 1984). Seismic drill-hole data indicate total southward displacement of the Salt Range and Potwar Plateau of at least 20 km (Farah et al., 1977; Baker et al., 1988). The western part of the Salt Range is characterized by a major strike-slip fault that extend along the western Salt Range and Indus River (Baker et al., 1988; McDougall and Khan, 1990)

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2. DATA

In this study we used teleseismic broadband data for three events which was recorded by the Pak-China seismic network of the PMD. The broadband seismic station KTAS of this network is situated in the Salt Range which is our study area as shown in Figure 1. The list of the events is shown in Table 1.

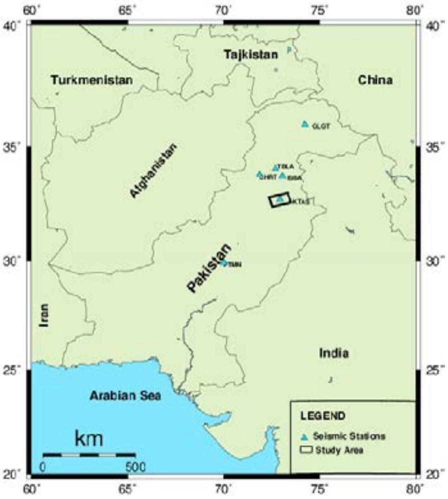


Figure 1. Regional map and study area (within the rectangle).

Table 1. The list of the events used in this study.

No.	Date & time(GMT)	Lat	Long	Mag	Depth (km)
1	07/31/2011 23:39:02	-3.64	144.53	6.8	10
2	03/21/2012 22:15:06	-6.21	146.14	6.9	110
3	03/14/2012 09:08:40	41.01	145.01	7.7	30.7

3. THEORY AND METHODOLOGY

Body waves in the course of propagation pass through different structural features and discontinuities in the crust or upper mantle of the earth. During this P-wave energies are partially converted to S-waves which appear within the P-wave coda after the P-wave. These converted S-waves (Ps) have greater amplitudes on horizontal components than on vertical components. Converted phase generation indicates the existence of discontinuities between homogeneous layers of crust and upper mantle through which the primary P waves pass. In order to model the converted phases from teleseismic waveforms we attempt to recover them by removing source and deep mantle effects from teleseismograms. We require three components of the data to equalize the source in order to remove the effects of the distant structures and the source from the seismogram, to study structure beneath the seismic station. For this purpose we follow the procedure given by Langston (1979), who assumed that three displacement components at a station are expressed by;

$$\begin{aligned} D_R(t) &= I(t) * S(t) * E_R(t) \\ D_T(t) &= I(t) * S(t) * E_T(t) \\ D_V(t) &= I(t) * S(t) * E_v(t) \end{aligned} \tag{1}$$

where V, R and T stand for vertical, radial and tangential components, respectively, $I(t)$ is the impulse response of the recording instrument $S(t)$ is the seismic source function, E is the impulse response of the structure and an asterisk indicates convolution operation. In Langston's (1979) method, it is assumed that $E_v \sim \delta(t)$ where $\delta(t)$ is Dirac delta function. Then by dividing the Fourier transform of the horizontal component by that of vertical component radial receiver function is calculated and is expressed by;

$$E_R(\omega) = \frac{D_R(\omega)\overline{D_v(\omega)}}{\varphi(\omega)}\, G(\omega) \tag{2}$$

where $\varphi(\omega) = \max[D_v(\omega)\overline{D_v(\omega)}, c\max\{D_v(\omega)\overline{D_v(\omega)},]$ and $G(\omega) = e^{\frac{-\omega^2}{4a^2}}$, where c stands for water level.

4. FORWARD MODELING AND INVERSION

We used a set of programs developed by Dr. C.J. Ammon to calculate observed and synthetic receiver functions (http://eqseis.geosc.psu.edu/~cammon/HTML/RftnDocs/rftn01.html). We calculated the observed receiver function for event 1 (Table 1) by setting 'c' as 0.01 and 'a' as 5 and compared it to the synthetic receiver functions of four crust models IK, I2, R0, and PD taken from CRUST 2.0 model package from REM website (http://igppweb.ucsd.edu/~gabi/crust2.html), which lie beneath and in the vicinity of KTAS seismic station (Figure 2a). We observed the significant differences between them and then we modified the crust model PD taking into account the presence of salt (halite) beds in the Salt Range area. However, Vs is set as 2.8 and 2.1 km/s and density is set to 2.2 and 2.4 g/cc for the first and second layer, respectively (Table 2). Their thicknesses are varied to make five different modified models. Comparison of synthetic receiver functions for these models and observed receiver function (Figure 2b) suggested significant effect of halite layer for receiver function and earlier parts (0 to 2 sec) were somewhat similar. This result suggests possible existence of halite beneath KTAS.

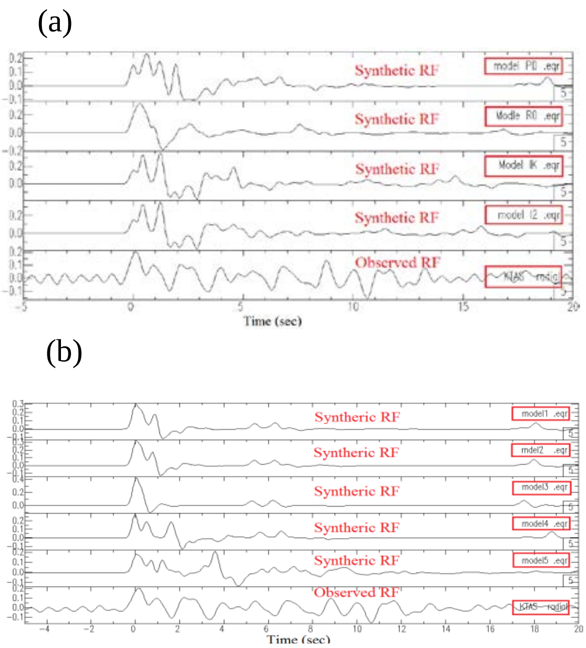


Figure 2. Comparison of observed RF with Synthetic RF's for PD, R0, IK, I2 crust types (a) and Synthetic RF's for five modified models (b).

Table 2. Comparison of original PD crust type model and its modified versions including halite property in the first layer (Bourbie et al., 1987).

Modified PD Models	h1(km) [Vs=2.8(km/s), rho=2.2(g/cc)]	h 2(km) [(Vs=2.1)km/s), rho=2.4(g/cc)]
Model 1	0.3	1.0
Model 2	0.15	1.0
Model 3	0.3	0.3
Model 4	0.3	2.0
Model 5	0.6	4.0
Original PD Model	h1(km) [Vs=1.2(km/s), rho=2.1(g/cc)]	h2(km) [Vs=2.1(km/s), rho=2.4(g/cc]
	1.0	1.0

5. RECEIVER FUNCTION INVERSION BY GENETIC ALGORITHM

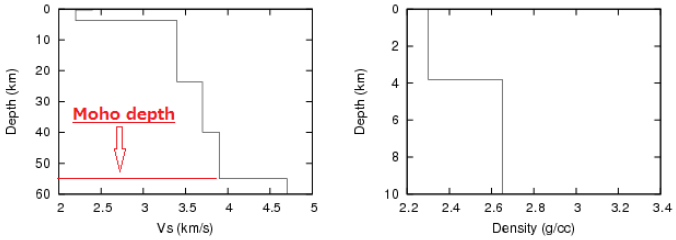
We used Genetic Algorithm inversion program developed by Shibutani et al. (1996), who adopted 'tournament selection scheme' (e.g., Sambridge and Gallagher, 1993). The model parameters are thickness of layers, shear wave velocity, Vp/Vs ratio and density of each of six layers, which are a sediment layer, hard sediment, upper crust, middle crust, lower crust and mantle (Table 3). The range of these parameters for the shallowest ‘sediment’ layer is set for halite following Bourbie et al. (1987). For other layers the parameter ranges are set referring to Shibutani et al. (1996) and CRUST 2.0 model package. For each model parameter, upper and lower bounds and 2^n possible values are specified. In our case the total number of bits is 41. These model parameters are coded into a binary string in the inversion process.The model space to be searched is 2^{41}. Events no.1 and 2 were stacked, and used as data for inversion .The final model is shown in Figure 3 and Table 4.

Table 3. Model parameters in genetic algorithm receiver function inversion.

		“Halite”	Hard Sediment	Crust			Mantle
				Upper	Middle	lower	
Thickness (km)	Lower Upper n Increment	0 0.45 2 0.15	0 3.5 3 0.5	10.00 20.0 4 0.7	10.00 20.50 4 0.7	8.00 18.50 4 0.7	0.0 0.0 0.0 0
Vs (km/s)	Lower Upper n Increment	2.4 3.10 3 0.1	2.10 2.80 3 0.1	3.30 3.6 2 0.1	3.50 3.80 2 0.1	3.70 4.0 2 0.1	4.0 4.7 3 0.1
Vp/Vs	Lower Upper n Increment	1..70 2.4 3 0.1	1.70 2.0 2 0.1	1.73 1.73 0 0.0	1.73 1.73 0 0.0	1.73 1.73 0 0.0	1.73 1.73 0 0.0
Density (g/cc)	Lower Upper n Increment	2.00 2.3 2 0.1	2.3 2.6 2 0.1	2.67 2.67 0 0.0	2.81 2.81 0 0.0	3.18 3.18 0 0.0	3.25 3.25 0 0.0
Qa		300	675	1450	1450	1450	1450
Qb		150	300	600	600	600	600

The shear wave velocity of the shallowest layer is 2.4 km/s, which is a little slower than typical values of halite (Bourbie et al., 1987), The estimated thickness is 300 m. A comparison of synthetic RF for this model and observed RF is given in Figure 4. From 0 to 2 seconds the part of the synthetic receiver function is consistent with that of the observed receiver function which is consistent with the comparison shown in Figure 2(b). These results suggest the presence of halite in the region. The differences in the later part of the receiver functions are likely due to complex deep crustal structures.

In Figure 5 we can see that Moho depth is not well constrained and is varying according to different models. Although, there exists a certain uncertainty for Moho depth considering the differences among those of these models, it seems that the depth of Moho is larger than 50 km. An integrated study by Johnson and Vincent (2002) estimated the average regional Moho depth to be 50 km. The studies by Jhonson and Vincent (2002) and Soomro (2009) suggested that the crust becomes thinner in the central and southern part of Pakistan. This seems inconsistent with our study, where the Moho depth beneath KTAS is about 55 km. However, the deep crust ‘trough’ extends toward our study area in the model by Jhonson and Vincent (2002) (Figure 9 of their paper), and our result is consistent with their model.



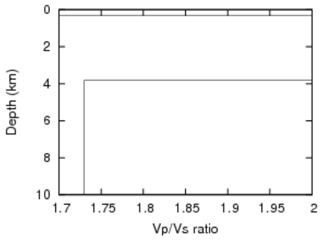


Figure 3. Vs, density and Vp/Vs for the final model obtained by RF inversion are shown in the upper left and right, and lower left panels, respectively.

Table 4. The final model obtained by inversion.

Layer	Thickness (km)	Vs (km/s)	Vp/Vs	Density (g/cc)
1	0.3(0.3)	2.40	1.70	2.30
2	3.5(3.8)	2.20	2.00	2.30
3	19.8(23.6)	3.40	1.73	2.65
4	16.3(39.9)	3.70	1.73	2.77
5	15.0(54.9)	3.90	1.73	2.86
6	0.0(54.9)	4.70	1.73	3.30

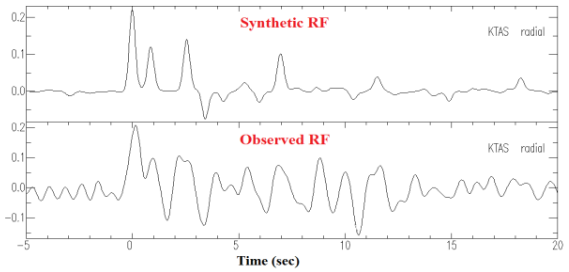


Figure 4. The synthetic RF for the final model and the observed RF.

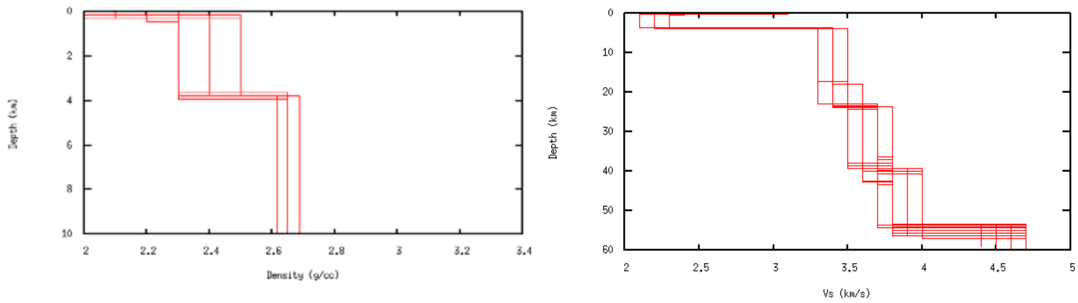
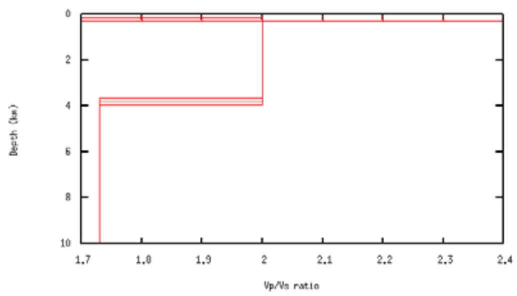


Figure 5. Models whose residuals between the synthetic and observed RFs are comparable to that of the final model. The densities, Vs and Vp/Vs are shown in the upper left, upper right, and lower right panels, respectively.



6. CONCLUSION

We performed receiver function analysis to study the crustal structure beneath the KTAS seismic station of the Pak-China seismic network, which is located in the Salt Range area of Pakistan. We used broadband waveform data recorded at KTAS for three teleseismic events with magnitudes larger than 6.0.We calculated radial receiver functions using the source equalization technique developed by Langston (1979) by the receiver function codes developed by Charles J. Ammon.

Then, we compared the observed receiver functions to synthetic receiver functions computed for the four crust models, which are designated in the vicinity of KTAS in the global crust model CRUST 2.0. We found that the observed and synthetic receiver functions are significantly different. Considering the possible existence of halite beds in the study area, we modified one of the four models so that the shear wave velocity and density of the shallowest layer are in the possible range of halite. The early part of the observed receiver functions are consistent with that of the synthetic receiver functions computed for some of these modified models, which suggests a possible existence of halite beds.

We performed inversion of the observed receiver functions for crust structure beneath KTAS using a genetic algorithm. We set the parameter ranges considering halite property for the shallowest layer. The shear wave velocity of the shallowest layer of the obtained model is 2.4 km/s, which is consistent with a possible existence of halite considering the estimation uncertainty, although it is a little slower than typical values of shear wave velocities for halite. The estimated Moho depth is about 55 km, which is consistent with the model developed by Jhonson and Vincent (2002).

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