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NEWS AND COMMENTARY

FEATURE ARTICLES

Geophysics in archaeology: a scrapbook of worldwide data

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Introduction

Cultural heritage sites are usually mapped for either anthropological pursuit, or as required by government planning policy. High-resolution geophysics can be employed to rapidly image buried archaeological sites, to help guide the labour-intensive excavations or even to defer the need to disturb the site. Ground Penetrating Radar (GPR) is commonly used for the 3D information which can be achieved (Conyers and Goodman, 1997). Typical frequencies employed range from 50 MHz, which has a resolution and depth penetration of about 50 cm and 5 m respectively, to 450 MHz with resolution/penetration of about 5 cm/1 m. Other popular methods are magnetics (usually gradiometry), electrical and electromagnetics. Here a suite of geophysical images is presented from sites in Japan, China, the Americas and Pompeii.

Fig. 1. *Reconstructed kofun and burial chamber. From http://travel.webshots.com/photo.*

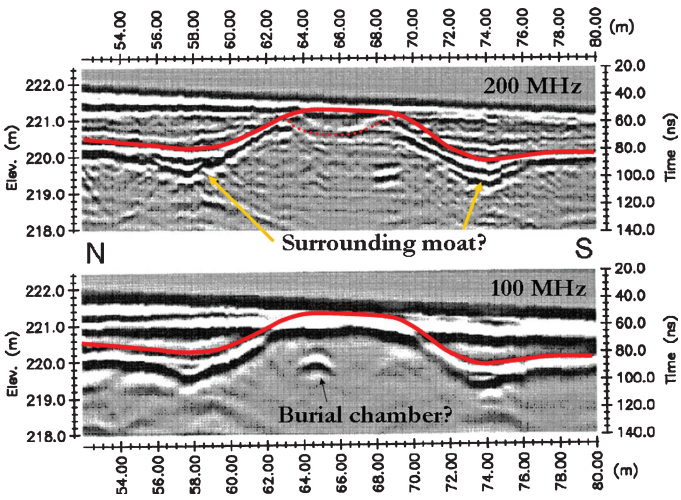

Fig. 2. *GPR profiles over a buried kofun at Komochi village.*

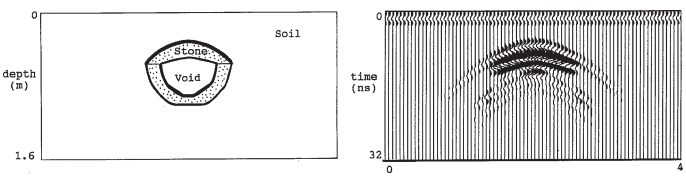

Fig. 3. *Simulated radar response from the air-filled cavity of a stone tomb (Goodman 1994).*

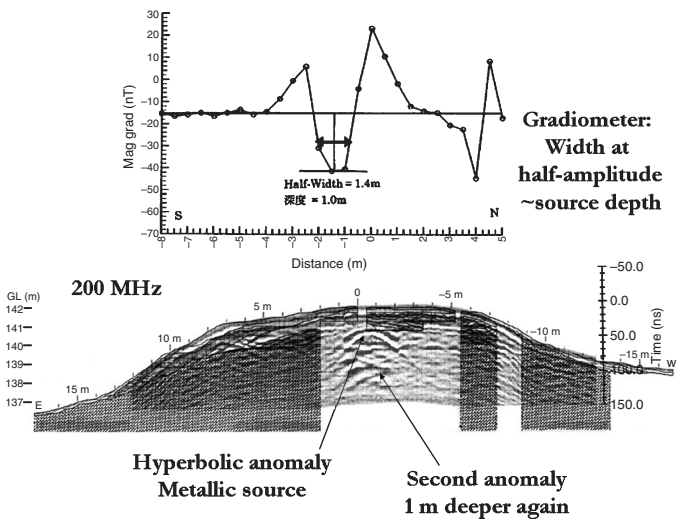

Fig. 4. *200 MHz GPR section at Mount Zoubi, the radar depth correlating with the gradiometer half-width rule.*

Japan

The period 300–600 AD in Japan is known as the *kofun jidai*, after the kofun (burial mounds) found throughout the country. They range in size from circular mounds of a few metres in diameter to giant keyhole shapes, hundreds of metres in length.

A reconstruction of an average sized kofun and the typical burial chamber is shown in Figure 1. Komochi village in Gunma prefecture is known as the 'Pompeii of Japan', where numerous kofun were buried by over 4 m of volcanic ash in the 6th century AD. Figure 2 shows both 200 MHz and 100 MHz GPR profiles recorded over a sealed road, clearly showing the topography of a buried mound and clear internal features. The anomaly in the 100 MHz data is potentially an air-filled cavity, as shown in the modeling of Figure 3.

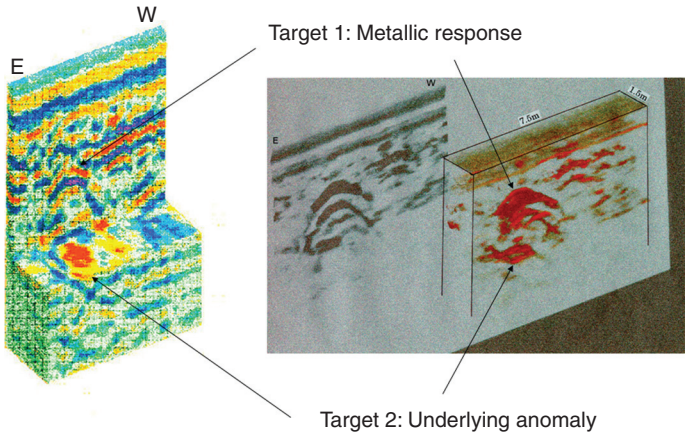

Fig. 5. *3D GPR results showing the diffraction from the buried ferrous object and a second deeper radar anomaly.*

At Mount Zoubi in Yoro Town, Gifu prefecture, are some of the oldest kofun of the period. Being at a major strategic east-west junction, many military leaders are entombed here, dating from the start of 300s AD. A fluxgate magnetometer survey and 200 MHz GPR survey (Figure 4) shows coincident anomalies, due to a buried ferrous object. The GPR source was calculated to be at 1 m depth, by fitting a hyperbola to the radar diffraction (Powers and Olhoeft, 1995), which also correlated with the depth from the magnetic 'half-width' rule. Of more interest to the archaeologists was the second, deeper anomaly. This prompted a 3D GPR survey, which clearly shows both shallow and underlying anomalies (Figure 5). Guided by the geophysics, the mound was excavated and a number of heavily corroded swords were discovered at 1 m depth. The deeper anomaly was not excavated.

Ema Castle in northern Gifu prefecture was built by a lord of the area in the early 1400s and destroyed by fire in 1582. Excavations in the 1970s revealed Chinese and Japanese pottery from the 1200–1500s and evidence of triangular cross-section

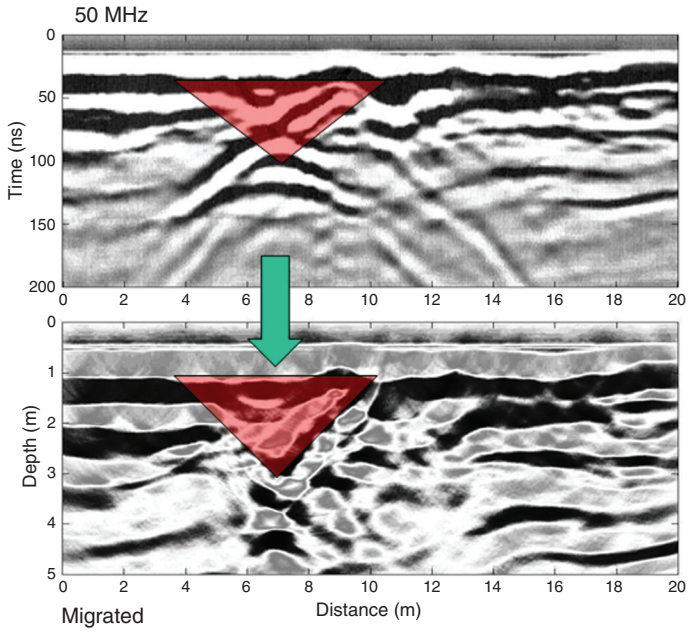

Fig. 6. *Raw and migrated 50 MHz GPR sections at Ema Castle.*

Fig. 7. *Photo of the excavated V-shaped moat.*

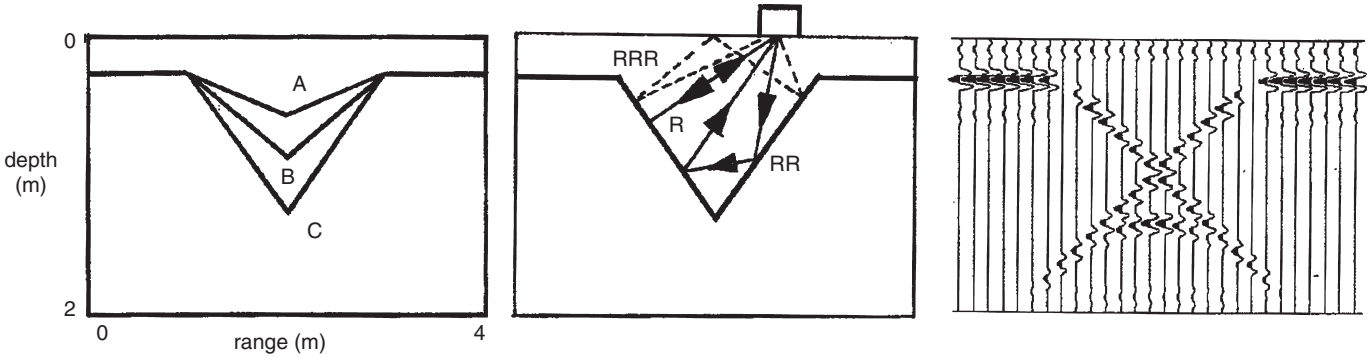

Fig. 8. *Synthetic radar modeling of a V-trench model (Goodman 1994).*

Fig. 9. *Resistance mapping procedure using 0.5 m mobile electrode spacing.*

defence moats called *yagenbori*. A 50 MHz radar survey (Figure 6) over an unexcavated area showed a complex diffraction pattern but migration of the data shows the structure as a steep-sided V-shaped trench, and proven by excavation (Figure 7). The 'bow-tie' response arises due to multiple reflections (Figure 8).

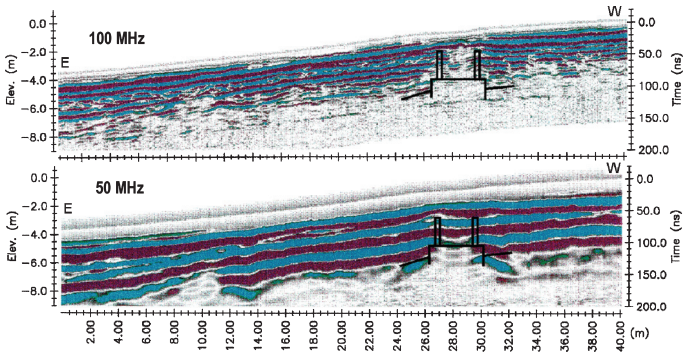

Fig. 11. *GPR profiles at 100 MHz and 200 MHz at Joya de Ceren.*

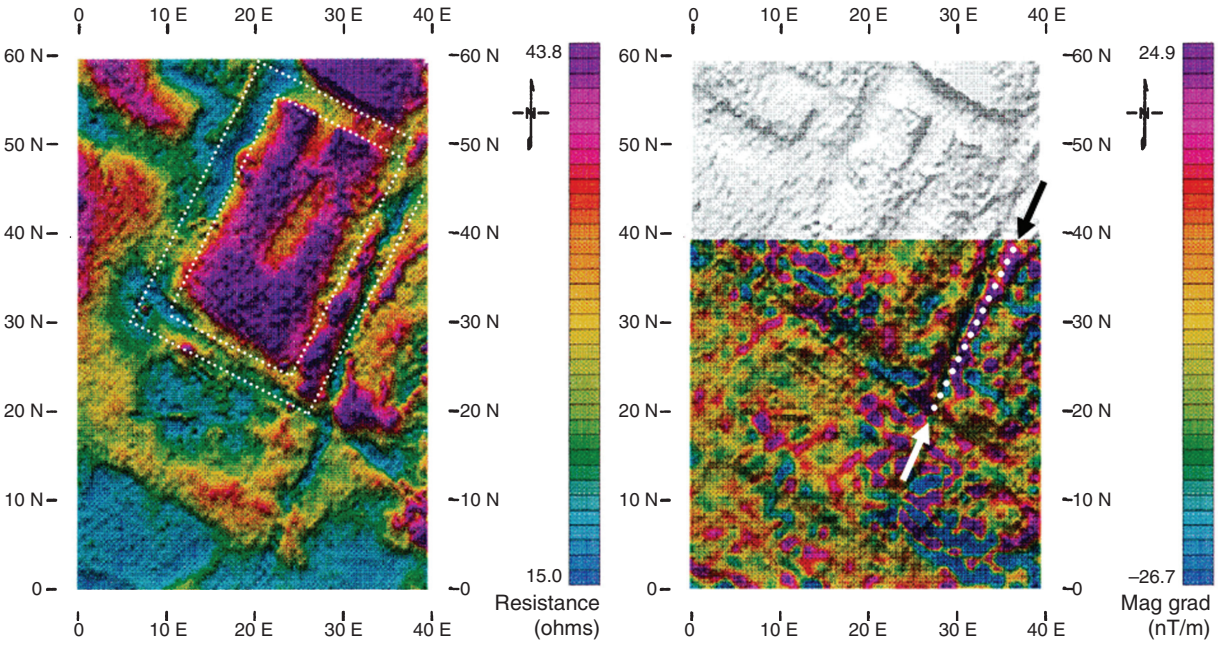

Fig. 10. *Resistance and magnetic images of the Kaminaljuyu site (resistance shading overlain on the magnetic gradient colour map).*

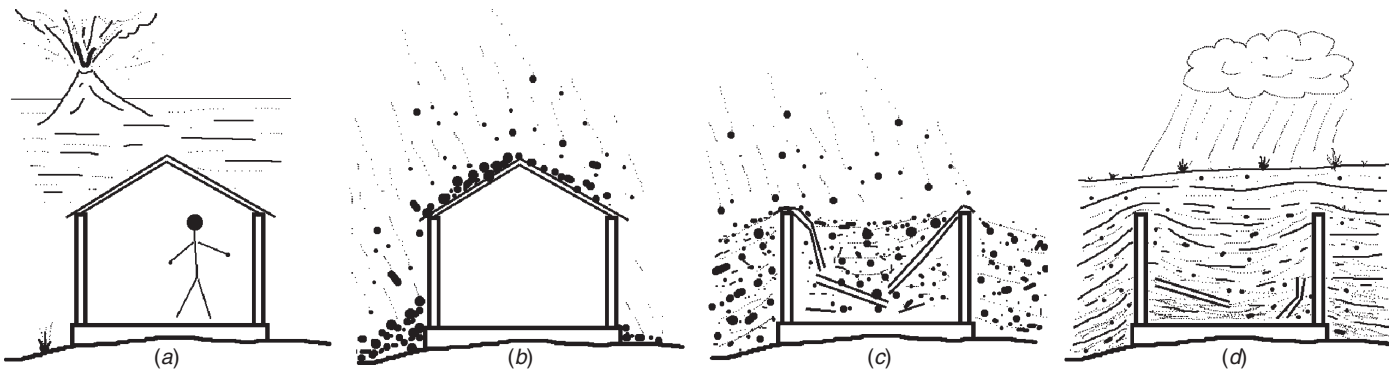

Fig. 12. *A cartoon speculating on the demise of a typical clay-walled house buried by volcanic ash.*

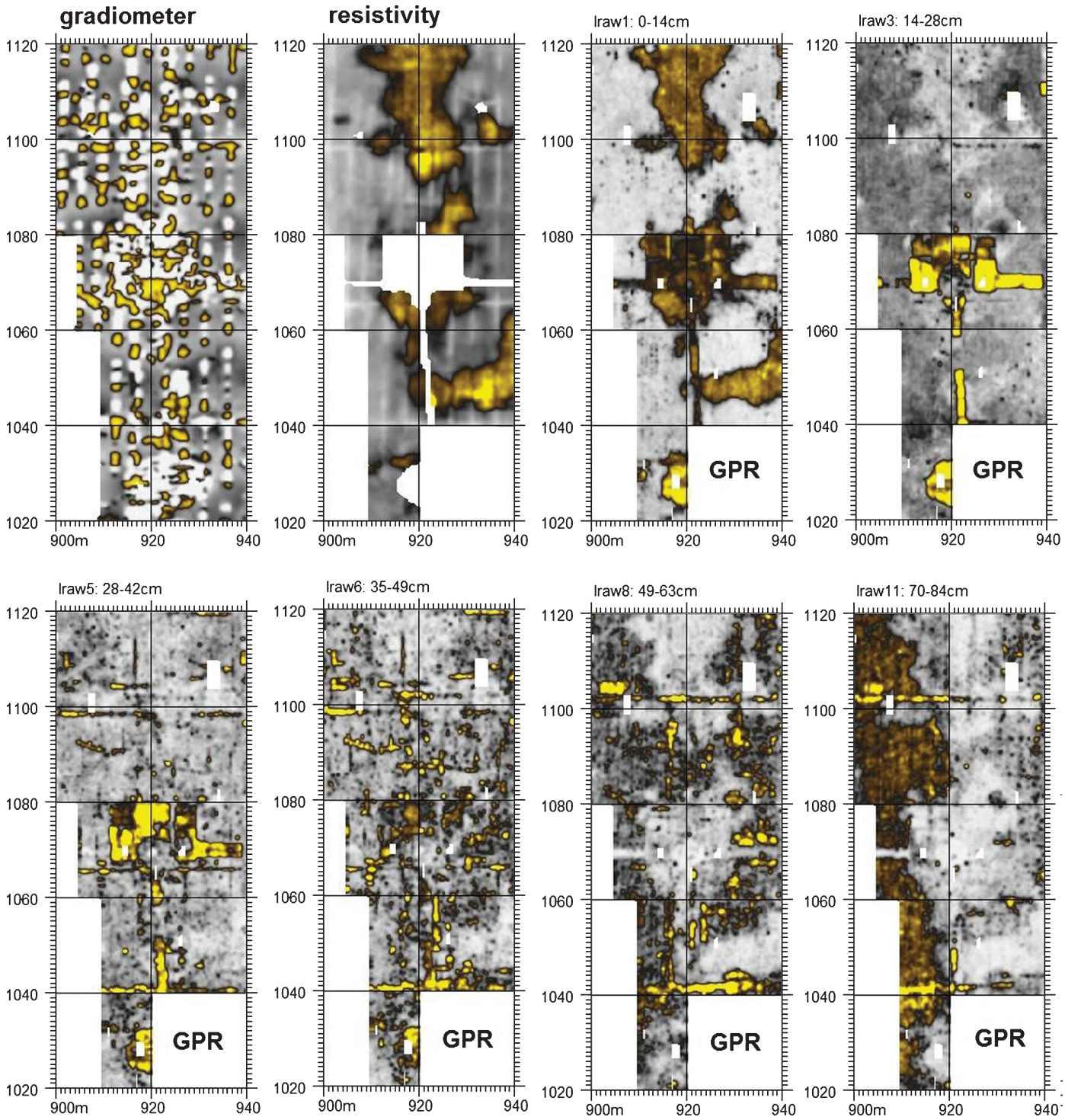

Fig. 13. *Magnetic gradient, resistivity and series of GPR timeslices at the Presidio fort in San Francisco.*

Americas

In Guatemala City, El Salvador, sites of Mayan civilization were buried by volcanic ash some time after about 1000 AD. Figure 9 shows the resistance mapping equipment being used with 0.5 m current-potential (A-M) electrode spacing. The geometry relative to the remote electrodes (B-N) is not regular, so the measurement is in resistance, not resistivity. Figure 10 shows the electrical resistance and fluxgate gradiometer maps from the central part of the Kaminaljuyu site. The edges of the buried foundations are clearly discernable, and the coincident resistance and magnetic anomalies suggest there may be construction with magmatic or basaltic rock, or some induced magnetism in an earthen foundation.

Joya de Ceren in El Salvador was an agricultural village of 40–50 families, buried by up to 6 m of volcanic ash from the nearby Loma Caldera in ~590AD. Excavations reveal clay structures with thick walls and foundations. Radar has been applied here from its earliest inceptions (Conyers and Goodman,

Fig. 14. *100 MHz GPR survey being conducted at Turpan.*

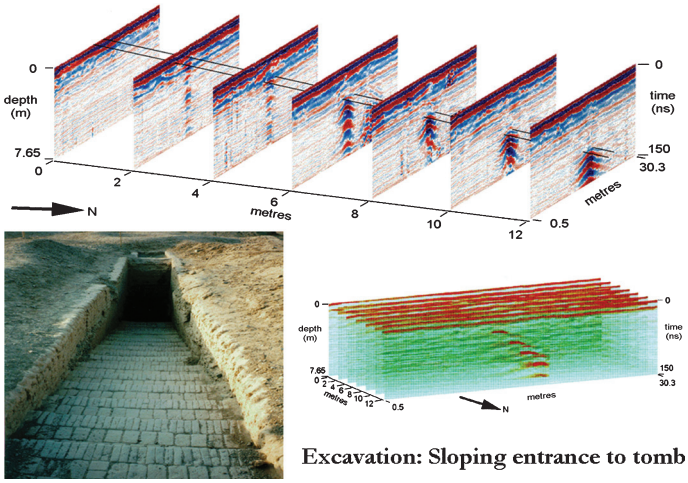

Fig. 15. *The 100 MHz GPR results and an excavated entrance to a buried tomb at Turpan.*

1997). The GPR data show a disruption in the encumbering ash, interpreted to be the standing walls of a house (Figure 11). The cartoon of Figure 12 speculates how this unfortunate event may have progressed.

The Presidio in San Francisco is the area next to the Golden Gate Bridge where the first fort was built by the Spanish in 1776. Gradiometer, resistivity and GPR were used in a study to detect old adobe walls of the fort, the comparison images shown in Figure 13. The gradiometer and the shallow resistivity were very effective in detecting old drainage at the site. Note how the top GPR time slice looks very similar to resistivity, but the deeper radar timeslices clearly show the old adobe foundations.

China

The tombs of Turpan in far northeast China on the 'Silk Road' date from the 1st century BC. Early excavations in the 1930s unearthed hundreds of artefacts. A GPR survey was conducted adjacent to an unexcavated tomb cluster (Figure 14) and the results clearly show the sloping tomb entrance (Figure 15). The accurate 3D radar positioning helps guide excavations to minimize chance of disturbing the targets.

Pompeii

Possibly the most famous site to have been buried by a volcanic event, Pompeii was encumbered by up to 5 m of scoria and ash

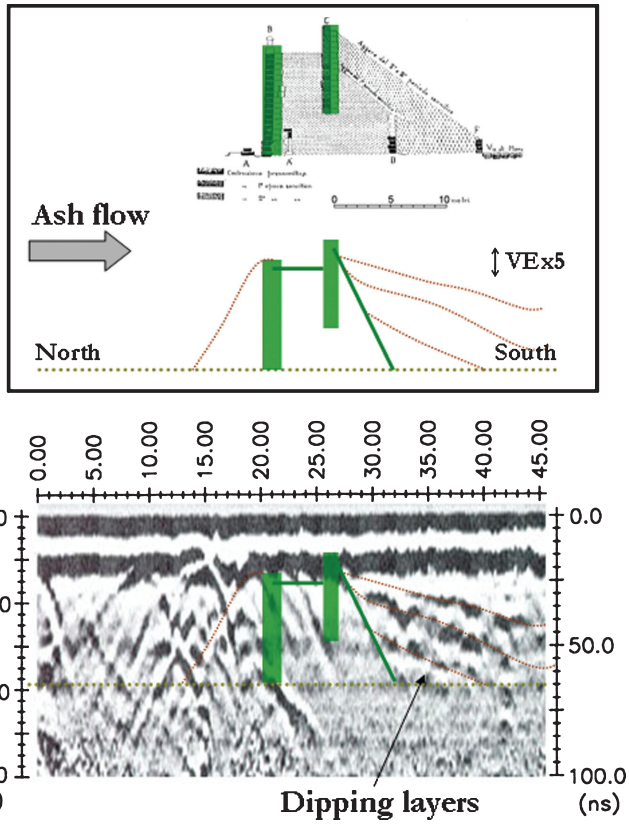

Fig. 16. *50 MHz GPR section over the northern fortification wall at Pompeii and cartoon of the interpretation.*

in the 79 AD eruption of Mt Vesuvius, some 10 km to the north of the city. Much of the site has been excavated, although the northern Porta di Capua fortification walls remain under modern farmland. GPR survey results over the anticipated wall location are shown in Figure 16. When compared to an already excavated section of the wall, the radar interpretation is supported by the diffractions from the tops of the rocks walls and the sloping ash on the downwind side. Dipole–dipole resistivity simulation and field data at a nearby location show good correlation to support the interpretation of a buried twin-wall (Figure 17).

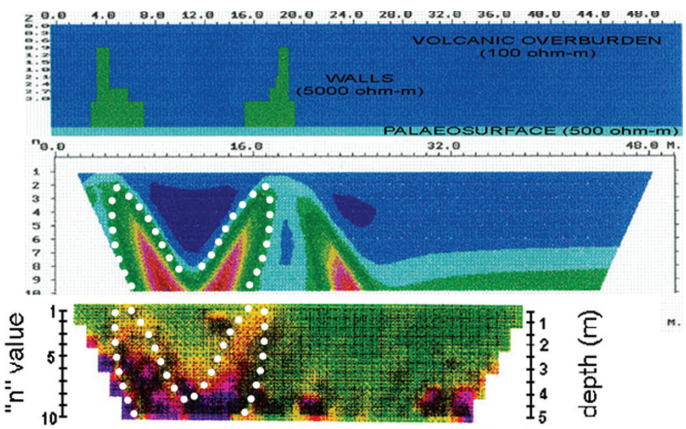

Fig. 17. *Dipole–dipole resistivity simulation and field results over a twin-wall fortification.*