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Estimating bedrock depth in the case of regolith sites using ambient noise analysis

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ABSTRACT

Subsurface geometry, particularly the depth of bedrock, is crucial in seismic hazard studies because the basin geometry has been shown to play an important role in the altering of seismic waves. Estimating the bedrock surface using ambient seismic noise analysis has been undertaken by many researchers, with most studies focusing on sites with a strong impedance contrast between the bedrock and the overlying materials. The application of this technique at regolith sites, which is subjected to impedance contrasts in the low to high range is underdeveloped and requires further attention. This study seeks to address this need and is focused on the city of Adelaide in South Australia, which exhibits site amplification and is associated with various impedance contrasts. Analyses of ambient noise data are carried out using the generic function (GF) of the classic horizontal vertical spectral ratio (HVSR) method and the spatial autocorrelation (SPAC) technique to estimate the depth to bedrock. Comparison of the bedrock depth predictions from the seismic methods with boreholes drilled in close proximity to the measured sites demonstrate that the SPAC method provides superior estimates especially to those obtained from the other approach. This work demonstrates that the microtremor SPAC method is an effective tool for estimating bedrock structure at regolith sites.

1. Introduction

Local site effects need to be considered when conducting seismic hazard assessments (Booth et al., 1986; Brebbia et al., 1996; Street et al., 2001) as earthquake motion can be significantly amplified at vulnerable soil sites and cause severe structural damage, such as that which occurred in the 1985 Mexico, 1988 Armenian, 1989 Loma Prieta, 1989 Newcastle, and 1995 Kobe earthquakes. The bedrock profile and overburden sedimentary deposits contribute to site amplification effects (Graves et al., 1998; Bakir et al., 2002; Narayan and Rao, 2003; Narayan, 2005). Irregular sub-surface profiles, subjected to incident body waves, can result in focusing and defocusing of the seismic wave field manifested at ground level. The basin interface may change the velocity and direction of the waves. In certain circumstances, the focusing and defocusing phenomenon may cause amplification and de-amplification at the ground surface. The effect of the basin bedrock profile is revealed by the damage patterns of the Northridge, Sherman Oaks, and Santa Monica, California earthquakes (Somerville and Graves, 1996; Graves et al., 1998).

Single station ambient noise measurements are useful for investigating the depth of bedrock. Ibs-von Seht and Wohlenberg (1999) developed an empirical relationship between fundamental resonance frequencies and overburden thickness for the Lower Rhine Embayment in Germany and suggested good agreement between the horizontal to vertical spectral ratio (HVSR) peak frequency with the overall overburden thickness, ranging from tens to > 1000 m. These developments have provided a practical means of estimating overburden thickness using ambient noise data. Subsequently, many studies have used similar approaches for estimating the thickness of sediments overlying bedrock (e.g. Bodin et al., 2001; Parolai et al., 2002; Gosar, 2007; D'Amico et al., 2004; Hinzen et al., 2004; Lane et al., 2008; Dinesh et al., 2010; Paudyal et al., 2012a & b; Guo et al., 2014; Guo and Aydin, 2016). All of these studies were carried out essentially in relatively thick, homogenous and uniformly layered systems and in high impedance contrast sites. Estimating the bedrock surface using ambient noise analysis at regolith sites subjected to a complex layered system and various (low to high) impedance contrasts is the subject of ongoing research.

The present study is focused on bedrock depth estimation in

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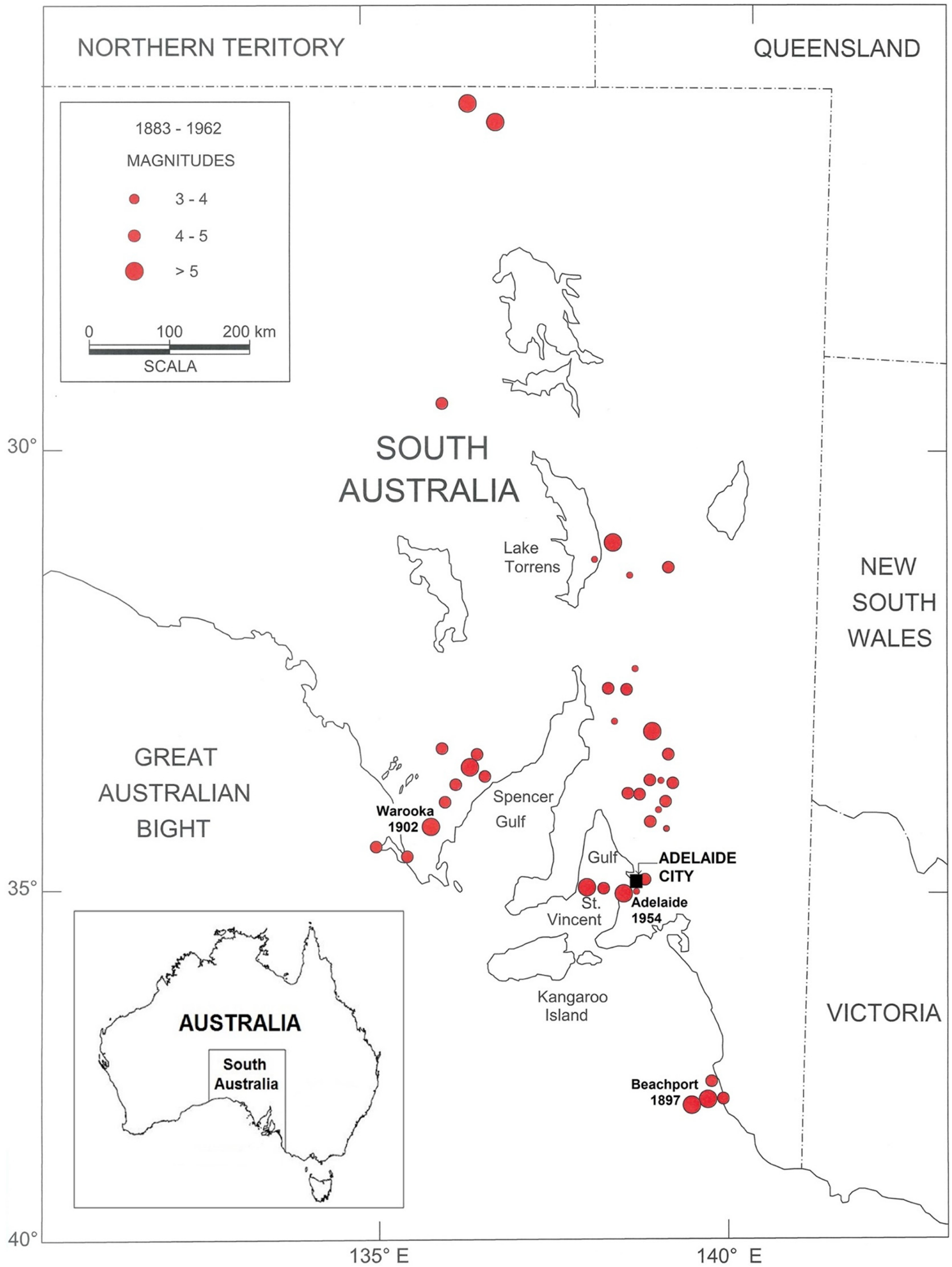

Fig. 1. Epicenters of the historical earthquakes (Malpas, 1991) including Adelaide city study area (Black Square).

presence of a complex subsurface profile and various impedance contrast sites, which is manifested in Adelaide's regolith. Regoliths include all weathered materials in the zone between the ground surface and the underlying bedrock (Wilford and Thomas, 2013). The Australian National Committee on Soil and Terrain (NCST) (2009) characterizes the regolith as the mantle of earth and rock altered or formed by land surface processes, whereas bedrock is the zone formed or altered by deep-seated crustal processes. The NCST characterized regolith and bedrock by different processes, rather than grouping them into different classes of material. Thus, characterizing earth layers as either regolith or bedrock is a task which involves many parameters including mineralogy and structure; climate, particularly rainfall and temperature; aeolian inputs; topography; biota, including vegetation and organisms; age, and soil-landscape history (Wilford and Thomas, 2013). The unique processes and parameters that control the development of a regolith when compared to bedrock result in different characteristics of masses within the regolith zone to those within the bedrock zone. Generally, the regolith tends to have lower density, strength, and cohesion than bedrock (NCST, 2009). Two previous investigations, namely Leonard (2015) and Collins et al. (2006), suggested various (~2.1 to ~3.5) impedance contrasts for the regolith at the investigated sites. Collins et al. (2006) measured the shear wave velocity at the Government House Site (GHS) in Adelaide, South Australia, using the spectral analysis of surface waves (SASW) method. Collins et al. (2006)