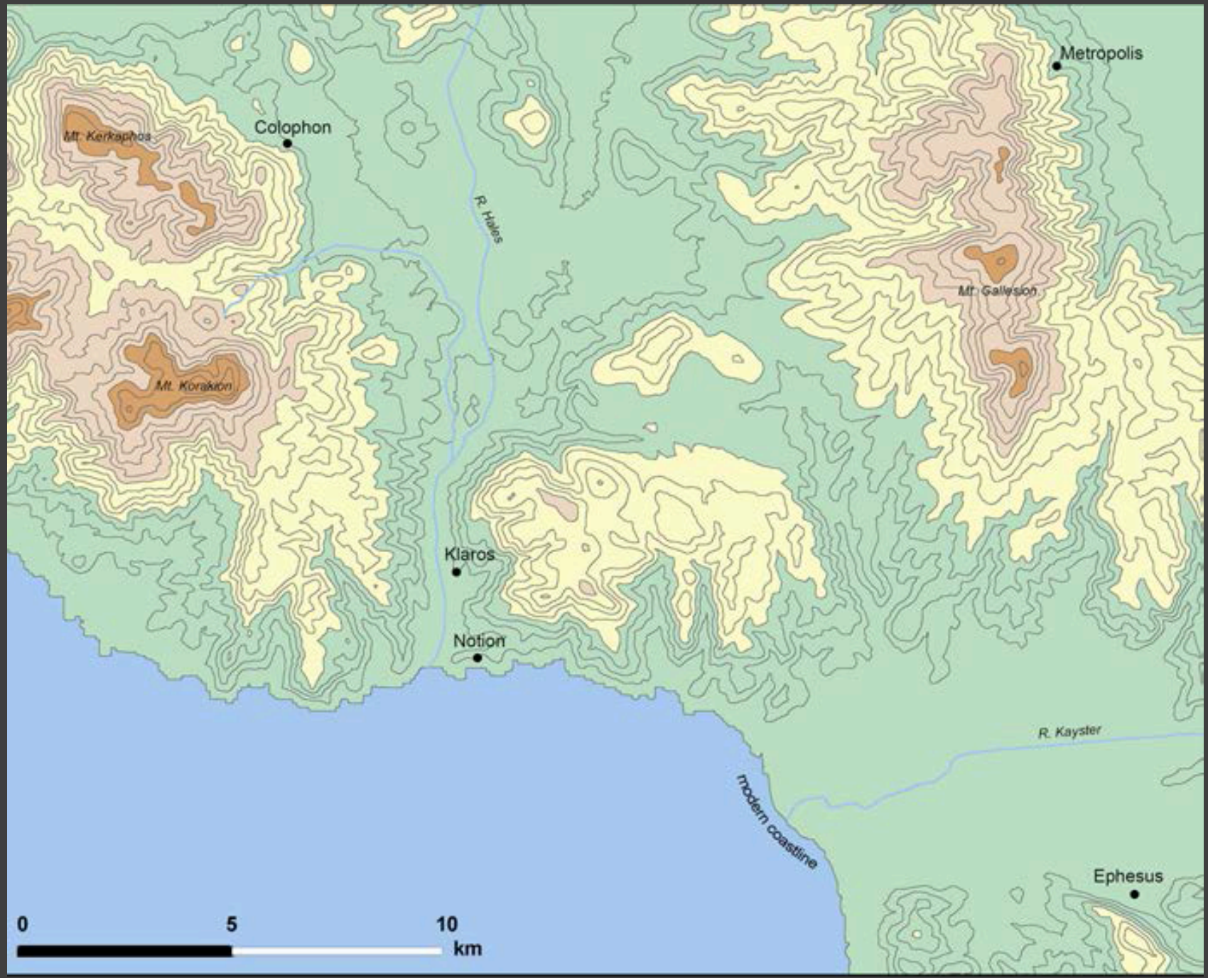
Mapping Notion: Non-Invasive Survey Using Aerial Photogrammetry, Personal Autopsy, Thermal Sensing, and Geophysical Prospection

Matthew Naglak & Gregory Tucker
University of Michigan

Map of Mediterranean Region

Regional map of Notion and environs



Previous Investigations

- C. Schuchardt (1885-86)
- T. Macridy (1897, 1904)
  General Survey
- R. Demangel and A. Laumonier (early 1920s):
  Temple of Athena
- E. Atalay (1985-86)
  Theater and Necropolis
- M. Buyukkolanci (1994)
  Heroon, Bouleuterion, and “North Gate”

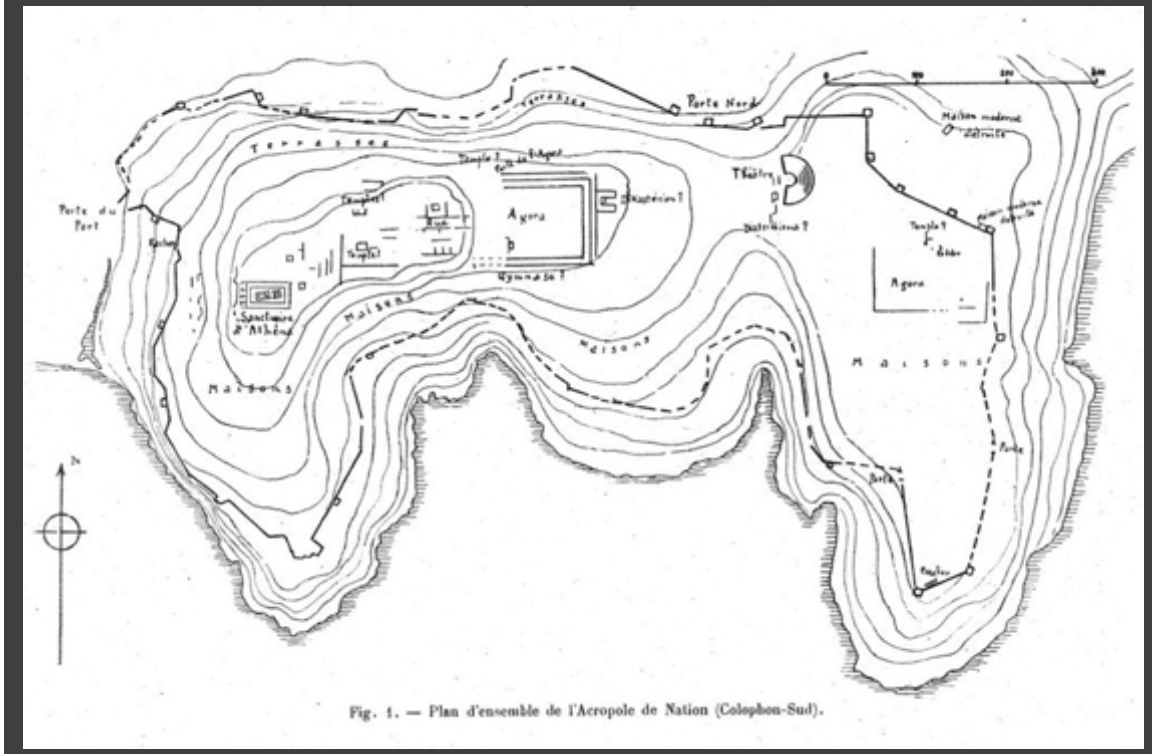
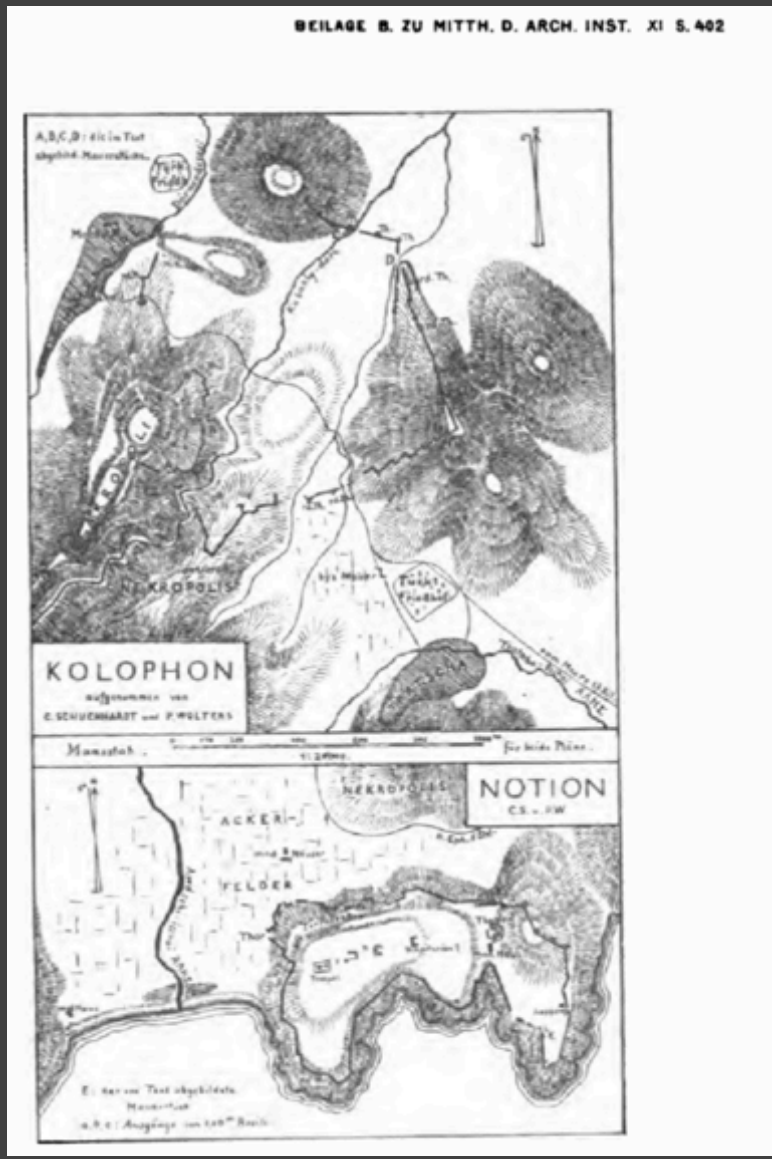


Fig. 1. — Plan d'ensemble de l'Acropole de Nation (Colophon-Sud).



Satellite view of Notion

Aerial Imagery Techniques

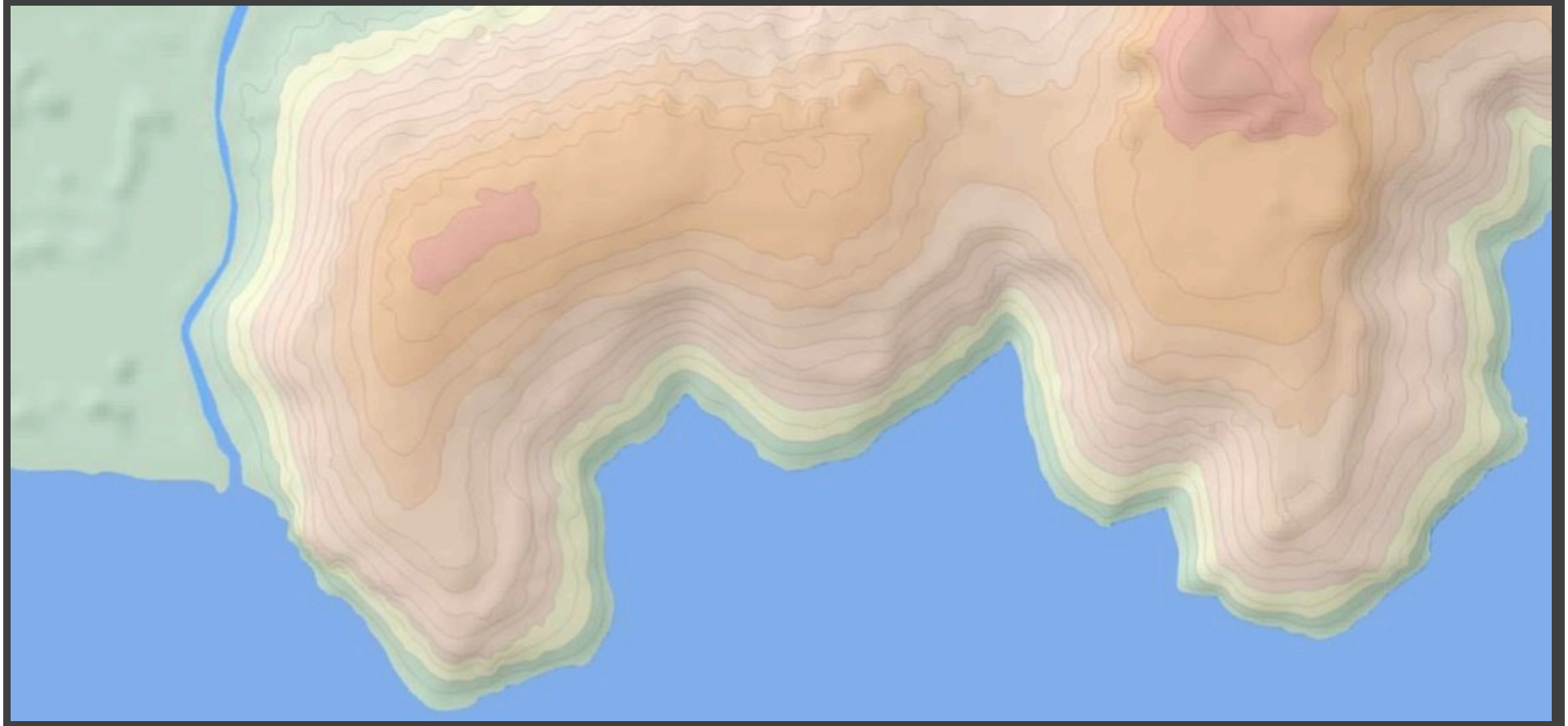
2014

2015

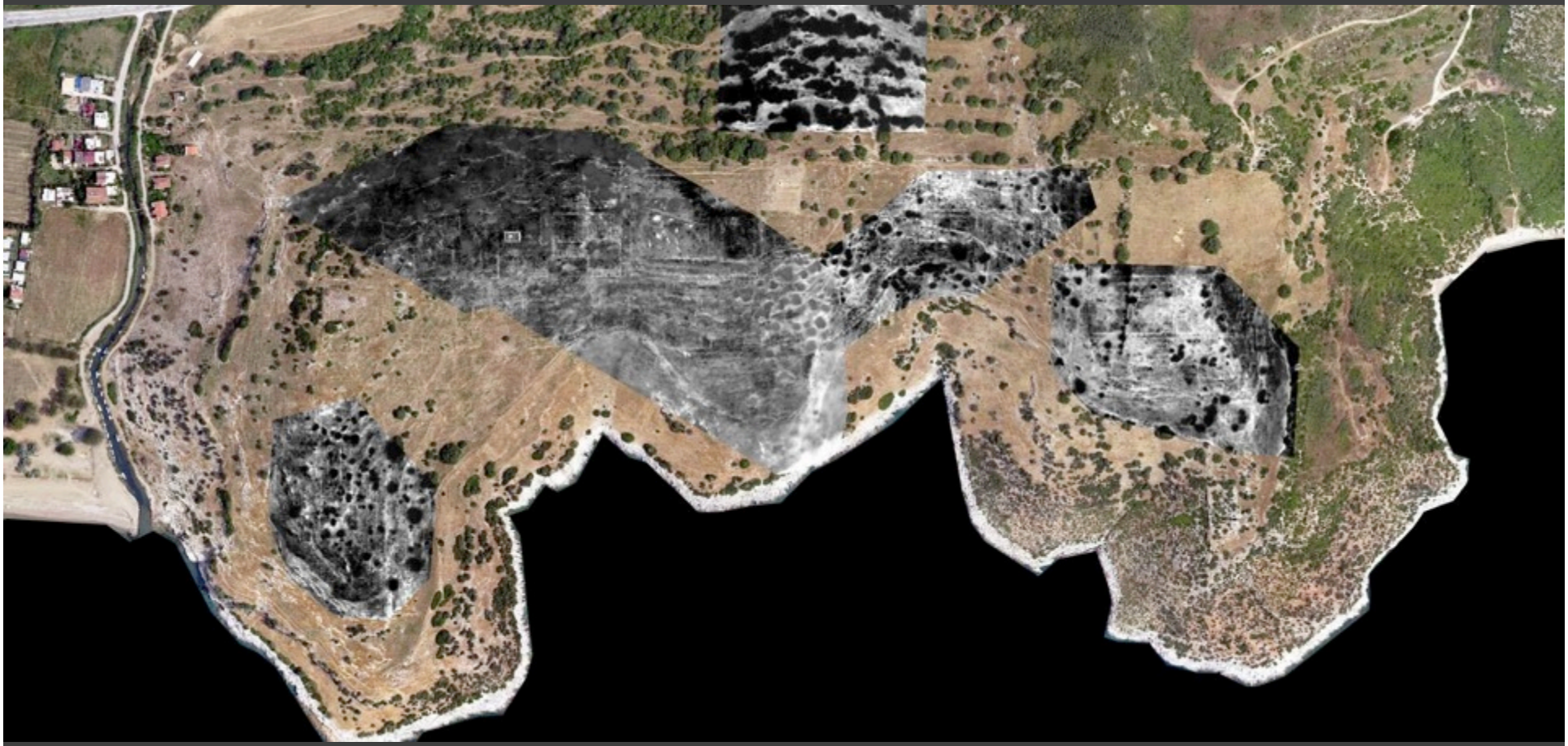
Notion Orthophoto (3cm)

Temple of Athena (2cm)

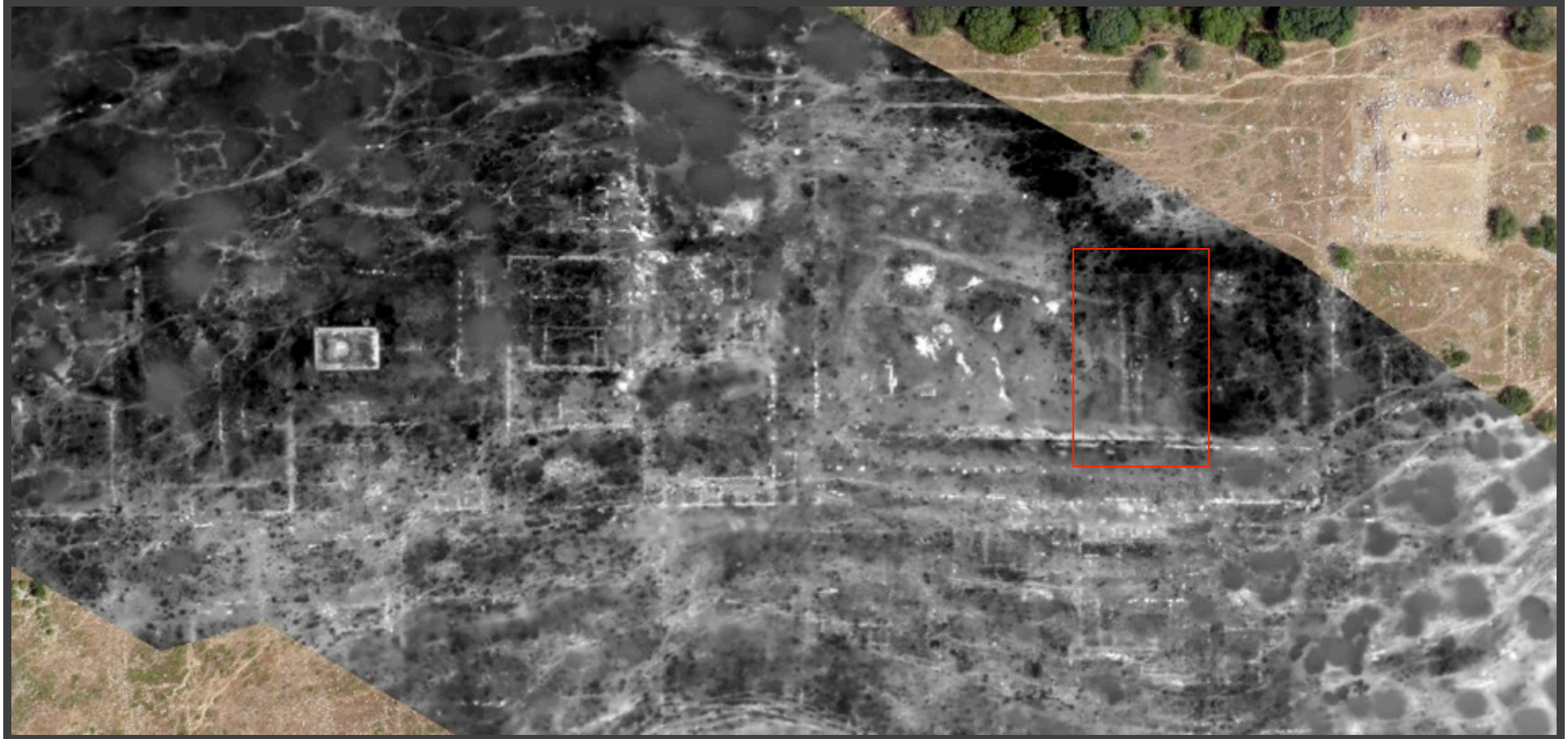
Digital Terrain Model (2015)



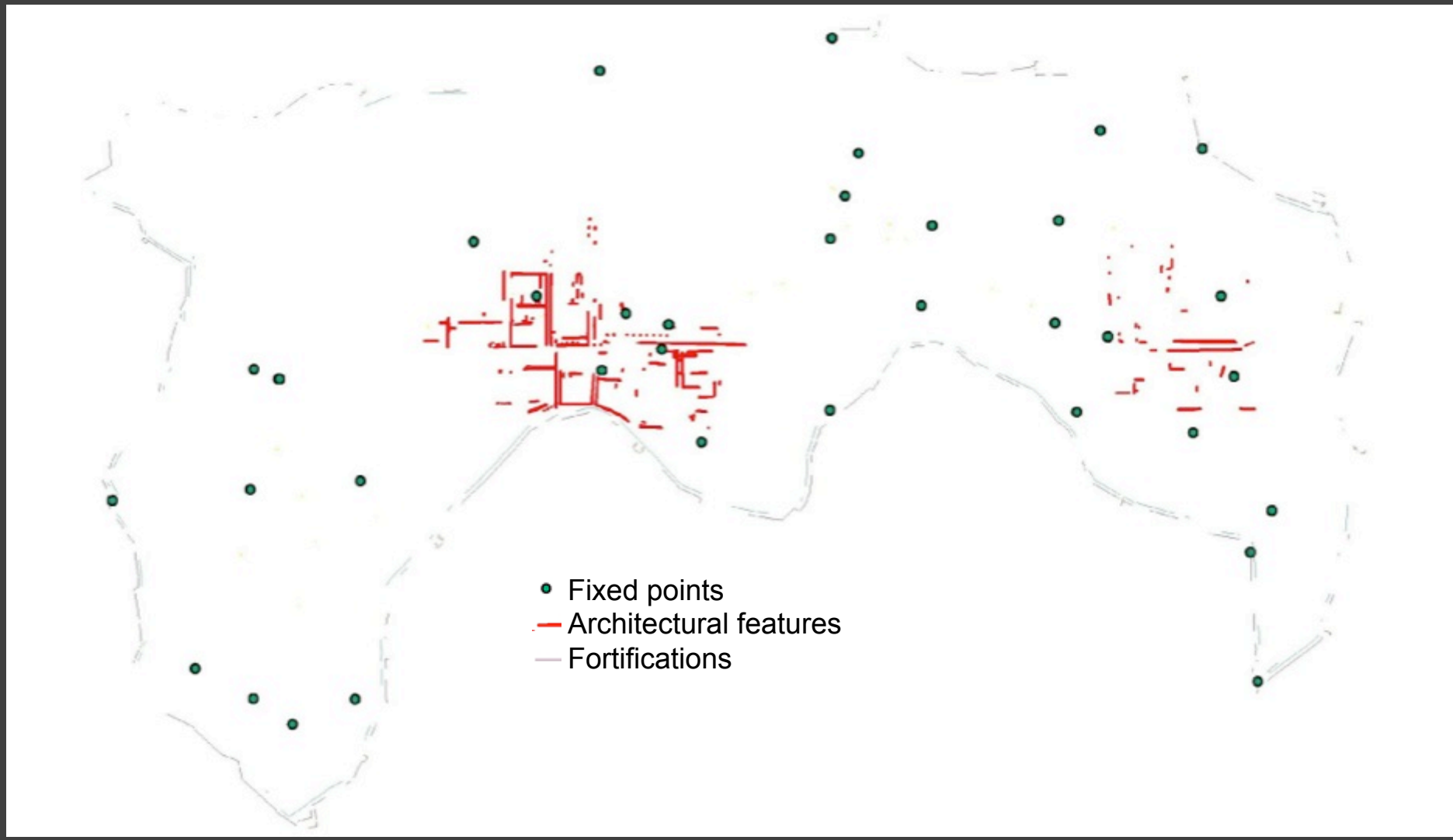
Thermal mapping (2015)



Thermal mapping of city center (2015)



GIS and RTK mapping (2015)



Geophysical prospection (2014-15)

Geophysical prospection (2014 results faded on left, 2015 results on right)

Northern Stoa

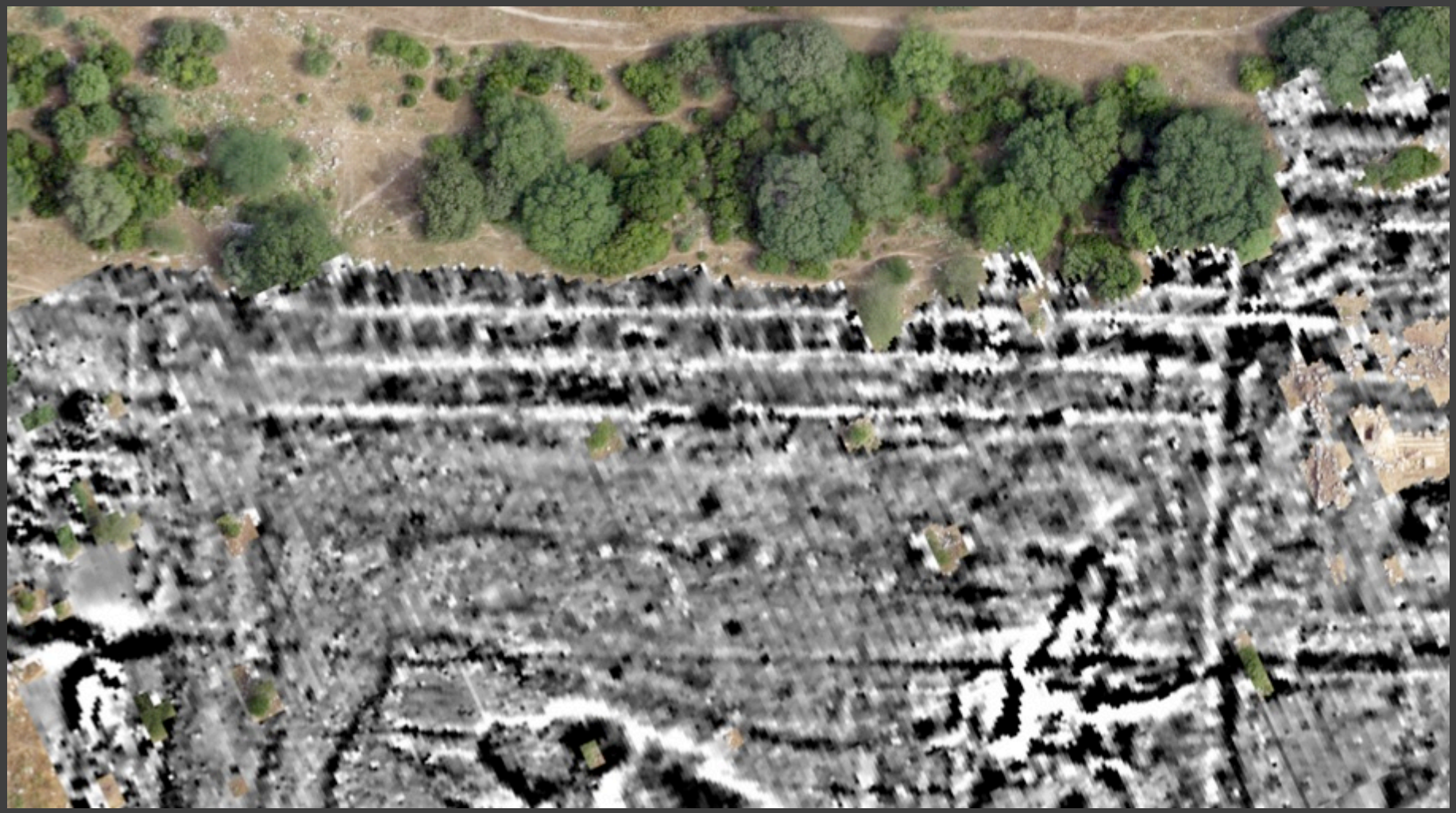
Northern stoa orthophoto (3cm)

Northern stoa orthophoto (interpreted)

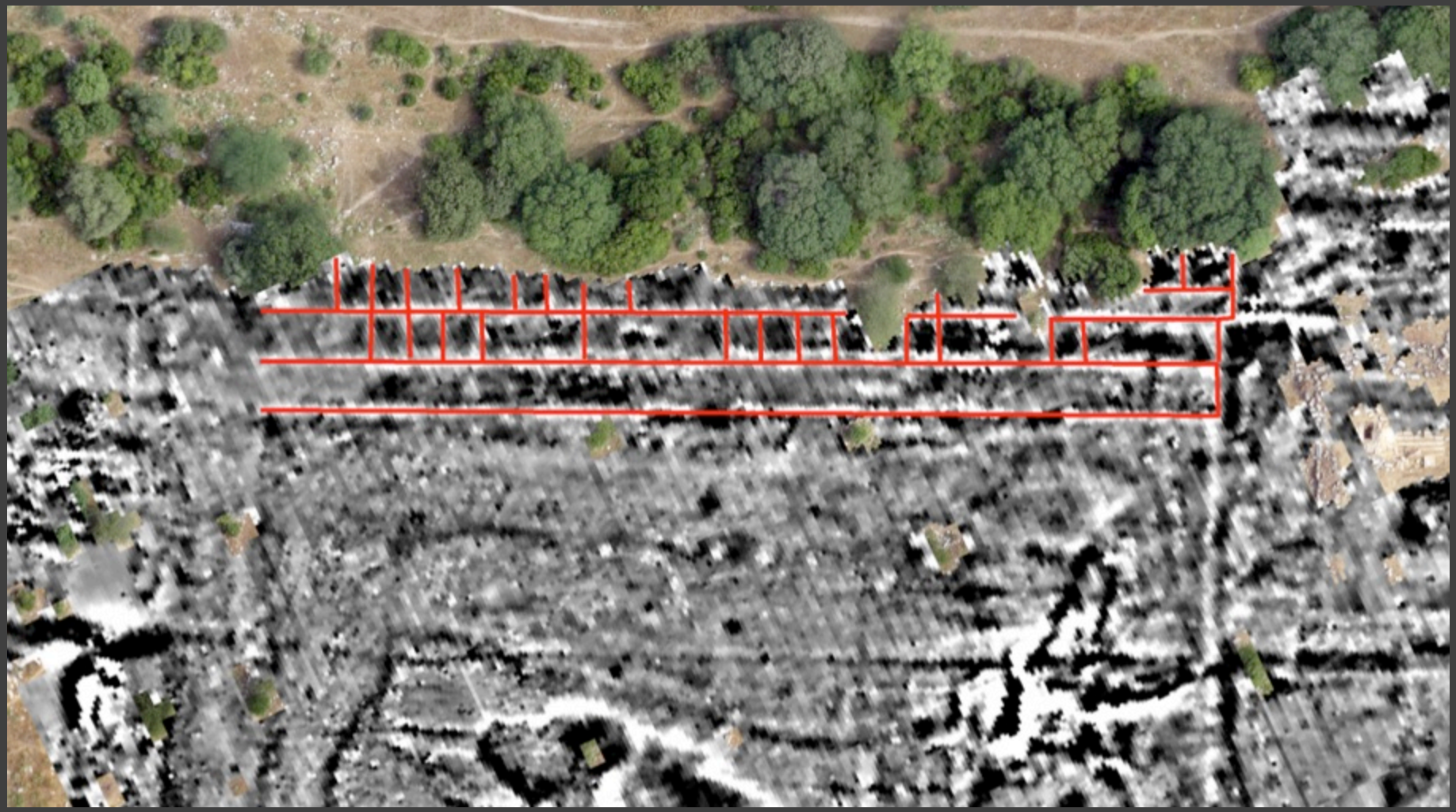
Northern stoa thermal

Northern stoa thermal (interpreted)

Northern stoa magnetic gradiometry



Northern stoa magnetic gradiometry (interpreted)



South of Agora

Orthophoto (3cm)

Thermal imagery

Personal autopsy

Geophysical Prospection

Integrated Analysis (plan from personal autopsy on magnetic gradiometry results)

Notion, looking east across the site

Mapping Notion: Non-Invasive Survey Using Aerial Photogrammetry, Personal Autopsy, Thermal Sensing, and Geophysical Prospection

Matthew Naglak and Gregory Tucker

The ancient city of Notion, on the Aegean coast of Turkey, is first mentioned in surviving textual sources as the harbor town of Kolophon.

The city prospered in the Hellenistic and early Roman periods thanks to its position on the coast and its close proximity to the famous oracle of Apollo at nearby Klaros. For the past two summers, the Notion Archaeological Survey, a joint research program of the University of Michigan and Brown University, has undertaken urban survey of the site. In a session later this morning Christopher Ratté, Angela Commito, and Catie Steidl will be talking other early results of this project, including the fortifications, water system, and quarries. Here we wish to present the methodologies and preliminary results of a multi-method mapping program.

Several prior archaeological expeditions have contributed to our understanding of Notion and the region, but the city has never been the subject of intensive investigation or systematic excavation. Excavations have focused solely on the surviving monumental structures, while prior to the beginning of our project, a topographical sketch from the early 1920s was the most detailed plan of Notion available. One of the many goals of the Notion Archaeological Survey is to create a detailed city plan documenting both the visible structures and the near surface buried remains while at the same time making available high resolution images of the entire site. In 2014 and 2015 we pursued this goal using an integrated, non-invasive approach bringing together many techniques of urban survey, including aerial imaging, surface inspection, and near surface geophysics. By combining the results of these techniques, a more holistic perspective of

the city is emerging, filling in gaps in prior research and bringing to light aspects of the site that could not have been detected in earlier surveys.

In our pilot season, we first utilized publically available satellite imagery, such as this image from Google Earth. In this imagery, only the outline of the fortification walls can be seen along with the basic organization of the street system.

As this imagery was insufficient for a detailed study of the topography or for a close examination of surface features, we have produced much higher resolution imagery using two types of unmanned aerial vehicles: a tethered balloon and lightweight drones. During the 2014 season, aerial photographs using a Canon Mark V camera taken from a tethered blimp were used to produce high-resolution, georeferenced, orthorectified images.

In 2015, this program of low-altitude aerial photography and photogrammetry was continued and expanded with the help of the non-profit organization DroneAdventures employing light, easy to deploy eBee drones carrying S110 RGB cameras for mapping in the visual spectrum.

The entirety of the site and the nearby region were mapped in this way with spatial resolutions ranging from 2 to 6 cm, clear enough for stone-by-stone digitization across the site.

Using this imagery, it was possible to create a detailed digital terrain model with Terra3D software created by Pix4D. Such a high resolution DTM allows for a study of landscape forms which may reveal underlying features not visible on the surface. This analysis is currently in process, while at the same time the DTM is being used to model future plans for site conservation and presentation.

In addition to the visible spectrum, approximately 40% of the site was surveyed using drone-mounted thermoMap cameras with a spatial resolution of approximately 12 cm. Thanks to

differential heat dissipation by various materials on the ground, this technique proved effective for efficiently mapping stone and bedrock visible on the surface. It also proved fruitful in other ways, such as revealing the presence of earlier excavation. The N-S trench in the agora dug by Atalay, for example, is more visible in the thermal imagery than the visible spectrum.

Close study of the remote-sensing imagery helps us identify features which we then survey in more precisely in the field with a combination of a Total Station and a Real Time Kinematic Global Navigation Satellite System to create a GIS database. At the same time, we used tablet computers linked to the GIS to record information not available in the aerial photographs according to a detailed set of specific attributes (separating out threshold blocks from walls, for example, or specifying whether wall joints are bonded or unbonded). Using these methods, we are making a detailed feature-by-feature map of the site, which will provide an unusually complete record of the ancient city plan.

In addition to intensive visual inspection of surface features we have concurrently carried out an *extensive* program of geophysical prospection, which, to date, has mapped one-third of the intramural area of the site with magnetic gradiometry. This technique is conducted by passing magnetic sensors over the ground and is most effective in open sites with buried material within 1-2 meters of the surface. Although magnetic gradiometry is most effective at sensing fired materials such as ceramic tiles or bricks, it able to detect subtle changes in the magnetic field caused by the different geophysical properties of buried features even when they do not contain fired materials.

In some areas the results have rewarded us with the shape of buried features not at all visible in other techniques due to their depth or surface vegetation. In addition, one of the contributions that the results have had at Notion is to improve the clarity of features that have

been identified through other techniques by detecting buried portions, which allows us to connect otherwise dis-joined features.

Each of these approaches contributes in a different way to our understanding of the city. From gaining overall feel for the urban plan in a time efficient manner to understanding how surface features relate to buried structures, their contributions become even more valuable when combined in a broader program of research.

A brief look at the northern stoa of the agora reveals the benefits of a multi-method survey strategy. Visible imagery allowed us to take an initial look at the area and plan our approach. While the imagery was detailed, it was possible to recognize only a few linear stone features due to obstruction by vegetation and scatter due to post-abandonment natural and anthropogenic processes.

Thermal imaging, where available, suffers from these same issues and is distorted by the debris scattered around the area. In any case, the recognized features were quickly identified on the ground and documented in full on the tablets. The lack of exposed bedrock suggested that geophysical survey might be useful in this area.

Indeed, geophysical prospection provides a clear, more complete, plan of the structure which is only partially visible on the surface. It appears to be a colonnaded stoa with shops facing both south toward the agora and north toward the edge of the agora terrace. Further details of the construction can be gathered from the personal autopsy.

Moving to the region just south of the agora it is again possible to show the potential of an integrated approach to our work at Notion.

This portion of the site is on a steep incline and although architectural features are occasionally visible on the surface, the topographic and environmental conditions make it

difficult to study the remains from ground level, as is evident from the blank spaces on the earlier plans of the site. From satellite imagery alone, this area is also difficult to interpret. A few linear stretches of wall are visible which likely indicate city blocks, but internal features are difficult to recognize with certainty. A look at the topographic model, however, does offer a hint of terracing.

The thermal imaging, while confirming the larger stretches of wall, also offers more evidencethat the material overburden in this area is of differential depth, revealing large swaths of the area with no thermal response. Combined with the data from the DTM, this suggests the area was heavily terraced and the slope created from centuries of accumulation and natural weathering has obscured this pattern. In this case, these remote sensing approaches helped us to understand the form of the terraces in greater detail, even if their existence could be concluded from other evidence. Such a result suggests the area may be promising for future excavation.

Personal autopsy of individual features recognized in the aerial imaging confirmed their existence and allowed a qualitative assessment. The presence of numerous threseholds in this area suggests a possible series of terraced residences overlooking the sea. It was at this point the material, construction, and functionality of each feature could be observed, as well as any telltale signs of movement from its original location.

The magnetic gradiometry survey of this area, although not as refined as on the flat, open areas of the site, is still able to provide insight to areas where there are no surface features visible. Take for instance this city block here. Not only is the outline of the block well defined by the surrounding roads but these features, probably walls, offer an idea of what the appearance of the interior form of the structures may have looked like.

By combining these techniques we are able to identify a four city block sized area that on the surface is not notably revealing or easily comprehensible, but through a combination of approaches the form and quality of the area becomes known. We can now confidently describe the area as consisting of city blocks containing as many as four terraces along a stepped street running down the hillside, with architecture of varying qualities, and interior walls which can help us hypothesize as to the exact shape of the space. It also provides the necessary knowledge for the planning of possible future excavation.

A thorough understanding of the urban fabric of the city through a combination of these techniques provides us with the data necessary to draw conclusions as to aspects of urban development beyond just a description of the cities form. Differing orientations or overlapping features offer an opportunity to interpret chronological depth to the city, how it has evolved over time. In isolation each of these techniques contribute to our knowledge of the city and although there is some redundancy in what they are detecting, the benefits of an integrated, thorough approach to urban survey will ensure that we are able to describe urban development at Notion in as much detail as possible.