Passive seismic imaging of bedrock depth and sediment fill of an alpine valley in the Colorado Plateau (US)

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Unaweep Canyon is a large gorge that bisects Colorado`s Uncompahgre Plateau and is globally unique, named for the odd occurrence of a divide in its midst, from which two creeks flow in opposite directions. The 50 km long canyon incises through Mesozoic strata into Precambrian basement but hosts a thick sediment fill of Pleistocene and possibly older age. The shape of the canyon and geologic observations led to the hypothesis that the valley was glacially overdeepened in the late Paleozoic, which would challenge current climate models of that period. Previous geophysical and drilling campaigns provided bedrock depth estimates of more than 350 m along cross-sections. To investigate the longitudinal structure of the bedrock and the sediment fill, we deployed 120 passive seismic recorders along a 4.5 km long section in Unaweep Canyon over the period of one month. The recorded seismic data contain continuous ambient noise (traffic, quarry activities) as well as several teleseismic earthquakes. The seismic ambient noise is subjected to interferometric analysis to reconstruct surface waves propagating through the array. Those surface waves show clear dispersive behaviour in the frequency range 1–6 Hz, allowing to image the 2D-shear wave velocity structure of the sediments down to maximum depths of ca. 400 m. The bedrock depth is imaged from auto-correlation analysis of the coda waves of the teleseismic events. Assuming near-vertical incidence of planar P-waves, auto-correlation can approximate the vertical reflectivity structure below the recording stations. Compared to the ballistic (first) arrival, the coda waves exhibit higher frequencies which are crucial to image the shallow bedrock interface. We obtain a very sharp image of an undulating bedrock interface along the entire section, which is also validated by a recent drilling result. Depending on the choice of the velocity model, the maximum depth of the bedrock along the investigated section is ca. 500 m. The structure suggests that the valley has been glacially overdeepened, although the lack of a 2D P-wave velocity model required for accurate depth conversion and the intricate 3D-structure of the canyon leave some uncertainty on this interpretation. We conclude that passive seismic imaging is a meaningful and cost-effective method to investigate local and regional structures, in particular in areas with difficult access. While ambient noise is required for velocity modelling and might not always be prevalent, teleseismic events are abundant everywhere and the frequency content of their coda waves can be high enough for shallow reflectivity imaging.