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## Testing Google Earth Engine for the automatic identification and vectorization of archaeological features: A case study from Faynan, Jordan



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### ABSTRACT

Google Earth Engine (GEE) is an in-development, cloud-based platform providing access to petabytes of satellite imagery data for planetary-scale analysis (Google Earth Engine Team 2015). Combining this massive database with the parallel computing power of Google's infrastructure facilitates quick and easy analysis of satellite imagery on any scale, opening new avenues for research in a number of fields. This paper evaluates the potential role GEE can play in the future of archaeological research. To do so, GEE was employed/tested in two case studies. First, GEE was used to automatically identify specific archaeological features across the landscape of the archaeologically-rich Faynan region of Southern Jordan. Second, GEE-based edge-detection and automatic vectorization for mapping archaeological sites was tested at the Iron Age (ca. 1200–900 BCE) site of Khirbat al-Jariya in Faynan. Based on the test results, the authors concluded that GEE has significant potential for assisting archaeologists with automated feature detection and vectorization, tasks that are often onerous and expensive.

### 1. Introduction

Archaeology, as with most research-driven fields, is fundamentally dependent on two precious and scarce resources: time and money. Archaeologists often have to travel great distances to access regions of interest and dedicate significant time to excavation and/or survey. In addition, post-field vectorization of archaeological features is one of the most time-consuming and labor-intensive activities in today's cutting-edge digital archaeology. As such, archaeologists frequently turn to advancing technologies that can afford cheaper and quicker methodologies for archaeological research. While excavation remains dependent (for now) on the keen eye and steady hand of a trained archaeologist, archaeological survey has greatly benefitted from the latest technological developments. In particular, satellite imaging and remote sensing have secured a spot in the archaeological toolbox for their unique benefits over terrestrial survey (see [Parcak, 2009](#) for a general overview, and [Casana, 2015](#) for a regional case study). Satellite imagery provides an advantageous point of view to examine the earth's surface, and it allows archaeologists to quickly and (relatively) cheaply survey large areas for archaeological remains. However, the scale of satellite-derived data means that these images are often enormous datasets, with individual tiles potentially consisting of many gigabytes. Consequently, performing complex analyses on satellite data can be computationally intensive, to a prohibitive degree. Thus, researchers' inability to acquire necessary computing resources for analysis and visualization can be

inhibitive to research.

The in-development Google Earth Engine (GEE) platform affords a currently free solution to the problem of limited access to computational processing power. GEE is a cloud-based platform allowing for planetary-scale analysis on petabytes of freely-available satellite imagery ([Google Earth Engine Team, 2015](#)). Combining this massive database (including over 40 years of historical data that is updated daily with new image collections) with the parallel computing power of Google's infrastructure facilitates quick and easy analysis of satellite images on any scale ([Google Earth Engine Team, 2015](#)). Furthermore, GEE provides readily available analytical tools (similar to those available in other geoprocessing softwares, such as ArcGIS or IDRISI) to investigate and manipulate satellite imagery, and users are also free to create custom scripts particular to specific research questions. Through the users' ability to apply spatial tools to satellite data on Google computers, GEE affords a unique opportunity for the application of spatial analyses that wouldn't be feasible with more limited resources.

This paper explores the possible function of using GEE to rapidly identify archaeological features on a regional scale and to automatically digitize elements on the site scale. In other words, it investigates the possibility of supplementing traditional forms of archaeological survey and mapping with GEE in order to cover significantly greater areas with shorter data processing times and without the immediate need to travel to the location of interest. Moreover, automated vectorization of features would allow archaeologists to bypass the stage of tracing features

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manually, allowing them to instead simply select important and relevant features from previously-generated vectors. This concept has the potential to be an ideal solution as it would remove much of the labor from the process of mapping archaeological sites yet still allow for the interpretative process of feature selection that is a critical component of site mapping. These applications, while possible in other geoprocessing platforms (e.g. Casana, 2014 and Luo et al., 2014), can benefit from GEE's ability to circumvent the limitations of the scales and types of analysis possible with affordable computers. To test these concepts, this paper employs GEE in two case studies. First, GEE is used to automatically identify particular archaeological features (specifically, mounds of metallurgical waste known as slag) across the landscape of the archaeologically-rich Faynan region of Southern Jordan. Second, GEE-based edge-detection and automatic vectorization for mapping archaeological sites is tested at the site of Khirbat al-Jariya in Faynan. These analyses, though not unique to GEE, provide a basis for evaluating GEE's potential for contributing to archaeological research.

## 2. Archaeological background

The Faynan region, located in modern Jordan approximately 30 km south of the Dead Sea, is one of the largest copper ore resource zones in the Levant (Fig. 1). These ores were frequently exploited in antiquity, from as early as the Early Bronze Age (ca. 3600–2000 BCE) to as late as the Middle Islamic Period (ca. 1000–1400 CE) (Levy et al., 2001; Jones et al., 2012). Copper production in Faynan reached an industrial peak during the early Iron Age (ca. 12th–9th centuries BCE), as evidenced through large smelting centers (such as Khirbat en-Nahas and Khirbat al-Jariya) associated with massive slag mounds (Levy et al., 2014). These Iron Age slag mounds are still visible on the surface throughout Faynan and total over an estimated 100,000 tons of material (Hauptmann, 2007: 147). The extent of ancient copper production in the region has only recently been uncovered, as no sites in the region were intensively excavated until 1999, likely due to Faynan's remote location and the logistical challenges for carrying out large-scale excavations there (see Levy et al., 2012 for a history of research). The inaccessibility of terrain in the region as well as the short history of archaeological research mean that analysis of satellite imagery can be a more fruitful endeavor than in regions more easily accessible or with a

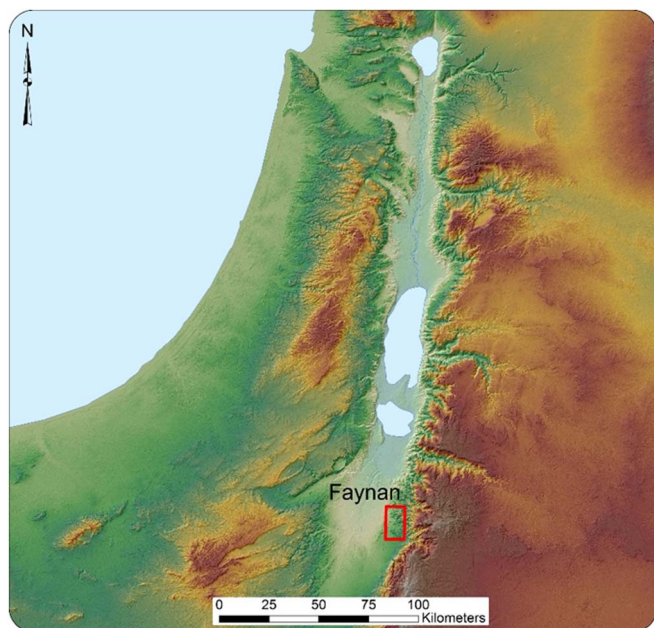


Fig. 1. Map showing location of Faynan in Southern Jordan. Map Produced by Matthew D. Howland, UCSD Levantine and Cyber-Archaeology Lab. ASTER GDEM is a product of METI and NASA.

longer history of excavation and survey. Additionally, the lack of vegetation in Faynan renders the landscape more visible from above and thus more suitable for satellite-based analysis than in more heavily-vegetated areas. GEE can facilitate such analysis by providing a methodological connection between computing power, remote sensing algorithms, satellite imagery, and archaeological applications.

## 3. Conceptual framework

GEE and its associated data catalogue are currently accessible to approved users through two web-based platforms: GEE Explorer and Code Editor.<sup>1</sup> The GEE Explorer allows the user to view and analyze satellite imagery with a limited set of included tools, whereas the GEE Code Editor functionality allows users to fully customize their desired analysis by programming in JavaScript or Python code. GEE provides hundreds of mathematical and spatial operations that can be performed on imagery in the Code Editor, which can be combined and tailored to specific research goals as will be demonstrated below.

The first case study relies on the supervised classification function in order to automatically identify slag mounds in Faynan. It is important to identify and map the extent of these locations where the actual smelting of ores took place to understand the regional infrastructure of ancient metal production. Supervised classification is the process by which a computer can be trained to detect a specific land cover in satellite imagery based on its unique spectral signature (i.e. their reflected energy at different wavelengths). Classifier training is accomplished in GEE through providing the Code Editor with known locations of the ground cover of interest in the form of points or polygons (these markers can be created directly within GEE or uploaded from a shapefile through a Google Fusion Table). Once trained, the GEE Code Editor uses a classifier of the user's choice to evaluate the pixels within an image (on any scale) and identify their class i.e. if the pixel spectrally matches the ground cover of interest or not.

The potential of this technique to locate slag heaps is dependent on their spectral signature differing significantly from the exposed ground in Faynan. Given that slag mounds on the surface of Faynan are abundantly obvious to the human eye (their black color stands out in stark contrast to the surrounding arid environs), one would expect a substantial difference in spectral signature on a large scale. However, the spectral and spatial resolution of the satellite itself needs to be sufficient to discern slag mounds. If these conditions are met, the GEE Code Editor can be used to automatically identify the slag mound spectral signature in individual pixels within a given satellite image and, in turn, create a map of potential slag mounds across Faynan (a portion of Faynan was used in this study, see below). These identified features would be subject to ground-truthing, but the created map would allow more efficient surveys. Furthermore, GEE's use of Google's computer resources greatly reduces the limitations on the speed and size of the area on which this analysis can be conducted with regard to computational limitations.

The second case study relies on GEE's edge detection algorithms, which can provide automated feature detection and vectorization when properly applied. This technique, also a standard form of analysis, can be useful for archaeologists interested in rapidly generating maps of archaeological and landscape features without needing to go through the time-consuming process of manual vectorization. GEE can potentially speed the process up given the processing power of the platform, allowing for edge detection algorithms to be applied at wider scales than normally possible in other softwares. We use GEE here to identify features at the Khirbat al-Jariya archaeological site and to generate a raster dataset with detected edges. The detected edges can be subsequently vectorized into polylines using GEE data conversion tools. With

<sup>1</sup> Those interested in GEE can request access to these platforms at <https://earthengine.google.com/>.

the generated polylines, it is possible to analyze the results qualitatively and to judge to what extent the polylines accurately represent the archaeological record. The final component of the case study is selectively editing the produced polylines to create a rudimentary map of the site. This stage involves using ArcGIS to remove all polylines that do not reflect archaeological remains at the site. From this result, a map of the site can be generated and critically analyzed to determine whether or not the automatic vectorization method represents a viable workflow for mapping archaeological remains.

#### 4. Methodology

Both case studies utilized the GEE Code Editor (rather than the GEE Explorer) for the versatility and functionality of the platform. Moreover, satellite imagery downloaded from a DigitalGlobe Foundation Imagery Grant provided the base for analysis in both cases, specifically, WorldView-2 satellite imagery with 8 bands of spectral resolution and spatial resolution of 1.84 m.<sup>2</sup> Though the freely-available Landsat imagery provided within GEE was not of sufficient spatial resolution to conduct the precise analyses described here adequately, the cyber-infrastructure provided within the GEE platform still represented an advantage over conducting similar, intensive analyses on less powerful machines with other geoprocessing software. Two tiles of imagery covering an area of 135 km<sup>2</sup> in the Faynan region were used for classification (Fig. 2). The necessary code (see Appendix A and B) for the specific case studies was modified from code provided by GEE in its documentation (Google Earth Engine Team, 2015).

For the automatic identification of slag mounds, the GEE Code Editor was used for supervised classification. To train the classifier to identify possible slag mounds, polygons encompassing the locations of slag mounds ( $n = 25$ ) at one of the larger smelting sites (Khirbat en-Nahas) in Faynan were drawn in ArcGIS and imported into GEE (11 slag mounds at the site were intentionally left out of the training set to function as test cases). In addition, polygons representing the landscape without slag ( $n = 40$ ) in Faynan were imported so negative regions (i.e. areas not covered by slag) could also be identified. All the polygons were used to train a Random Forest classifier within GEE (Breiman, 2001; Pal, 2005). A Random Forest classifier combines a collection of individual predictor trees which has been found to increase the accuracy of the classifier (in this case, increasing the classifier's ability to successfully identify relevant pixels of slag) (Breiman, 2001). GEE also allows the user to determine the number of predictor trees used in the Random Forest; using 300 decision trees was found to be successful at both eliminating noise and identifying slag after some experimentation. This trained classifier then analyzes all the pixels in the tile of satellite imagery and determines if their spectral signature is similar to slag and identifies them as such. In other words, each pixel is analyzed by the individual decision trees to determine if it is slag or exposed earth, and it is classified based on the majority of determinations. To summarize, the above methodology trains a classifier within the GEE Code Editor to identify pixels matching the spectral signature of slag.

For automated vectorization of archaeological features on the site scale, the Canny algorithm was applied, which identifies diagonal, vertical, and horizontal edges in an image and records the most significant edges (Canny, 1986; Google Earth Engine Team, 2015). The Canny algorithm has been shown to be an effective method of edge detection in images, though it is computationally intensive (Maini and Aggarwal, 2009; Liu and Jezek, 2004). Fortunately, GEE's ability to process data on Google's infrastructure renders the challenge of computational intensity irrelevant. For this method, a high threshold (40)

<sup>2</sup> The available satellite imagery in the GEE database did not provide the necessary spatial resolution for this analysis. An attempt to identify slag mounds using Landsat 8 imagery with 30 m resolution yielded poor results as many slag mounds are smaller than a 30 m pixel.

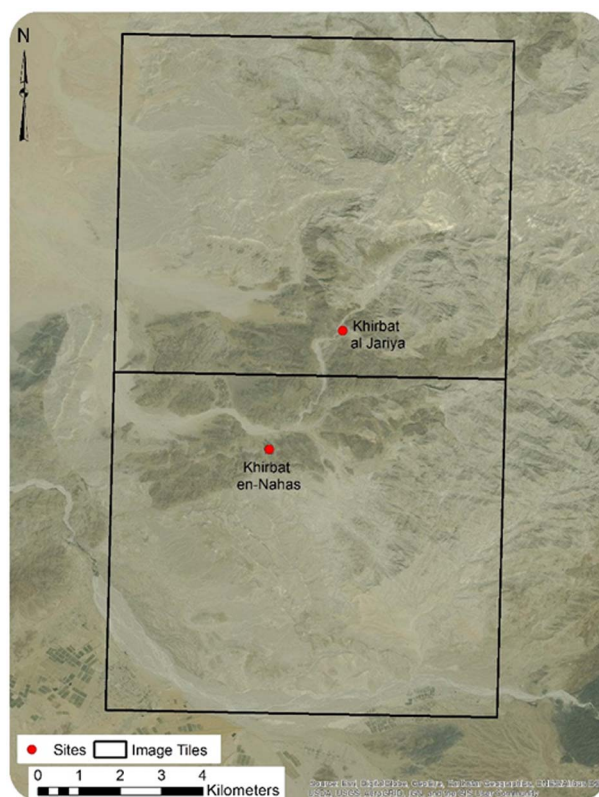


Fig. 2. Map showing locations and size of DigitalGlobe imagery tiles as well as sites mentioned in the text. Map produced by Brady Liss, UCSD Levantine and Cyber-Archaeology Lab. Satellite image courtesy of ESRI.

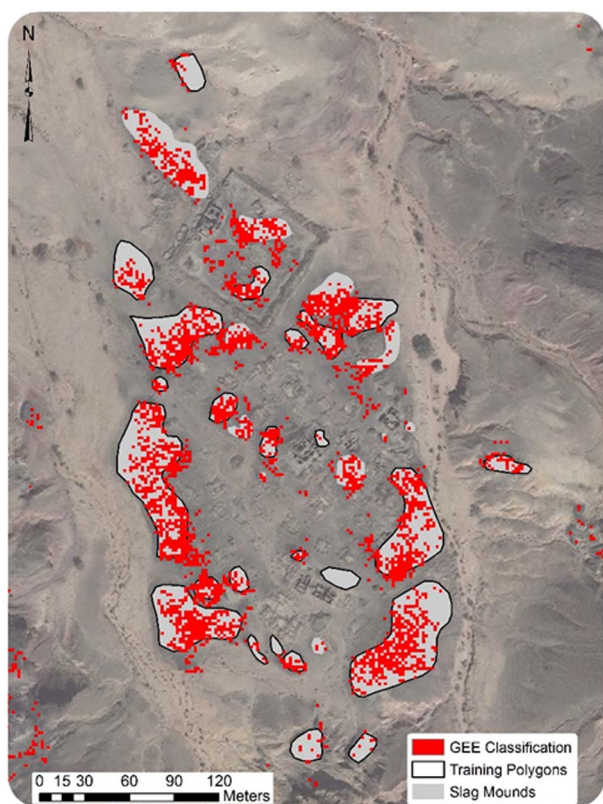
was selected in order to eliminate some of the noise picked up by the algorithm in initial tests. In the case of Khirbat al-Jariya, the archaeological remains stand out enough against the background sediment in initial tests to be identified by the edge detector even at high thresholds, while slight changes in sediment color/type became less significant in the produced raster. This result appeared to be a quality representation of features in the landscape and as such was judged as an appropriate result of the Canny algorithm.

#### 5. Results

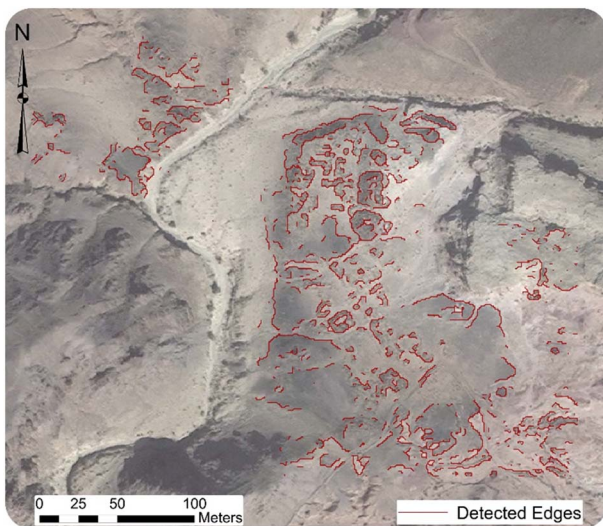
Using the training polygon set and classifier described above, the 135 sq. km portion of the Faynan region was tested for slag mounds. Conducting the analysis on this area took ca. 45 s, indicating the efficiency of GEE's computational resources. To validate the results of the automated classification, Khirbat en-Nahas was selected as a test site because it is the largest Iron Age copper smelting center in the Faynan region and includes many extant slag mounds. The classifier successfully identified pixels of slag in 34 of the 36 (94.4%) mounds at Khirbat en-Nahas (Fig. 3). Moreover, known slag mounds were also identified at another large, contemporary smelting site, Khirbat al-Jariya, located approximately three kilometers from the training site. Pixels classified as possible slag were not limited to only smelting sites, but were found throughout the entire analyzed region, the overall goal of the analysis. However, there were also obvious flaws in the classification as well. Based on a previous knowledge of the region, it was determined that GEE also inappropriately classified certain deposits of dark-colored soil as slag (i.e. false-positives). The impact of these false-positives on the overall results of the analysis is discussed further below.

The final result of the Canny edge detection algorithms for the ca. 7 ha area of KAJ after vectorization and manual editing is shown in Fig. 4. This site represents a small portion of the 135 sq. km area on





**Fig. 3.** Map displaying the results of GEE slag classification at Khirbat en-Nahas, Faynan. The red squares represent individual pixels identified as slag by GEE. Map produced by Brady Liss, UCSD Levantine and Cyber-Archaeology Lab. Satellite image courtesy of the Digital Globe Foundation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



**Fig. 4.** Map displaying the result of Canny edge detection at Khirbat al-Jariya, Faynan. Polylines representing automatically detected edges are displayed in dark red. Map produced by Matthew D. Howland, UCSD Levantine and Cyber-Archaeology Lab. Satellite image courtesy of the Digital Globe Foundation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

which the edge detection was applied; analysis that completed in ca. 2 s. This method, applied with a high threshold setting, successfully identifies archaeological remains and significant changes in the landscape. While archaeologists are of course concerned primarily with

archaeological remains, the latter aspect is also important to mapping archaeological sites, as archaeologists often need to include physical features such as wadis or ridges in their mapping. In any case, since mapping of an archaeological site is an interpretive process, all results will need to be checked and classified by a trained archaeologist to determine their significance. An important drawback to the results is that the results here are unduly affected by the boundaries between pixels, in the sense that they are orthogonal and not following the natural curves of features. Thus, the vectorization generated here is not appropriate for detailed mapping on a sub-site scale, unless the results are modified by a smoothing function in GIS or elsewhere. However, at a site-wide or regional scale, the results attained here do successfully identify the main features in the landscape.

## 6. Discussion

From the slag mound case study, GEE proved to be a viable tool for the automatic identification of archaeological features in satellite imagery, accomplishing the supervised classification across the 135 sq. km area in less than a minute (substantially faster than visual inspection and digitization of the imagery for potential features). GEE was highly successful on the site scale, identifying pixels in 94.4% of the slag mounds at Khirbat en-Nahas. In addition, and emphasizing the power of GEE to rapidly run analyses on a significant scale, pixels of slag were correctly identified at Khirbat al-Jariya. Potential slag mounds were also identified throughout the entire tile of satellite imagery (see Fig. 2). Of course, any object/location identified as archaeological remains in an image cannot be accepted as definite without confirmation from the ground. However, the map produced through GEE can be taken by the archaeologist into the field to visit specific locations to determine the reality of its identification – a methodology that will be significantly quicker than comprehensively surveying the region without prior investigation. GEE shares these advantages with other digital survey techniques; however, the processing efficiency enabled by the use of GEE increases the potential scale and speed of automatically analyzing an archaeological landscape, since this approach can be performed in a matter of minutes, rather than hours or days. Thus, the workflow presented here can save processing time for digital survey of archaeological features and/or make the process of physical survey more efficient.

The major issue concerning the slag map is the frequent false-positives (a problem seen in similar attempts to identify slag mounds using remote sensing, see Savage et al., 2012). The local landscape contains deposits of dark soil with a similar spectral signature to slag that are misidentified as slag. Specifically, dark outcrops of the Dolomite Limestone Shale (DLS) geological unit were frequently identified as slag; these formations must have a similar spectral signature to slag (see Rabb'a, 1994 for the distribution of DLS throughout Faynan). It is possible that the classification results could be improved with additional training polygons. This study was limited to slag mounds from one site in Faynan, but other sites could be included for additional training. This issue, however, does not undermine the GEE methodology as it functioned as expected to quickly and automatically identify possible features. Moreover, this challenge will not be present in all areas of archaeological research; this project provided a proof of concept. The same methodology presented here could be utilized for identifying other archaeological features with distinct spectral signatures in comparison to the landscape, including entire sites.

Regarding the automatic vectorization of archaeological features, the Canny algorithm appears to be a potentially useful tool for rapid, limited-quality vectorization of archaeological and landscape features at a regional scale. This can be a useful technique in cases where an archaeologist might wish to create many maps of archaeological sites across an entire region on a short deadline, given GEE's ability to apply analyses across broad areas by utilizing Google's powerful computational infrastructure. Such an analysis would depend on the availability

of high-resolution satellite imagery, as freely-available imagery (e.g. Landsat) may not be of sufficient resolution for identification of many features. However, in such a case, the ability of Google's computers to handle demanding calculations on high-resolution datasets is even more beneficial to the analysis. At a sub-site scale, the results of edge detection seem less useful. As mentioned above, the edges detected are largely affected by pixel boundaries, meaning that many of the edges occur at right angles, a situation not representative of the actual spatial patterning of the archaeological record. Furthermore, automatic vectorization of archaeological features bypasses the fundamental interpretative stage of map generation. Maps of archaeological sites are not simply comprehensive catalogs of all aspects at a site, but rather a simplified representation of the archaeologically significant features present. As such, the results of automatic vectorization in any case should be subject to review by a trained archaeologist who can adequately judge which features should be included. Regardless, manual vectorization for the purpose of map generation is a time- and labor-consuming process that is not always possible to perform. In these cases, applying GEE and the Canny edge detection algorithm can be a viable alternative to set the stage as a rapid, basic form of vectorization.

## 7. Conclusion

Based on the results of these case studies, GEE is a capable and effective tool for conducting regional scale satellite imagery analyses with efficiency not otherwise possible. In particular, GEE proved successful in identifying slag mounds in the Faynan region. The GEE Code Editor facilitated this analysis by providing access to the API for analysis and manipulation and the computing power to investigate a large region, making it a valuable tool for projects of this fashion. In sum, the GEE Code Editor rapidly and automatically created a map of predicted slag mounds which can be quickly ground-truthed, especially in comparison to necessary time investment for traditional methods. Furthermore, the entire process was completed at little (depending on the need for higher resolution imagery) or no cost to the archaeologist. Thus, as aforementioned and shown above, GEE presents an opportunity for entirely new avenues of rapid and automated archaeological survey at previously inconceivable scales.

GEE can also be a useful tool for automatic vectorization of archaeological and landscape features if satellite imagery of sufficient resolution is available. The greatest advantage of such an approach is GEE's ability to apply such a process over a large area. As such, the coverage of available imagery is also important, in addition to its scale. If used properly, GEE-based automatic vectorization is an effective tool for limited-quality vectorization of archaeological and landscape features at a regional scale in an extremely short timeframe. The results of such an analysis can be useful for generating regional archaeological maps while avoiding the painstaking and time-consuming process of manual vectorization and the long processing times needed to generate such results on less powerful computers.

These methods—and countless others possible in the GEE platform—share the advantages of being able to be performed rapidly, at enormous scale, and without special investment in computational infrastructure. The GEE platform has the potential to be a truly revolutionary platform for satellite imagery analysis for archaeological ends, including and beyond those described here. As such, this paper hopes to inspire other archaeologists to explore the many possible applications of GEE towards their own research goals, regardless of region or time period of interest.

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## Appendix A. Code for supervised classification

```
Map.addLayer(image, {}, 'DG Imagery');
var Training_polygons = ee.FeatureCollection(ft:1qp_CXru2zolmw
GZC8m79L7UPy2zTvVUenXHaPcSt');
var Test_polygons =
ee.FeatureCollection(ft:19mFdp_0-
TWcrGyhPzToz85HERNMTzwtATgkKrN5V');
Map.addLayer(Training_polygons, {}, 'Training');
Map.addLayer(Test_polygons, {}, 'Test');
var bands = ['b1', 'b2', 'b3', 'b4', 'b5', 'b6', 'b7', 'b8'];
var image = image.select(bands);
var training = image.sampleRegions(Training_polygons,
['Class'], 10);
var trained = ee.Classifier.randomForest({'numberOfTrees': 300}).
train(training, 'Class', bands);
var classified = image.classify(trained);
Map.addLayer(classified, {min: 0, max: 1, palette: ['00FF00',
'FF0000']}, 'classification');
var mask = classified.mask(classified);
Map.addLayer(mask, {palette: ['00FF00']}, 'mask');
Export.image(mask);
```

## Appendix B. Code for Canny edge detection

```
// Canny Algorithm
var cannyN = ee.Algorithms.CannyEdgeDetector({image: imageN,
threshold: 40});
var cannymask = cannyN.updateMask(cannyN);
var cannylines = ee.Algorithms.HoughTransform(cannyN, 256,
1, 1);
Export.image(cannylines, 'cannylines', {region: KAJ});
```

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