Assessing Interior and Exterior Divisions of Space Using Phosphate Analysis Spot Test Methods

by JOHANNA M. ULLRICH

Phosphate analysis is a geoarchaeological soil analytical technique that can identify areas where organic debris was discarded or collected in the soil. Phosphate patterning is used to differentiate between areas where debris was deposited and areas that were kept clear of debris. This information is then analysed to create use-of-space models, help determine land-use patterns over sites and aid the archaeological interpretation of site and social dynamics. This research utilised this technique at the sites of four promontory forts on Achillbeg and Achill Island, Co. Mayo, Ireland, to determine how space was organised both on and adjacent to the sites. Several activity areas were identified based on the phosphate patterning, including sleeping, food preparation, and storage areas, a midden, previously unknown internal areas, entryways, pathways, and possible gate features. This article will catalogue the identified phosphate patterns, explicate the formation processes, provide examples where these patterns have been ground-truthed on excavated sites, and discuss the ways in which space was organised at the highlighted features. A study of this type will serve to illustrate how this information can be best applied in archaeology generally, as well as to answer questions based on site-specific research aims.

Keywords: phosphate analysis, promontory forts, geochemistry, use of space, Ireland

Introduction

Phosphate analysis is used in archaeology as an indication of past human activity. This is based on the consistent generation of organic debris as a result of human agency. Phosphates are esters of elemental phosphorus, and are one of the main building blocks for all forms of organic matter. Phosphates are released and become fixed to the soil upon the decomposition of organic matter. Archaeological sites and features are located through the identification of areas with increased phosphate content. Certain activities associated with settlement and other anthropogenic occupations generate phosphate levels that are easily discernible from natural phosphate levels. The habitual use of specific archaeological features creates distinct and identifiable patterns that are globally and cross-culturally applicable (Matthews et al. 1997).

The applicability of assigning functions to areas based on phosphate signatures has been tested through the comparison of several culturally and temporally distinctive archaeological and ethnographic sites by Middleton and Price (1996), Middleton (2004) and Wilson et al. (2005), among others. Middleton (2004: 56) tested house floor surfaces in Classical Period residences in Oaxaca, Mexico (AD 250 – 700) and Neolithic residences in Çatalhöyük, Turkey (7500 – 6500 BC). All tested house floors showed the same phosphate patterns. These specific patterns can be identified when phosphate levels are mapped across a site, and interpreted to create site-specific use-of-space models. These patterns allow for the breakdown of an archaeological site into different zones of use based on the presence of distinct phosphate patterns. Studies that test the validity of phosphate analysis techniques, the consistency of resultant patterning, interpretation techniques, and the presentation of phosphate data, can be used to make phosphate testing more applicable to archaeology. This article will discuss how fast, accurate phosphate analysis results can be obtained and analysed to best complement archaeological research goals.

The identification of phosphate patterns can lead to the location of specific structures and activity areas, which can illuminate the possible functions of archaeological sites of uncertain origin. The interiors of only five Irish promontory forts have been completely excavated (Childe 1935; Sidebotham 1949; O’Kelly 1952; Liversage 1968; Barry 1977; Casey 1999). In every instance, excavation yielded little to no material culture, except from later uses of the sites in some cases, and the original functions of the sites largely remained unclear. Phosphate analysis was applied to four promontory forts in Western Ireland to identify features not often visible in the archaeological record, and was able to give

Johanna M. Ullrich – johannamullrich@gmail.com
University College Dublin

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more detailed accounts of how promontory forts were used than any previous archaeological excavation.

**Phosphates and Soil**

Phosphates exist in organic and inorganic form. Inorganic phosphates are generally aggregate bonded and derived from soil parent material (Oonk et al. 2009: 1216). Organic phosphates are derived from vegetal and animal sources, which are deposited both naturally and anthropogenically. The natural deposition of phosphates occurs through the environmental processes of seasonal vegetal decay, as well as the presence of animals and their waste products, including faeces, bone, and tissue. Anthropogenic phosphates can be found in myriad sources including human waste and refuse, discarded bones, meat, fish, plants, and wood ash from fires. Organic phosphates are incorporated into soil matrices through the decay of these phosphate-rich materials. Organic phosphates released through this decay readily bond, or sorp, to iron and aluminium in acidic soils, and calcium in basic soils (Holliday and Gartner 2007: 302). Sorption is the process by which the association of a chemical with soil solids, typically the surface of a particle, is accomplished through chemical and biological mechanisms (Holliday and Gartner 2007: 303). Phosphates are affected by sorption and easily form bonds with elemental components of the parent soil.

Phosphates from all sources form strong bonds with soil particles, and are rarely lost through leaching and weathering processes. Phosphates are only lost when no aluminium, iron, or magnesium atoms are present with which phosphates could bond (Holliday and Gartner 2007: 304). It is possible to find phosphates in the exact area where they were originally deposited, and in the topsoil directly above the area of deposition (Sjoberg 1976: 448). The collection of phosphates in the topsoil has been identified as an effect of plant growth (Proudfoot 1976: 103). The upward movement of phosphates within a soil profile allows for the displacement of phosphates from lower horizons to the topsoil. The rate of this vertical movement is related to the quantity of root growth, and of phosphate uptake by those roots. This creates a build-up of active phosphates in the topsoil, thus forming a phosphate shadow in the topsoil that mirrors levels found in sub-soil horizons. However, horizontal leaching of phosphates rarely occurs (Proudfoot 1976: 100).

This process is not well understood, and is greatly dependant on levels of plant growth. The vertical correlation of soil samples with increased loosely-bonded inorganic phosphate levels in the topsoil, and the presence of buried archaeological features has been documented in Sweden (Linderholm 2007: 432). The translocation of phosphates generally occurs only with movement of the soil matrix, such as by erosion or ploughing. Even in these instances, if the buried archaeological feature remains *in situ*, anthropogenic phosphates will continue to percolate upwards and form a new phosphate shadow in the topsoil. Phosphate analysis methods that test topsoil phosphate levels take advantage of these natural processes to accurately and unobtrusively determine anthropogenic phosphate levels on archaeological sites, with no detrimental effect to buried archaeological features.

Human activity can influence the retention and cycling of phosphates by altering soil conditions. All fertiliser and cultivation systems alter the normal phosphate fractionation pathways (Zhen et al. 2002:1004). Different forms of modern agricultural practices affect phosphate cycling most distinctly through alterations to microbial activity levels in the soil (Bending et al. 2000). In most cases, these variations do not greatly affect the archaeological identification of phosphate patterns, but do make it more difficult to compare phosphate levels from different sites and to assign archaeological meaning to specific phosphate values.

All factors can interact in different ways based on specific on-site conditions, but the ways in which phosphates are enhanced can be difficult to predict. Phosphate patterns that result from past human activity are often still evident, even with the great number of variants that can alter phosphate cycling. One exception to this is when inorganic phosphate-based fertilisers have been applied to agricultural fields; past anthropogenic phosphate concentrations can be obscured when inorganic phosphates are later added to a soil at an equal or higher level than the previous activity deposited.

**Portable Spot Test Methods**

All forms of phosphate and total-phosphorus analyses are used in archaeology to identify
areas where human activity has affected the soil chemistry through the organised deposition of phosphate-rich organic material. Areas with both increased and decreased phosphate content form patterns that can be used to interpret use-of-space and landscape organisation. The nature of phosphate cycling in a soil system allows for the long-term retention and subsequent identification of the phosphate signature of a soil. Different phosphate testing techniques are used in conjunction with archaeology to test for various forms of phosphate content. More intensive laboratory methods result in a defined level of phosphate content (commonly expressed in parts per million), while portable field methods only generate a general level, based largely on the discretion of the individual performing the test. However, portable field testing techniques offer a quick and inexpensive alternative to more expensive laboratory methods. The general phosphate levels established through portable field techniques are adequate for the identification of phosphate patterning at most archaeological sites (Eidt and Wood 1974).

Portable phosphate analysis techniques measure the visible colorimetric reaction of molybdophosphoric compounds reduced in an acidic environment, which creates a blue sample solution. The intensity of this blue colour is then measured by recording the intensity and hue of the resultant colour, either in a clear glass vial or on filter paper. These techniques were developed in an archaeological context to allow for the quick determination of phosphate levels to prospect for archaeological sites and map ancient activity-areas (Schwartz 1967; Eidt 1973; Overstreet 1974). In the field, portable spot test approaches can positively identify archaeological settlement sites 75% of the time (Holliday and Gartner 2007: 313), and can sufficiently distinguish between different levels of phosphate content to infer phosphate patterns from the results. Improvements on the field-based technique have created a semi-quantitative procedure that measures the results of phosphate extraction through colorimetric determination (Holliday and Gartner 2007: 313-314). The accuracy of spot test methods can be increased through performing the test in a controlled environment, and creating a modified chart of phosphate levels by recalibrating the phosphate levels set out by Eidt and Wood (1974) to break down every level into quarters (e.g., 1.0, 1.25, 1.5, 1.75, 2) from zero to six (Ullrich 2007).

Portable spot test methodologies have been surpassed in popularity by newer laboratory procedures, but these laboratory procedures can be expensive and time-consuming, and require access to a well-equipped soil laboratory. Many studies have been undertaken to determine the validity of portable spot test methods compared to more intensive laboratory tests that assign a parts per million numerical value to phosphate content (Hamond 1983; Smyth et al. 1995; Bjeljac et al. 1996). The comparison of laboratory testing methods with portable field testing methods reveals that spot test levels are not as exact as laboratory methods, but do fall into definable ranges that are analogous to laboratory tests (Hamond 1983; Smyth et al. 1995). The quantitative laboratory levels that correspond to spot test levels in one example should not be projected onto other sites. The tests do indicate, however, that correlation between laboratory test results and portable field test results occur in the majority of cases (Hamond 1983: 47; Smyth et al. 1995: 329; Bjeljac et al. 1996: 246). The level of definition obtained from portable field techniques is thus sufficient for the accurate determination of phosphate patterning over most archaeological sites.

The ways in which different portable spot test techniques compare were examined through the use of four different spot test methods on the same set of soil samples by Terry et al. (2000: 157). An evaluation of the Mehlich II acid extraction test (Mehlich 1984), the Olsen bicarbonate extraction (Olsen and Sommers 1982), perchloric acid digestion for total-phosphorus (Terry et al. 2000: 157), and the Eidt ring test (Eidt and Woods 1974) performed on the same soil samples, revealed that the mean result for all tests was the same. The Mehlich II method produced higher phosphate levels than the other spot test methods. The Terry et al. (2000) and Olsen and Sommers (1982) results were comparable in most cases, but were less consistent than the other two methods. The Eidt ring test method proved less sensitive than the other methods, but the phosphate ratios between soil samples were indistinguishable from the results of the other tests. This study showed that while these tests vary in the level of phosphates that are measured, the resultant patterns of relative content ratios are the same (Terry et al. 2000: 158-160).

The Eidt and Wood phosphate method (Eidt and Wood 1974) uses hydrochloric acid to extract inorganic phosphates from their bonds in the active phosphate pool. These phos-
Phosphates are usually loosely bonded with iron, aluminium and calcium in the soil. Spot tests that extract only the readily accessible phosphates from the active phosphate pool extract inorganic phosphates. This is applicable to the prospection for archaeological sites because, even though anthropogenic phosphates are largely organic, the increase of organic material in a soil also increases the amount of microbial activity, which transforms organic phosphates into inorganic phosphates (Holliday and Gartner 2007: 313-314).

The ability of the Eidt and Wood portable field techniques to correctly identify archaeological sites and features has been tested through the examination of known archaeological sites and areas thought to be devoid of settlement. Soils from these areas were phosphate tested and then excavated to determine what archaeological features influenced the identified phosphate patterning (Bjelajac et al. 1996). Samples retrieved from various soil depths on archaeological sites, as well as from features, have been tested to determine the most accurate testing method. These tests were undertaken to assess the usefulness, as well as the precision, of portable field methods of phosphate analysis. The Eidt and Wood (1974) spot test was found to accurately identify archaeological features from soil samples retrieved from 20cm below ground surface 97% of the time (Bjelajac et al. 1996: 246). The Eidt and Wood (1974) method has also been the subject of more calibration studies than other protocols. This method has been used most often when soil samples were taken from the topsoil as part of surveys performed to locate sites or archaeological features prior to excavation, and has accurately identified archaeological sites and features on multiple occasions.

**Interpreting Phosphate Analysis Results**

Phosphate analysis can be used to aid the interpretation of large- and small-scale spatial organisation on archaeological sites. Just as different artefacts have different distributions, so do different chemical signatures of human use-of-space (Hodder and Orton 1976: 53; Entwistle et al. 2007); different activities produce distinguishable chemical residues. The classification of areas into phosphate-rich and phosphate-poor activity loci, for example, is relatively easy to determine (Matthews et al. 1997: 293). Areas kept clear of organic debris are generally used for sleeping, sitting, and other such phosphate-poor activities. Activities that generate organic debris include food storage, processing, consumption, and other such phosphate-rich activities. Garbage dumping areas have the highest concentrations of organic debris, followed by food preparation, storage, and consumption areas (Matthews et al. 1997: 293).

The specific phosphate patterns most commonly found on archaeological sites are outlined below, the depositional processes that formed the patterns are analysed, and mapped examples are given from the authors own work on four promontory forts in western Ireland.

Promontory forts are defined typologically as sites where a ditch and bank complex was constructed across the narrow isthmus of a natural headland (Macalister 1928: 286). This act of segregation formed a space surrounded on three sides by sea-cliffs and on one side by the complex itself. Four promontory forts were selected for phosphate analysis to show how the technique can be applied to the interpretation of archaeological sites. The patterns discussed below catalogue the most useful and distinctive patterns associated with interior and exterior divisions of space, which can be used to create site-specific use-of-space models and to increase our understanding of archaeological sites. Examples from the literature where the patterns were tested archaeologically are also discussed, to corroborate the interpreted results and illustrate the global applicability and accuracy of phosphate analysis spot test methods. Although excavation does not form part of this case study of promontory forts, such examples provide analogues that can aid in the interpretation of promontory fort use-of-space as is known from previous excavations and from the phosphate analysis in this case study.

Soil samples were taken from four promontory forts under license numbers 08E0514 (Dun Kilmore), 08E0515 (Dungurrough), 09E0320 (Dun Bunnafahy) and 09E0321 (Gubadoon) on Achillbeg and Achill Islands, Co. Mayo, Ireland (Figure 1). A grid was set out across each site and samples were taken at a three metre interval. Land on the exterior of the promontory forts was included in the sampled area to determine how the forts were approached, as well as the extent of the sites themselves. The three metre samples interval was chosen to maximise the detectability of phosphate patterns over the entire study area. A 1-inch diameter corkscrew auger was used to...
retrieve soil samples from 20cm below the ground surface, in accordance with the Eidt and Wood spot test standard protocols (Eidt and Wood 1974). The phosphate pattern maps were generated in a topographical landscape reconstruction framework based on slope-formula models within a mesh grid system using form-Z© landscape architecture software. Most of the examples of activity-area patterns outlined below are from the large promontory fort of Dun Kilmore on Achillbeg Island (the interior division of space, entryways, and constructed boundaries), several examples are from Dungurrough on Achillbeg Island (middens, banks and ditches), one example is from Dun Bunnafahy on Achill Island (structures) and one example is from Gubadoon on Achill Island (pathways).

A nearby headland, with no visible archaeological features and the same geological background, was phosphate tested as a control to identify background phosphate levels and allow for greater accuracy in the subsequent interpretations of the identified promontory forts. Phosphate levels on the control site were negligible when tested using the spot test method, and did not exceed a phosphate spot test level of 0.75. The bedrock in the area of the four tested promontory forts and the control headland is comprised of greenschist and sub-greenschist, which has not contributed greatly to the overall phosphate content of the soil. This natural headland was also selected as a control site for this study because it displayed similar agricultural markers to the tested promontory forts. The control site and the tested promontory forts show signs of significant use as pastureland, but this did not affect the identification of anthropogenic phosphate levels, as demonstrated by the results from the control site, due to the phosphate mineralisation rate.

A selection of soil samples, including samples from the control site, was tested in the University College Dublin Soils Lab (School of Agriculture and Science) to determine how the spot test results compare to a more specific numeric method of determination (Ullrich 2010). Many tests that compare spot test results to photometrically determined laboratory results have been carried out previously, including one in Ireland on soils from a crannóg (Hamond 1983). Spot test results on an arbitrary scale (1-6 in this study) can be correlated to parts per million (ppm) photometric laboratory results. All of the results for the soil samples in the study area did correspond to the spot test results in relative value. The results show a definite link between high- and low-level results from the spot and laboratory tests. In every instance, an increase in the spot test level of a sample corresponded to an increase in the ppm of the same sample. The rate at which the spot test value increases, however, is not equal to the rate at which the ppm value increases. The laboratory test results from the Dun Kilmore soil samples are discussed below as an example of possible variations and their causes.

Two different rates of change are identifiable in the Dun Kilmore sample set (Figure 2). The spot test values below level 3 show a relationship to the ppm where the spot test values increase at a faster rate than the ppm. After the spot test value of level 3, the
relationship is the inverse, with the ppm increasing at a faster rate than the spot test values. The slope of this relationship increased in the higher phosphate content values. The point of change occurred at spot test level 3, which is the first spot test level that indicates an increase from natural phosphate levels. The difference in the rate of change between spot test values and ppm may be tied to the abilities of the two methods to release specific fractionations of soil phosphates. This may also be a function of different source materials for the soil phosphates, variations in soil conditions and retention capabilities, later uses of the sites and many other factors. Overall, the laboratory method may extract a higher percentage of anthropogenically derived phosphates, but the Eidt and Wood results still show the same trends. These results illustrate the accuracy and applicability of the Eidt and Wood spot test method to this case study.

**The Interior Division of Space**

The purposeful division of interior space is visible in phosphate analysis through the organisation and consumption of food and the intent to maintain cleared space in certain areas (Matthews et al. 1997: 293; Terry et al. 2004). Four main categories of use can be determined within structures by identifying specific phosphate patterns. Sleeping, storage, food preparation/consumption, and receiving/living areas all maintain specific, identifiable phosphate patterns. Organic debris is not generated in sleeping areas, and these areas will often be identifiable in the phosphate patterning because the levels are relatively very low, often even lower than the natural background as a result of ground clearing. Storage areas often display mid-level phosphate increases over the entire area that was used for storage. The resultant increase in phosphate levels is from the collection of organic debris between the stored items, and a lack of clearing due to the presence of those items. Food preparation/consumption areas, such as areas around hearths, show overall increases in phosphate content and isolated peaks of relatively very high phosphate content within the area. This patterning results from the increased presence of ash and the incorporation of food scraps into the occupation surface. Receiving/living areas maintain relatively low levels of phosphate content due to the sweeping of organic debris to preserve a cleared space. Organic debris may be generated in these areas as a result of craft working, eating and other activities, but the debris is most often not allowed to collect and decompose (Matthews et al. 1997: 293). It is common to find a ring of increased phosphate content around the edges of receiving/living areas, where clearing of the area did not remove all traces of organic debris in corners and against structure walls. It is also possible to identify internal partitions as voids in the phosphate patterning, especially between areas of increased phosphate content (Matthews et al. 1997: 293).

![Image](image.png)

**Figure 3 Interior division of space patterning, Dun Kilmore.**

Interior division of space patterning is evident in the phosphate results from the case study within a circular foundation located on the Dun Kilmore headland. The foundation is located within the bank and ditch complex of the Dun Kilmore promontory fort, Achillbeg Island. Two distinct phosphate patterns were identified within the foundation, showing a clear division of internal space (Figure 3). The eastern half of the structure displays high phosphate levels (Level 3-4), and the western half of the structure displays low phosphate levels (Level 0-1). The well-defined boundary between the two areas suggests an activity was carried out in the eastern section that generated organic debris, and that the western half was deliberately kept clear of this debris. One possibility is that a hearth and associated food production/consumption activities were carried out in the eastern section that generated organic debris, and that the western half was deliberately kept clear of this debris. One possibility is that a hearth and associated food production/consumption activities were carried out in the eastern section that generated organic debris, and that the western half was deliberately kept clear of this debris. One possibility is that a hearth and associated food production/consumption activities were carried out in the eastern section that generated organic debris, and that the western half was deliberately kept clear of this debris. One possibility is that a hearth and associated food production/consumption activities were carried out in the eastern section that generated organic debris, and that the western half was deliberately kept clear of this debris. One possibility is that a hearth and associated food production/consumption activities were carried out in the eastern section that generated organic debris, and that the western half was deliberately kept clear of this debris.

**Structures**

The identification of structures not visible on the ground surface is possible in phosphate analysis through identification of the specific
assemblage

interior patterns described above. Areas that exhibit a variety of phosphate levels in a relatively small locale are often identifiable as interior areas. The location of relatively high and low phosphate concentrations clustered near each other suggests the presence of divided interior space (Craddock et al. 1985: 368; Matthews et al. 1997: 293). Increased areas of phosphate content can also relate to interior walls where debris collected or to exterior walls where debris was deposited as a result of clearing the interior (Terry et al. 2004: 1245). Matthews et al. (1997: 293) identified this patterning as a result of sweeping to clear interior areas. It is also possible that increased phosphate content against the exterior of walls can result from the natural accumulation of organic debris in a protected area. Both patterns result from the presence of standing structures.

Figure 4 Structure patterning, Dun Bunnafahy.

Two areas in the undefended land on the exterior of the Dun Bunnafahy promontory fort display phosphate patterns generally associated with the presence of circular structures (Figure 4). In this location, areas of increased phosphate content (Level 4) are located within mid-level phosphate concentrations (Level 3), indicating the presence of structures not visible on the ground surface. Areas between the higher increases (Level 4) remain lower (Level 3). The two central areas of decreased phosphate content are both between 6 and 9 metres in diameter. The patterning suggests the two possible structures were used in different ways. Phosphate patterning in the area of the western feature indicates a structure that was swept clear, with the build-up of some organic debris against the walls. Phosphate patterning in the area of the eastern feature is likely associated with the presence of an enclosed hearth, as has been identified and ground-truthed at a number of sites (Kerr 1993: 138; Weston 1995: 22; Smith et al. 2001: 258; Crowther 1998:118; Craddock et al. 1985: 368).

Entryways

Entryways are associated with patterning where increases in phosphate content flank either side of an area of relatively low phosphate levels (Yerkes et al. 2007: 865). Entryways create this pattern as a result of debris collecting against the exterior of walls or partitions on either side of a cleared entry. The phosphate increases on either side of the entryway can continue along the exterior of the structure, extend away from the structure flanking the path by which the structure is accessed or occur only as isolated increases in phosphate content directly beside the entrance.

At an Early Copper Age settlement in southeastern Hungary, voids in the relatively high phosphate levels around the perimeter of the site were interpreted as the entrances by which the site was accessed. Excavation was able to associate this patterning with breaks in the circular earthwork that enclosed the site (Yerkes et al. 2007: 865).

Figure 5 Entryway patterning, Dun Kilmore.

This formation of entryway patterning is visible in the phosphate patterning on Dun
Kilmore where the largest concentration of phosphates within the defended area of the promontory was also located (Figure 5). Two areas of relatively high phosphate levels (Level 4 and Level 3.5) flank an area of relatively lower phosphate level (Level 1.75), surrounded by a large area of increased phosphate level (Level 3). The pattern is indicative of the entrance to a structure, where material was built up along the structure's walls, and, to a smaller extent, in the area surrounding the building. The entryway was kept clear. Several large blocks of dressed stones are present in this area, in no obvious configuration, which is a further indication that a structure may have been present. The actual location of a structure associated with the increased phosphate levels and stones may be partially or entirely lost due to heavy erosion along the southern cliff-edge of the headland (Westropp 1919).

**Middens**

On archaeological sites, the highest phosphate levels are generally associated with midden locations. Kitchen garbage, especially bone, is one of the greatest contributors to soil phosphate content. Locating midden areas through phosphate analysis has been one of the main uses of the technique in archaeology (Eidt and Wood 1974: 44). Middens associated with settlements, and other areas of human activity, are clearly identifiable in phosphate patterning as relatively large foci of increased phosphate content (Wells 2004). The only other areas that exhibit equal or greater phosphate levels are cess/manure pits, outhouses, and some animal pens.

The defendable banks and ditches on the Dungurrough promontory fort, Achillbeg Island, are visible as linear bands of relatively high and low phosphate content (Yerkes et al. 2007: 866). This is a result of organic debris collecting in ditches and the inability of organic debris to remain fixed to banks. The material that contributed to the increase in phosphate content in ditches may not have necessarily been a result of human activity, although it is most common. It is possible that once a ditch was constructed it began to fill with naturally deposited material. This patterning, however, is still considered to be of anthropogenic origin because it results from the presence of a ditch.

**Banks and Ditches**

Bank and ditch features manifest in the phosphate record as linear bands of relatively high and low phosphate content (Yerkes et al. 2007: 866). This is a result of organic debris collecting in ditches and the inability of organic debris to remain fixed to banks. The material that contributed to the increase in phosphate content in ditches may not have necessarily been a result of human activity, although it is most common. It is possible that once a ditch was constructed it began to fill with naturally deposited material. This patterning, however, is still considered to be of anthropogenic origin because it results from the presence of a ditch.
located. The phosphate concentrations within the defendable complex are most likely representative of organic debris that collected in the depressions of the defendable ditches.

**Constructed Physical Boundaries: Fences and Gateways**

The construction of physical boundaries creates a barrier against which organic material often collects (Smith et al. 2001: 258). These divisions are generally visible in the phosphate patterning as bands of increased phosphate content along the length of the feature. The specific patterning of constructed physical boundaries varies depending on the form of the fence or gateway. Solid fences, such as stonewalls, will show a clear boundary between relatively high and low phosphate levels. Fences that are not completely solid show slightly more erratic, although still identifiable, increases in phosphate content. Gateways can manifest similarly to entryways, as areas of low phosphate content that break linear bands of increased phosphate content, but may also not appear in the phosphate patterning. The specific phosphate level present along a physical boundary is greatly dependent on the uses of the enclosed space and the surrounding area. Enough organic material will collect along a physical boundary to be identifiable in the phosphate record even in areas of low-level human activity.

Patterning denoting a constructed physical boundary is present in the phosphate results at the narrowest point of the neck of the Dun Kilmore headland, Achillbeg Island. An increase in phosphate content spans the headland at this location, marking the meeting of the headland and the narrow isthmus (Figure 8). This increase in phosphate content (Levels 3-4) suggests the presence of a gate structure, indicative of a constructed physical boundary in the area. There is no visible feature on the ground surface associated with this patterning. The pattern can indicate the presence of a bank, heave, wall, or other structure directly to one side of the patterns to allow for the collection of organic material in its windfall. It is also possible that there was another structure present, of different composition than the visible features, on the isthmus nearer to the main body of the headland. The possible gateway is located within the segregated space of the headland.

**Pathways**

Roads, tracks and informal paths are visible in phosphate patterns as a series of isolated increases in phosphate content that can be linked to indicate the trajectory of human movement (Parnell et al. 2002: 336). Identification of the ways in which people accessed sites, structures and other features can lead to greater insights into uses-of-space and site dynamics.

Roads, tracks and paths are identifiable by this patterning as a result of the casual discard of organic debris during use of the pathways to access other sites and areas within sites. The pathways would have been kept clear in most cases, and are visible as areas of decreased phosphate content along which isolated elevations in phosphate content are present. Where a formalised or recurring pathway is not present, isolated increases in phosphate content can indicate the haphazard traversal of spaces between activity areas. Contrary to this, animal droveways are identifiable as solid bands of relatively high phosphate levels (Craddock et al. 1985: 363).

Phosphate results on the promontory fort of Gubadoon, Achill Island, showed indicators of pathway patterning. Several isolated mid-level phosphate concentrations (Level 3) are located along the central axis of the fort (Figure 9). The increased presence of isolated phosphate increases along the central axis likely resulted from the discard of organic debris on either side of a pathway. The concentrations follow the trajectory of easiest movement, based on
topography, between the high phosphate concentration along the southwestern tip of the headland (now a sea stack) and the northern, secondary defendable complex.

These smaller isolated areas of phosphate increase mark the ways in which the most frequented areas of the headland were accessed. These phosphate increases are most present in the portion of the fort that would have been traversed to access the identified activity areas on Gubadoon, based on phosphate analysis.

**Archaeological Implications**

Phosphate analysis results can be used to generate use-of-space models that detail connections between the deposition of organic debris and broader patterns of use on archaeological sites. This type of analysis is based on the placement of identified phosphate patterns (as detailed above) to examine the particular location of, and connections between, areas used for a variety of purposes and tasks. Phosphate analysis offers a simple and effective means for the creation of use-of-space models and determination of land-use patterns over entire sites for inter- and intra-site comparisons. These endeavours aid in the interpretation of the nature of human activity at each site. Overall phosphate levels on the tested promontory forts discussed above were not high enough to indicate sedentary occupation.

In these ways, phosphate analysis can corroborate or disprove previous theories of use for a specific monument or monument type. Phosphate analysis at the four promontory forts discussed above was able to identify several modes of use that disprove previously suggested uses of the forts, further clarify other suggested uses, and allow for new interpretations to be put forward. Previous interpretations proposed promontory forts were settlement sites that functioned as small
farmsteads (Harding 2004: 147). This theory was disproved on the tested sites based on the overall phosphate levels, which were too low to indicate settlement. Other previous theories, such as use of the sites as enclosed ritual spaces (Westropp 1919: 306; Cunliffe 2005: 296), were further clarified through the phosphate analysis survey. The patterning on the tested promontory forts indicates that areas of these forts were regulated differently, as is evident in the character of the pathways. Several of the pathways show that certain areas approaching and within the forts were traversed in prescribed ways and were well-maintained. Others show certain areas were traversed in more haphazard ways to reach structures on the headlands, and formal pathways were not present.

Phosphate analysis also led to the formulation of new theories regarding the function of promontory forts as sites and as a group. Specific phosphate levels cannot be compared across sites due to the large number of natural and modern variables that can affect phosphate background levels and retention. Site-wide phosphate patterns, however, can be compared to other tested sites to determine if a variety of sites were used in similar or different ways when it has been determined that natural and other anthropogenic factors are not interfering with the identified phosphate patterning. In this case study, the overall phosphate levels differed between the four tested sites, but the overall patterning was very similar. The results from all of the tested forts showed increased use of the area with the best view of the sea and the area that offers the most protection from the weather. All forts showed movement to, from, and within headland was regulated through the use of buildings, gateways, and established pathways, albeit to varying degrees. The four forts may have been used in slightly different ways, but the repeated imprinting of headlands with analogous components of landscape organisation suggests that the tested promontory forts were used in similar ways (Ullrich 2010).

Phosphate analysis does have some limitations; all use-of-space models are based solely on the distribution of organic material and analysis cannot distinguish between organic materials from different sources. Phosphate analysis can be paired with other methodologies to counteract some of these limitations. Phosphate analysis has often been paired with other geoarchaeological techniques to increase the validity of the methodologies through corroboration of the results (Middleton and Price 1996; Wilson et al. 2005). Several of these techniques, specifically multi-elemental analysis, can also provide additional data regarding the exact source from which the organic matter was derived. Excavation and other archaeological techniques must be employed in conjunction with phosphate analysis to obtain a complete picture of site chronology and material culture. Phosphate analysis is especially applicable to sites that are not well-understood and where excavation has been unable to determine how sites were used, and sites that are greatly affected by erosion and/or modern encroachment and are being rapidly lost. Phosphate analysis is most helpful when used on sites before excavation, where the results can identify possible features, affect excavation planning, and integrate with the results.

Conclusions

Phosphate analysis is useful as an archaeological site and/or feature location technique, but its value is magnified through application to use-of-space modelling within identified sites. Phosphate analysis can be used to locate and interpret phosphate-rich and phosphate-poor activity areas (Matthews et al. 1997: 293), including sleeping areas (Terry et al. 2004: 1243), food consumption/production/storage areas (Sanchez et al. 1999: 56), areas where refuse was deposited (Crowther 1998: 118), and some craft areas (Eidt and Wood 1974: 44). Phosphate analysis can also be used to interpret less archaeologically tangible components of use-of-space such as the placement of entryways (Yerkes et al. 2002: 865) and pathways (Parnell et al. 2002: 336), which can help interpret how people were creating and using their own landscapes. Phosphate analysis is a valuable source of information in this regard, because in many cases these features cannot be identified through conventional archaeological excavation. The utilisation of this information to create use-of-space models helps determine land-use patterns over sites, allows for greater trends between sites to be identified and aids in the archaeological interpretation of large- and small-scale intra-site dynamics.

A better understanding of the accuracy and applicability of the method, as well as how to link specific phosphate patterns to the location and function of on-site features and uses, is important to make phosphate analysis results both accessible and of greater value to archaeologists. The continued use of phosphate analysis on archaeological sites will
allow for further insights into the function and use of examined monument types and develop understandings of the connections between human activity and phosphate patterns. To this end, the construction of a database for specific phosphate patterns, and how they relate to excavated archaeological features, will allow for more detailed interpretations of archaeological sites worldwide. The accessibility of this information by archaeologists will aid in site-specific and inter-site social system interpretations. This will serve to inform archaeologists about the applications of phosphate analysis, show how the technique can be used to clarify issues of function and use on archaeological sites and contribute to the advancement of the use of phosphate analysis in the field.

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