Subsurface Imaging in Tiwanaku’s Monumental Core

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Ground-penetrating radar (GPR), magnetometry, induced electrical conductivity, and magnetic susceptibility mapping in the northeast quadrant of Tiwanaku’s monumental core has revealed a series of previously unknown architectural features. Several of these were tested with excavations and confirmed to be wall foundations and conduits. Others await subsurface testing but the synergy of geophysical data, aerial photographs, and topographic data provide strong evidence for the following features: two residential compounds, four pools for water retention, a series of conduits, revetments, and a square structure. The combination of GPR and magnetometry has proven particularly useful at Tiwanaku. While the majority of buried architectural features seem to be detected with GPR, magnetometry helps to distinguish between local building materials (mostly sandstone and other sedimentary rocks) and the ritually significant andesite imported from the shores of Lake Titicaca. The data suggest that a series of east facing revetments were built with andesite while those facing north were not, a pattern consistent elsewhere at Tiwanaku. These revetments may have been most visible to pilgrims entering the city from the east.

The city of Tiwanaku has attracted antiquarian and archaeological interest since the time of European conquest. Today the site stands with several large monuments in various stages of excavation and reconstruction (Figure 1). In the center lies the Akapana, a large platform mound which likely housed a sunken court at its summit. To the north lies the Kalasasaya, a large platform temple with massive upright stones marking the annual solar cycle, and adjacent Semisubterranean Temple, one of the earliest monumental constructions. To the east lies the scattered ruins of the Kantatayita, the only monument visible on the surface that has not yet been excavated (though excavations are currently underway). Far to the southwest lies the Pumapunku, a large platform mound similar to the Akapana that may have served as a gateway to the city for pilgrims traveling from Lake Titicaca some 10 km to the west (Vranich 2006). For decades these large monumental structures formed the basis for archaeological inquiry and interpretation, leading the long-held belief that Tiwanaku was a vacant ceremonial center (Bennett 1934). Extensive survey and excavations beginning in the 1980s showed that Tiwanaku had a large residential population that covered some six square kilometers at its peak (Kolata 2003b). At least eight residential compounds have been partially excavated—four within the monumental core and four more distant (Kolata 2003a). Yet, large expanses of the site remain unexcavated and are no doubt filled with complex layers of Tiwanaku occupational levels, residential
compounds, burials, waterways, revetments, and structures. Large-area geophysical survey provides a means to explore these areas in considerable detail, revealing not only the locations of buried features, but a buried landscape that is otherwise invisible short of complete site-wide excavation. Extensive geophysical surveys allow us to ask and begin to answer new archaeological questions.

Geophysical investigations have recently taken a prominent role in Tiwanaku Archaeology. Williams, Couture, and Blom (2007) conducted geophysical surveys (magnetometry, resistance, and ground-penetrating radar) in small portions of the Putuni complex, Akapana East 1 residential complex, and a large area at Mollu Kontu to the south. These and other preliminary investigations showed the potential of geophysical methods at Tiwanaku. The current project (Proyecto Arqueologico Pumapunku-Akapana, PAPA) includes five years of geophysical survey over vast portions of the monumental core. Koons (2006) conducted a very large GPR survey directly east of the Akapana and also reinterpreted data collected by Henderson (2004) directly west of the Akapana. To complement and extend these surveys we have used electrical resistance, electromagnetic induction (EMI), and magnetometry over selected areas previously surveyed with GPR. We have also extended the GPR survey to the northeast sector of the monumental core.
The multi-sensor approach is very useful in discovering several subsurface features and distinguishing their depth and nature of construction materials. Ground-penetrating radar has proven to be the most useful and versatile method because it detects the majority of subsurface features and allows their depths to be estimated. Magnetometry provides a powerful complement by distinguishing between igneous rock (e.g. andesite) and other common rocks used in construction (e.g. sandstone and limestone). Magnetic susceptibility and conductivity (both from the EMI instrument) provide additional insight for feature interpretation. The large geophysical dataset provides a database of information that is too detailed to describe here in its entirety, so we focus on selected features located east and northeast of Akapana. These include what we interpret to be two residential compounds, a series of conduits, circular water retention features, revetments, and a square structure. In some cases we have tested these interpretations with excavations, but many remain untested. Our interpretations were made using knowledge from previous excavations and the multiple geophysical datasets available, but their accuracy will no doubt be assessed by future excavations.

Geophysical Methods

Archaeological geophysics includes a suite of techniques that enable detection of buried archaeological features and related deposits. The most common and arguably successful techniques include ground-penetrating radar (GPR), electrical resistance, magnetometry, magnetic susceptibility, and induced electrical conductivity. The latter two datasets can be obtained from an electromagnetic induction (EMI) instrument. We have employed all of these at Tiwanaku with considerable success, though electrical resistance survey was abandoned after initial tests because it was too difficult to insert the electrodes into the dry soils that characterize the altiplano during winter. The following is a brief explanation of GPR, EMI, and magnetometry (for more details see Clark 1996; Conyers 2004; Gaffney and Gater 2003; Johnson 2006; Witten 2006).

Ground-penetrating Radar

Electromagnetic waves are sent into the subsurface from an antenna that is pulled along the ground. When the waves encounter an interface, such as the boundary between site matrix and rock architecture, some of them are reflected back to the surface and recorded (Conyers 2004). At the same time, portions of the signal travel deeper and reflect from other buried interfaces. This continues until the signal deteriorates and cannot be distinguished from noise. The time it takes for each reflection to be recorded by the receiving antenna is measured and therefore depth can be approximated. The types of interfaces that can be detected include changes in moisture, sediment size, and compaction. Thus GPR is well suited for detecting rock and mud-brick architecture, and many other types of features including pathways, ditches, and graves. Depth penetration varies widely depending on the frequency used and the electrical properties of local soils and sediments (Conyers 2004). A GSSI SIR2000 system with 400 MHz antenna was used at Tiwanaku (Figure 2) with relatively limited depth penetration (about one meter) due to high percentages of clay, but this was still sufficient to detect most of the cultural layers at Tiwanaku. Data were collected in rectangular sub-regions using half-meter line spacing. Processing included gaining, band-pass filtering, background removal, and position correction. Time slices representing 3-6, 6-9, and 9-12 nanoseconds (ns) were created representing approximate depth intervals of 27-40, 40-54, and 54-67 cm. For display and interpretation these slices were combined into one layer capturing the majority of anomalies using principal components.
analysis (Kvamme 2006a, 2007). Original slice maps and reflection profiles were consulted whenever depth or other details were needed.

**Electromagnetic Induction (EMI): Conductivity**

Electromagnetic Induction (EMI) is a method that creates electromagnetic fields which are induced into the ground. These frequencies are much lower than those used for GPR, and the method is fundamentally different (Witten 2006). Electromagnetic (EM) fields emanate outward in all directions from the transmitter, but most importantly into the ground. This primary field induces eddy currents in the ground in response to its electrical and magnetic properties, which collectively create a secondary field that is measured by a receiver (Witten 2006). The secondary field is used to approximate the electrical (conductivity) and magnetic (susceptibility) properties of the subsurface within the range of the instrument. Conductivity is useful for detecting differences in ground moisture and grain size, where high conductivity often indicates moisture retention or relatively high percentages of clay (McNeill 1980a). Thus conductivity is useful for mapping sedimentology, but also archaeological features if they have moisture or sediment size contrast with the surrounding site matrix. Sometimes rock or brick walls can be detected because they are drier than surrounding materials. A Geonics EM38 (Figure 3) was used at Tiwanaku for separate conductivity and magnetic susceptibility surveys. Conductivity data represent a weighted average of conductivity for approximately the upper 1.5 meters of ground (McNeill 1980b). In both cases lines of data were collected every half meter, with four readings per meter taken in the survey direction. Data were downloaded and processed to remove drift, then integrated with other geophysical layers in GIS.

![Figure 2: Geophysical Survey Systems Inc. (GSSI) SIR-2000 GPR system with 400 MHz antenna and survey wheel.](image1)

![Figure 3: Geonics EM38 EMI instrument.](image2)

**Electromagnetic Induction (EMI): Magnetic Susceptibility**

Magnetic susceptibility is a measure of a material’s ability to become magnetized in the presence of a magnetizing field (Clark 1996; Dalan 2006).
Materials that are susceptible include anything containing relatively high amounts magnetic minerals such as magnetite, maghemite, and many others (Dalan 2006). Topsoil is often much more magnetic than subsoil due to soil formation processes (Dalan 2006). In addition, human activity tends to enhance the magnetic susceptibility of soils by disturbance, using fire, and depositing waste (Dalan 2006). As a result soils at archaeological sites are often more magnetic than nearby soils (Clark 1996), and this provides additional contrast for archaeological features created by the accumulation or removal of topsoil such as graves, pits, burials, ditches, and middens. The depth of penetration for magnetic susceptibility is limited to about 0.5 m with the EM38 (and much less with other sensors). Data were collected with the EM38 (Figure 3) using the same sampling densities as conductivity (see above) and were processed in the same way.

Magnetometry

Unlike GPR and EMI, which actively generate EM fields, magnetometers passively measure subtle variations the earth’s magnetic field without imposing an artificial field (Clark 1996). Magnetometers are sensitive to two types of magnetism: induced and remnant. Induced magnetism includes magnetic fields that are created by and external magnetic field, in this case Earth’s magnetic field. If the Earth’s magnetic field could be “turned off” this type of magnetism would also cease. Induced magnetic fields indicate a material’s magnetic susceptibility, so this component of magnetometry data is similar to magnetic susceptibility measured by EMI (the only difference is the way it is measured). Remnant magnetic fields include all magnetic fields that are fixed and do not rely on external magnetizing fields. Objects that possess remnant magnetic fields usually have a history of extreme heating. When objects are heated to a high enough temperature their magnetic minerals align to earth’s magnetic field, and then are “frozen” that way when cooled (Clark 1996). Igneous rocks, which form from molten rock, have remnant magnetic fields. Other fired items, such as pottery, fired brick, kilns, hearths, and burned foundations also have remnant magnetic fields. The depth of penetration of a magnetometer is generally about 1.5 meters (Kvamme 2006b), but strongly magnetic features such as the large andesite blocks at Tiwanaku can be detected at greater depths. Depth estimation is very difficult, but at Tiwanaku there are places where large magnetic anomalies suggest andesite blocks that are not visible in GPR, suggesting they are deeper than the maximum depth penetration of GPR, or beyond about one meter. Magnetometry data were collected using a Geometrics G-858 Cesium gradiometer in 2005 and a Bartington fluxgate dual gradiometer system (Figure 4) in lines spaced .5 m apart with 8 samples per meter in the survey direction. Data were downloaded and processed to remove striping errors, then assembled into mosaics and integrated with the other data in GIS.

Study Area

The region to the east and northeast of Akapana was chosen for geophysical study because little was known about this large, open space. Excavations in and around this area provide important clues to what might be lie beneath the surface elsewhere, and provide a baseline for interpretation of geophysical anomalies. The stratigraphy can be simplified into two separate phases. Deeper deposits generally represent earlier period architecture (before about A.D. 800). A gravel layer is encountered above this, which is interpreted to be a pavement that covered earlier architecture, representing a period of
Figure 4. Magnetometry instruments used for this project. (a) Geometrics G-858 cesium magnetic gradiometer; (b) Bartington dual-fluxgate gradiometer.

urban renewal beginning at roughly A.D. 800 (Couture and Sampeck 2003). The urban renewal included razing the earlier architecture, so it is only found in fragmentary form and it is clear that stones from earlier structures were taken for use in subsequent building (Couture 2002; Couture and Sampeck 2003). Conduits for controlling water flow are commonly found beneath the gravel layer, but are associated with the pavement construction. It has long been established that monumental and residential architecture at Tiwanaku is generally oriented with the cardinal directions (Kolata 2003a), so geophysical anomalies oriented in this way probably represent architecture. In contrast, conduits can be oriented in any direction, allowing us to interpret angled linear geophysical anomalies as conduits. Prior to urban renewal the monumental core was a place of domestic residence, so remnants of these are expected (Couture and Sampeck 2003). Typical residential compounds consist of a large walled enclosure, perhaps 30 m in width (Williams, et al. 2007), which enclose distinct social groups (Kolata 2003b). Wall foundations are often built of parallel courses of stone (often local field stone but sometimes andesite or basalt is included) filled with adobe (Kolata 2003b). Features inside residential compounds are highly variable, but may include residences, cooking areas, and specialized craft areas (Kolata 2003b).

The use of andesite imported from the Lake Titicaca shore up to 90 km away from Tiwanaku (Ponce Sanginés and Mogrovejo Terrazas 1970) presents a somewhat unique and beneficial situation for archaeological geophysics. Rock constructions of all types should be detected by GPR as long as it is within the upper meter, but magnetometry data easily distinguishes between igneous (e.g. andesite) and sedimentary (e.g. sandstone) rocks. Thus, the combination of GPR and magnetometry data allow subsurface architecture to be delineated and the probable rock type identified. Vranich (2006) has shown that andesite is concentrated on the east and west facades of several Tiwanaku monuments, where pilgrims most likely would have passed. In contrast, north and south facing sides were constructed to be less showy and included minimal amounts of andesite. Andesite must have had very important ritual significance because the architects and craftsmen of Tiwanaku went to the shores of Lake Titicaca for its procurement. The presence of Andesite at the site, and fine workmanship would have been impressive and awe-inspiring to the pilgrims.
Results and Interpretations

The following geophysical datasets were collected in the study area: six hectares of GPR (Figure 5), 4 hectares of magnetometry (Figure 5), and 1.6 hectares of EMI (magnetic susceptibility and conductivity) (Figure 6). These data provide a vast database of information that cannot be completely described here, so we will focus on a few key geophysical features. Some of these features have been confirmed by excavations, which were placed to test GPR anomalies as part of the second author’s master’s thesis (Koons 2006). Other anomalies are described using quotations where necessary to signal that they have not yet been tested by excavation. The main geophysical features include circular water retention features that may have been “pools” or “baths”, a series of water conduits, “residential compounds”, small segments of wall foundations (probably razed remains from urban renewal), a gravel pavement, “revetments” aligned with the cardinal directions, and a “square structure.”

![Figure 5](image_url)
Figure 5. (a) Extent of GPR survey on the east side of Akapana, about six hectares; and (b) extend of magnetometry surveys, about four hectares.
"Pools"

A series of circular anomalies located due east of the Akapana were detected with all geophysical data types, each providing valuable clues for interpretation. The largest of these is shown in Figure 7. GPR reflections around the perimeter suggest that the edges slope toward the center (Figure 7b). The dearth of reflections from inside the circle are probably due to the fact that this area has more clay than surrounding sediments, causing attenuation of the GPR signal and limited depth penetration. In addition, if the sloping edges continue toward the center, they may be beyond the depth capabilities of GPR in this area. Magnetometry data show several large dipolar anomalies on the outside of the circle, with only a few small, weak anomalies inside, suggesting that this feature is surrounded by blocks of andesite (Figure 7c). Conductivity data indicate that the interior, particularly the southwestern quadrant, contains more clay and/or moisture than surrounding materials (Figure 7d). Magnetic susceptibility is low inside the feature, suggesting that the topsoil has been removed or heavily disturbed (Figure 7e). Finally, a 1952 aerial photo shows vegetation growth concentrated around the perimeter. Together these data suggest that the feature is a circular or semi-circular water retention feature or "pool" surrounded by blocks of andesite.

At first this interpretation seemed unlikely, but further research indicated that indeed this type of feature is known from Tiwanaku. German archaeologist Max Uhle took photos of two such features in 1893 (Figure 8). The first is a monumental spring located south of Pumapunku, where andesite blocks surround a depression created to collect water from a natural spring. The second is very similar, but the exact location at Tiwanaku is not known. These photographs show nearly an exact match to the information gathered with geophysics and strongly suggest that a number of these "pools" were built east of Akapana. Test excavations on the southern edge of this feature were placed to test the GPR data (Koons 2006) and encountered an abundance of moist, clay-rich sediment. This further supports the interpretation. Future excavations utilizing the other geophysical data sets are needed, however.
Figure 7. Possible pool discovered east of Akapana: (a) location of the most prominent circular anomaly within the GPR survey area; (b) GPR data show a circular pattern with strong reflections around the perimeter and none on the inside; (c) magnetometry data suggest that this feature is surrounded by large blocks of andesite, with none inside the circle; (d) the interior of the circle is relatively highly conductive, suggesting moisture retention and/or clay deposits; (e) magnetic susceptibility is low inside the circle, suggesting that topsoil was removed; (f) 1952 aerial photo shows thick vegetation growing around the perimeter. All of this suggest that this is a water retention feature surrounded by blocks of andesite.

Figure 8. Examples of “pools” at Tiwanaku known from photos by Max Uhle (1893). (left) located south of Pumapunku, this feature is composed of blocks of andesite surrounding a depression where spring water collects. (right) A similar feature found at Tiwanaku, exact location unknown. (photos courtesy Alexei Vranich).
“Residential Compounds”

Two possible residential compounds have been identified in the geophysical data. One is located east of the modern fence, southeast of the Kantatayita (Figure 9a). Subtle lineations are discernable in the GPR data (Figure 9b), but these are much clearer in magnetometry (Figure 9c). Together the two datasets suggest a rectangular compound measuring 33 m east-west and 27 m north-south. This agrees with projections by Williams et al. (2007), who found that a residential compound located east of the present geophysical survey area was about 30 meters wide. The magnetic anomalies are relatively weak and may indicate wall foundations built of moderately magnetic stone (perhaps sandstone) and/or baked adobe. The southern wall consists of parallel lineations, perhaps representing two separate courses of foundation stone, which is typical for residential compound walls elsewhere at Tiwanaku (Janusek 2003; Kolata 2003b). Magnetic anomalies inside the “compound walls” could represent burned features, such as cooking or firing areas, or large pieces of andesite.

![Figure 9. “Residential Compound” interpreted based on GPR and magnetometry anomalies. (a) location of anomalies within GPR survey; (b) anomalies in GPR that suggest a rectangular feature (green arrows); (c) magnetometry data have anomalies in the same locations, plus a more complete rectangular outline with more detail of the west and south boundaries (pink arrows). The size and orientation of these anomalies suggest that this is a residential compound, and the southern wall appears to have two parallel components consistent with other residential compound walls at Tiwanaku. Interior magnetic dipolar anomalies could indicate cooking or firing areas, or blocks of andesite.](image)

**Wall Foundations**

The GPR data show many short linear anomalies oriented in the cardinal directions. A handful of these were tested in 2005 (Koons 2006), revealing portions of wall foundations. Two excavation units were placed west of the Kantatayita (Figure 10a-c). Unit S2 revealed a wall foundation oriented north-south, consistent with the anomaly (Figure 10c). More wall foundations were found in Units S1 and S8 (Figure 11). In both cases GPR anomalies proved to be very reliable indicators of subsurface architecture. Not only were the wall foundations encountered exactly where predicted, but they disappear exactly where the GPR anomalies disappear.
Figure 10. Portions of wall foundations discovered by testing GPR anomalies. (a) location of magnified area, (b) magnified area showing the Kantatayita (where no GPR data were collected), the 40 x 40 m GPR survey region, and two excavation units measuring 5 x 5 and 5 x 7 meters; (c) magnified GPR slice showing anomalies that were tested and excavation units (after Koons 2006); (d) unit S2 showing a wall foundation indicated by the GPR anomaly (after Koons 2006).

Figure 11. More wall foundations encountered when testing GPR anomalies. (a) GPR slice showing anomalies tested by excavation units S1 and S8; (b) wall foundation encountered in these units, consistent with the GPR anomalies. (after Koons 2006)
**Conduits**

Additional linear GPR anomalies oriented obliquely were also tested with 5 x 5 m excavation units (Koons 2006) (Figure 12a-b). Both units encountered water conduits beneath a clean gravel pavement situated 45-50 cm below the surface (Figure 12c). As with the wall foundations discussed above, these GPR anomalies proved to be very reliable indicators of subsurface architecture. The linear anomalies representing wall foundations and conduits are very similar in the GPR data, but can be distinguished by their grid orientation. All of the wall foundations are oriented with the cardinal directions, but canals are oriented obliquely. This relationship may not be foolproof, but is one way to interpret anomalies such as those indicted in Figure 13.

![Figure 12. Test of oblique linear GPR anomalies. (a) location of magnified area; (b) magnified GPR image showing locations of excavation units; (c) results of two 5 x 5 m test excavations revealing conduits as the source of the oblique linear GPR anomalies (after Koons 2006).](image)

**Gravel Pavement**

The gravel pavement has been found in all excavation units in this area (Cortez Ferrel 2006; Koons 2006). It is composed of gravel mixed with clay, which should cause high amplitude GPR reflections. Yet, the pavement is not visible in the GPR data in most locations for two reasons. One problem is contrast. Archaeological features are detected with geophysics because they contrast with immediately surrounding deposits. Since the gravel layer extends over a very large area (indeed it could be larger than the GPR survey area), there is no contrast from one place to the next. In other words, when something exists everywhere it becomes part of the background and will only be detected on its edges. Also if the pavement is detected it will create flat-lying reflections, which can easily be confused with noise and removed with a
standard “background removal” filter (Conyers 2004). Figure 14 illustrates this problem. The upper profile (Figure 14a) contains horizontal banding from noise (unwanted radio signals recorded by the receiving antenna), but also contains reflections from horizontal layers in the ground. When a background removal filter is applied both the noise and flat-lying reflectors are removed (Figure 14b). The result is a general improvement compared to the original data but extensive flat-lying reflections are also removed. We are currently working on a new background removal filter that does not remove the gravel pavement reflections.

Figure 13. Linear GPR anomalies west of the Kantatayita oriented at various angles. Those oriented with the cardinal directions are interpreted as wall foundations or other components of architecture, while obliquely angled anomalies are more likely to represent conduits. (a) location of magnified area; (b) magnified portion of GPR slice composite showing linear anomalies.

Excavation unit S3 (Figure 12b) was placed to test a broad amorphous GPR anomaly, which appears in profile as a sloping reflection (Figure 15a). No corresponding sloping feature was encountered. Instead, the flat-lying gravel pavement was found throughout the unit (Figure 15b). The modern ground surface above, however, is gently sloped where the anomaly appears. Since the GPR data have not been topographically corrected, the reflection profiles treat all subsurface reflections as if they occurred beneath a perfectly flat surface. Since the ground is sloped in this area, a flat-lying reflection will appear sloped and will be the mirror-image of the ground above. Therefore, the southward-dipping reflection occurs where the surface slopes down northward, and the reflection actually represents the flat-lying gravel layer. Thus, the gravel layer becomes highly visible in GPR reflection profiles and slice maps wherever the surface is sloped (Figure 15c). The digital elevation model (DEM) created by Barnes and Cothren (2007) is not detailed enough to show this slope, but we can infer ground surface slope based on the GPR data and field notes taken during geophysical data collection and excavations. It is unclear at this time if the surface topography is related to the buried urban landscape or more recent erosional processes.
Figure 14: Accidental removal of horizontal reflections with background removal filter. (a) a reflection profile before background removal, showing horizontal banding related to noise, and a flat-lying reflection that could be archaeological interest (outlined in red); (b) after background removal the horizontal banding is removed, but so is the flat-lying reflection that is probably not related to noise.

“Revetments”

The northern portion of the survey area contains several very long linear anomalies in GPR (Figure 16a) and magnetometry (figure 16b), which are aligned with the cardinal directions. A 1952 aerial photo also shows vegetation marks that coincide with the geophysical anomalies (Figure 16c). Figure 16d is a composite of the two geophysical datasets, with magnetometry in the background and GPR superimposed on top and 50% transparent. Anomalies described in the text are labeled A-K on the appropriate images in Figures 16. Anomaly “A” is a revetment (retaining wall) built of a variety of stones including andesite, known from excavations by a French expedition in 1903 (Stanish 2002). This revetment probably was built to stabilize the edge of a terrace to the west. Part of the revetment (“B”) that was not excavated is clearly visible in GPR and the aerial photograph. These anomalies are somewhat complicated because a modern pedestrian pathway is located along the west side of the excavation trench (now filled), and in other locations in this area (“C”).

Magnetometry data and the 1952 aerial photograph suggest a second revetment is located about 40 meters to the east (“D”). It is also difficult to see in the slice composite. This linear feature is interpreted as a revetment because it is similar and parallel to the known revetment to the west. Alternatively, it could be large, deep conduit like others found at Tiwanaku (Couture and Sampeck 2003). The strong magnetic dipoles suggest that this feature was built using large pieces of andesite. A third possible revetment (“E”) is indicated by GPR, magnetometry, and the 1952 aerial photograph. The GPR anomalies indicate that the surface slopes toward the east, perhaps indicating that the modern surface still preserves some of the ancient topography created by terrace and revetment construction. Magnetometry indicates that some portions of this feature may include andesite.
Figure 15. Gravel pavement layer visible where modern surface is sloped. (a) reflection profile showing a dipping reflection that corresponds to the horizontal gravel pavement (after Koons 2006); (b) 5 x 5 m excavation unit showing the flat gravel pavement and sloping ground surface, with left red arrow indicating location of profile in “a” (after Koons 2006); (c) portion of GPR survey area showing GPR anomalies created by the gravel pavement underneath the sloping modern surface. Green arrows point out the anomalies and indicate the direction of surface slope (north and west).

A series of east-west lineations (“F” – “L”) also occur in this area. These features are clearly shown in the GPR data, and some are apparent in the 1952 aerial photograph, but they do not show up in magnetometry suggesting an absence of andesite and other igneous rocks. They could be built of sandstone or some other weak- or non-magnetic material. These lineations could also be revetments, and they seem to make connections between the north-south “revetments.” Together these long linear anomalies suggest a series of terraces bounded by revetments descending east from the Semisubterranean temple and north from the Akapana. The broad area between “D” and “E” may indicate a plaza, as the DEM indicates that this area was relatively flat compared to the surroundings (see Barnes and Cothren 2007).
Figure 16. Northern portion of survey area showing possible revetments and other features. (a) ground penetrating radar; (b) magnetometry; (c) 1952 aerial photograph; and (d) combination of magnetometry (blue) and GPR (magenta). Key: A = 1903 excavation trench and revetment; B = unexcavated portion of revetment visible in GPR data; C = location of modern pedestrian pathways; D = possible revetment constructed with andesite or large water conduit; E = possible revetment; F-L = possible east-west revetments constructed of sedimentary rock or some other non-magnetic material.
“Square Structure”

North of the east-west “revetments” is a possible square structure indicated by GPR (Figure 17). This geophysical feature is very difficult to interpret because there are few similar features in the archaeological record. It measures about 20 meters across and is roughly square, much like the Semisubterranean Temple to the southwest (Figure 1). An absence of magnetometry anomalies suggests that it does not include any andesite, but large dipolar anomalies to the west may indicate andesite blocks associated with this feature. The newly created DEM (Barnes and Cothren 2007) shows a slight topographic rise in this area, further suggesting the presence of buried architecture. Without many similarly sized and shaped features in the archaeological record, and without additional geophysical data to the north and east it is very difficult to interpret this feature. Test excavations are needed.

![Figure 17. “Square structure” indicated by GPR. (a) northern portion of GPR survey area showing location of a possible square structure; (b) magnetometry data in same area does not show the square feature (indicated in red based on GPR), but anomalies to the west could be related.](image)

Discussion & Conclusions

The combination of GPR and magnetometry has proven to be a very effective and reliable approach at Tiwanaku. One major advantage is the import and selective use of andesite at Tiwanaku, which can be distinguished from other common building materials because of its strong remnant magnetic field. This combined with GPR, which reveals the majority of architecture in the upper meter, allows delineation of much of the buried landscape in the northeast monumental core. These interpretations admittedly suffer from a lack testing, but limited excavations presented above show the geophysical data to be very reliable. Aerial photos, conductivity, and magnetic susceptibility data also greatly aided interpretation. The northeastern monumental core area at one time may have been constructed in a series of terraces stepping down east of the Semisubterranean Temple and north from the Akapana and Kantatayita. East-facing “revetments” probably included large blocks of andesite, while north-facing “revetments” did not. This is consistent with findings elsewhere at Tiwanaku, where east and west facing facades include much andesite, but north and south facing portions are constructed with little or no andesite and are clearly not meant to impress pilgrims (Isbell and Vranich 2004; Vranich 2006). If our interpretations are correct this suggests that the east-facing revetments were constructed with andesite to impress pilgrims entering the city from the east.
In addition to the possible terraces and revetments in the northeast, several other features have been identified and some verified by excavation. A possible square structure was identified in the northernmost portion of the survey area. A series of “pools” may have been constructed east of Akapana, perhaps for ritual bathing or other ceremonial activities. In addition, two possible residential compounds were identified (one of them shown in Figure 9). Many other anomalies suggest additional archaeological features, but we chose to focus on a few key features for this paper. The geophysical data serve as an immense database of information for future excavation and interpretation.

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