

# BRITISH ARCHAEOLOGICAL JOBS RESOURCE

## :: A Short Guide to GPS ::

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<b>A SHORT GUIDE TO GPS</b>	<b>2</b>
<b>1. HOW THE GPS WORKS: PRINCIPLES</b>	<b>2</b>
<b>2. ACCURACY</b>	<b>3</b>
<b>ERROR SOURCES</b>	<b>3</b>
IONOSPHERIC DELAYS	3
SATELLITE AND RECEIVER CLOCK ERRORS	4
MULTIPATH ERROR	4
SATELLITE GEOMETRY	4
<b>3. TYPES OF GPS</b>	<b>5</b>
<b>3.1. HAND-HELD GPS</b>	<b>5</b>
<b>3.2 DIFFERENTIAL CODE-PHASE GPS (DGPS)</b>	<b>5</b>
<b>3.3 CARRIER-PHASE GPS</b>	<b>6</b>
GPS MEASURING TECHNIQUES	7
<b>4. CO-ORDINATE SYSTEMS</b>	<b>8</b>
<b>4.1 OSGB36</b>	<b>9</b>
<b>4.2 GPS CO-ORDINATES SYSTEMS: WGS84 AND ETRS89</b>	<b>9</b>
<b>5. USE OF GPS IN ARCHAEOLOGY</b>	<b>10</b>
<b>5.1 GPS VERSUS TOTAL STATION</b>	<b>11</b>
<b>5.2 CONSIDERING A GPS</b>	<b>12</b>
<b>6. ADDITIONAL INFORMATION</b>	<b>13</b>

## A SHORT GUIDE TO GPS

As Global Positioning System (GPS) may be used either as a positioning tool or as a survey tool, archaeologists are introducing this technique to many of their survey tasks on site. This guide outlines the basic principles of GPS and its use in archaeological work.

This introduction to GPS is focussed on applications in archaeology. It is not intended as a 'do and don't do' manual.

### 1. How the GPS works: principles

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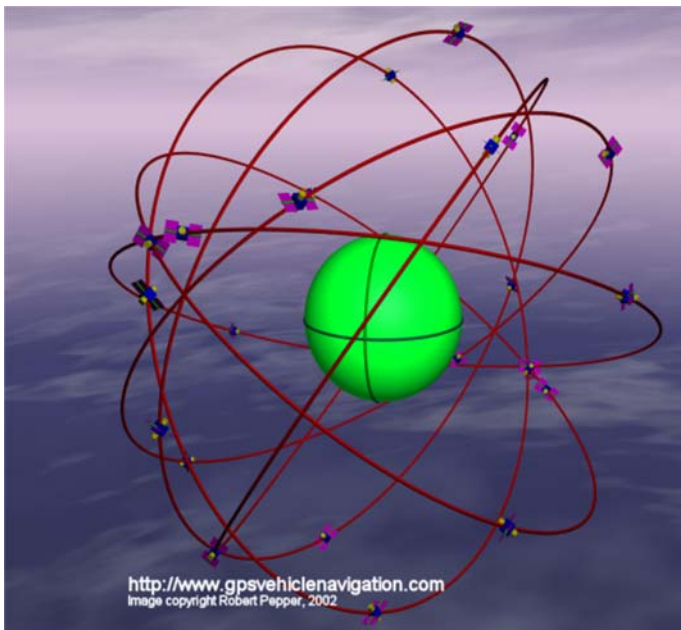


Figure 1: NAVSTAR GPS (© 2002 Robert Pepper)

The use of GPS may appear at first complicated, but the principle is quite simple.

GPS stands for Global Positioning System -a shorted term for NAVSTAR GPS (NAVigation Satellite Timing and Ranging) -a system for locating ourselves on earth. It is a satellite-based system created and controlled by the US Department of Defense, initially for military purposes but extended later for civilian usage. It consists of a constellation of 24 satellites (4 satellites in 6 orbital planes) orbiting at an approximate altitude of 20200 km every 12 hours.

Each satellite broadcasts two carrier waves in L-Band (used for radio) that travel to earth at the speed of light. The L1 channel produces a Carrier Phase signal at 575.42 MHz as well as a C/A and P Code. The L2 channel produces a Carrier Phase signal of 1227.6 MHz, but only P Code.

These codes are binary data modulated on the carrier signal. The C/A or Coarse/Acquisition Code (also known as the civilian code), is modulated and repeated every millisecond; the P-Code, or Precise Code, is modulated is repeated every seven days.

The GPS system works with a receiver (essentially a radio receiver) that acquires signal from satellites in order to locate its position geographically. The GPS receiver simply calculates the distance to the satellite by measuring the travel time of the signals transmitted from the satellite and multiplying it by the velocity.

$$\text{Distance} = \text{velocity (speed of light)} \times \text{Time}$$

The GPS receiver computes its position and time by making simultaneous measurements to the satellites. A signal from three satellites will sort out a 2-dimensional position or horizontal position. In order to get a 3 dimensional position (latitude, longitude and height) at least four satellites are needed within signal range.

Additional explanations of how more complex GPS function will be described further on. For more information on satellite signals consult:

[http://www.gmat.unsw.edu.au/snap/gps/gps\\_survey/chap3/311.htm#prn%20code](http://www.gmat.unsw.edu.au/snap/gps/gps_survey/chap3/311.htm#prn%20code)

## **2. Accuracy**

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There has been a misconception over the past years about the accuracy of GPS. It is true that for many years the US Department of Defense maintained intentional degradation of accuracy called Select Availability (S/A), a system for randomly degrading the accuracy of the signals being transmitted to civilian GPS receivers. However, the S/A was removed in May 2000.

Therefore, the accuracy of GPS should be a discussion based on the type of system (device) and its ability to eliminate error sources and not on the availability of reliable satellite signals.

Error sources are variable; here are some of the more commonly occurring:

- *Ionospheric delays.* The ionosphere is the upper layer of the atmosphere ranging in altitude from 50 to 500 km. It consists largely of ionized particles which cause a disturbing effect on the GPS signals. Since the density of the ionosphere is affected by the sun there is less ionospheric influence during night time. The ionosphere has also a cyclical period of 11 years which reaches a maximum and a minimum of the magnitude of its effect. For the current cycle, it reached its maximum in 1998 and its minimum in 2004.

In addition, low elevation satellite signals (anywhere between the horizon and up to 15 degrees above it) will be affected by a longer ionospheric delay as the distance the signal has to travel further and generally "noisier". In the more sophisticated GPS receivers an "elevation mask" can be set so that satellites below the mask are not used in computing position.

- *Satellite and receiver clock errors.* Each satellite is equipped with a very accurate clock which is continuously monitored by ground stations (US Department of Defense). Despite this, errors of precision can be up to one metre.  
Each receiver also has a clock but less accurate than the satellite's clock (its cost – around \$50000- and weight –20kg- would not be suitable for a land GPS).
- *Multipath error.* This is where more than one signal is received due to a reflection on other objects nearby (tall buildings or lakes) causing erroneous measurements.
- *Satellite geometry.* This means the relative position of the satellites at a specific moment. When satellites are located at wide angles relative to each other, the possible error margin is small. On the contrary, when satellites are grouped together or located in a line the geometry will be poor. The effect of the geometry of the satellites on the position error is called Geometric Dilution of Precision (GDOP). GDOP comprises the components shown below, which can be individually computed but are not independent of each other:

PDOP - Position Dilution of Precision (3-D)

HDOP - Horizontal Dilution of Precision (Latitude, Longitude)

VDOP - Vertical Dilution of Precision (Height)

TDOP - Time Dilution of Precision (Time)

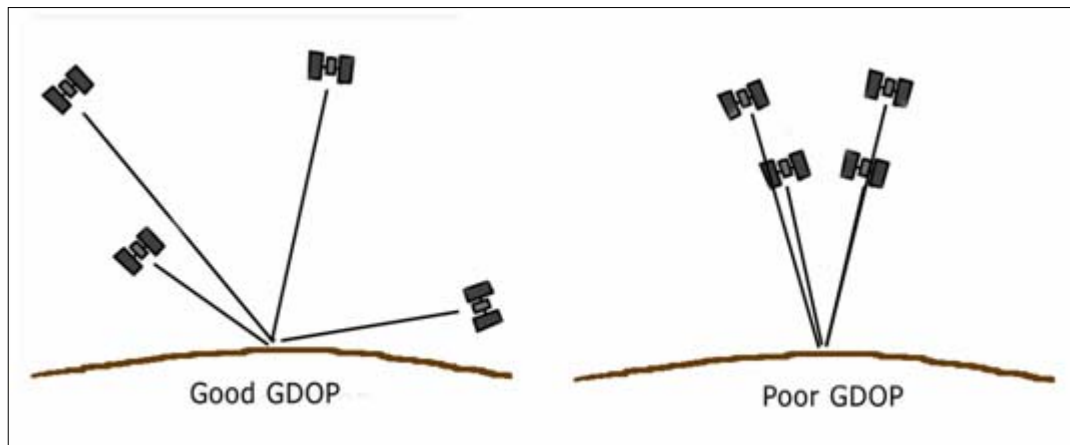


Figure 2: Representation of satellite geometry

### 3. Types of GPS

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Broadly speaking, there are three types of GPS, depending on the level of acquired accuracy.

- Hand-held GPS or Navigational (> c. 10m)
- Differential Code-Phase GPS (DGPS) (< 1m)
- Carrier-Phase GPS (< cm)

#### 3.1. Hand-held GPS

The Navigational or hand-held GPS consists of a single receiver, as easy to use as a mobile phone and around the same cost. It is the simpler technique of GPS but also the least accurate. The position calculated from the satellites' signal is frequently distorted by sources of error, which can degrade its accuracy by several metres (about 15 to 100 m).



Figure 3: Hand-held GPS

#### 3.2 Differential Code-Phase GPS (DGPS)

This differential measurement technique eliminates most of source errors, achieving results of sub-metre accuracy. It is obviously a more complex system than hand-held GPS - which is reflected in its substantially higher cost.



It consists of a base station and a rover receiver connected by a radio link. The base station or reference receiver when located at a known point can estimate what the ranges to the satellites should be and work out the differences between the computed and calculated range values. These differences are known as corrections. The base station transmits these real time differential corrections to the rover receiver (through the radio) so they can be used to correct its measurements. The DGPS corrections are transmitted in a standard format specified by the Radio Technical Commission Marine (RTCM).

Figure 4: Beacon Receiver

One of the powerful radio transmitters is the Radio Beacon. Set up around the coastline of many countries, these transmitters are located at old Radio Beacon stations, and have ranges of 100-150 miles. The DGPS signals are radiated on frequencies in the old MF (medium frequency) Beacon band, around 300 kHz. (For a detailed table with Radio Beacons available in the UK consult the Northern Light-House Board at:

<http://www.nlb.org.uk/dgps/dgpschart.htm>

The users of these transmitters were mainly marine craft navigators, but in some countries such as the UK -where the system transmitters cover the inland territories, they are now being operated by other users.

Another radio transmitter is the OmniSTAR Inc, working in a similar way to the beacons. It consists of a network of GPS base receivers around the world, which broadcast corrections to user receivers. Access to these corrections is available by subscription. For more information consult:

[www.omnistar.com](http://www.omnistar.com)

There are also new satellite-based differential systems, free of charge, such as WAAS, EGNOS and MSAS. The Wide Area Augmentation System (WAAS) is designed to provide a higher confidence level in autonomous GPS positioning for use in aviation. Unlike radio and satellite differential, WAAS corrects the atmospheric and orbital data so that autonomous calculations can better determine true position. But as the system is designed for aircraft, there are still some limitations for non aviation users.

The European Geostationary Navigation Overlay Service (EGNOS) is Europe's first step into satellite navigation, an initiative of the European Space Agency (ESA), the European Commission and Eurocontrol. For more information consult: <http://www.esa.int/export/esaNA/egnos.html>

The Japanese Multi-function Transport Satellite Augmentation System (MSAS), sponsored by the Japanese Civil Aviation Bureau, is designed to provide a satellite-system in some of the Far Eastern areas.

### **3.3 Carrier-Phase GPS**

This differential system achieves accuracy ranging from centimetre to millimetre, depending on the measuring technique. The Carrier-Phase GPS uses a minimum of two receivers simultaneously.



Figure 5: Carrier-Phase GPS

After an autonomous position is calculated using differential code methods, clock errors can be annulled by observing two satellites from two receivers by a method known as *double differencing*.

Once the better approximation of the position is known, a statistical calculation of phase intersections from multiple satellites can be used to resolve ambiguous results.

### *GPS Measuring Techniques*

There are several measuring techniques that can be applied when surveying with Carrier-Phase GPS. A brief description of the more commonly used is given below.

- *Static*  
Used for high accuracy (about 5mm + 1ppm), measuring long distances. It requires data to be collected for several hours on two receivers simultaneously to achieve the best results. The time of data collection is relative to the length of the baseline between the receivers.
- *Rapid Static*  
A form of static GPS which requires minutes instead of hours for satellite observation due to special ambiguity resolution techniques which use extra information. Accuracy can reach the centimetre on baselines less than 20km.

- *Real Time Kinematic*

This technique uses a radio to link so that the reference station broadcasts the data obtained from the satellites to the rover instantaneously. As data is transferred by radio, it limits baseline lengths and accuracy will be in the range of 1-5cm. Nevertheless, it is becoming the most popular technique as results are fast and co-ordinates are displayed in real time.

Most of GPS measurements techniques mention above collect data for post-processing, with the exception of Real Time Kinematic. Data collected by both receivers can be processed to obtain a better accuracy and/or to eliminate the noise caused by the real-time operation.

#### 4. Co-ordinate systems

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It is essential to mention some elements of geodesy as the study of the Earth's shape and its representation, for a better understanding of GPS survey and its relation to local mapping. The Earth is represented by various co-ordinate systems made to fit specific areas of its surface. Each mapping system is based on a local ellipsoid, designed to match the geoid. The ellipsoid is a mathematical surface that approximates the shape of the earth and the geoid is a theoretical surface which most closely matches mean sea level, both created to ease the representation of the Earth.

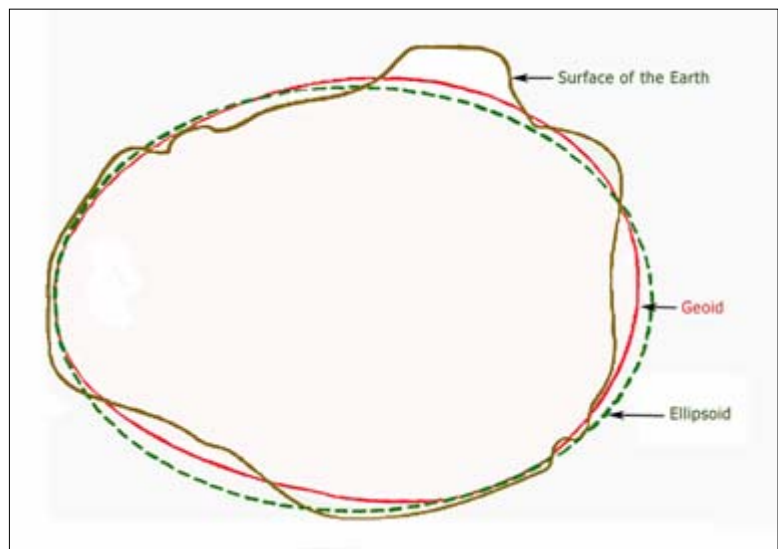


Figure 6: Geoid, ellipsoid and surface of the Earth (after Ordnance Survey ©Crown Copyright 2002. All rights reserved. License 100015565).

To provide grid co-ordinates, each local co-ordinate system will have been projected onto a plane surface, using the projection that better suits the area to be represented. A projection is the method used to represent the 3 dimensional curved surface of the spheroid on a plane surface.

## 4.1 OSGB36

In Great Britain, the National Grid is based on a Transverse Mercator Map projection. This projection is based on a cylinder that is slightly smaller than the spheroid and is then flattened out. The Easting and Northing axes are given a false origin just south-west of the Scilly Isles to ensure that all co-ordinates in Britain are positive. The false origin is 400 km west and 100 km north of the true origin on the central meridian at 49° N 2° W. To reduce the number of figures needed to give a National Grid reference, the grid is divided into 100 km squares which each have a two-letter code. National Grid positions can be given with this code followed by an Easting between 0 and 100 000 m and a Northing between 0 and 100 000 m.

All Great Britain height values above sea level are related to ODN, Ordnance Datum Newlyn, a traditional vertical co-ordinate system based on mean sea level tidal observations at Newlyn in Cornwall between 1915 and 1921.

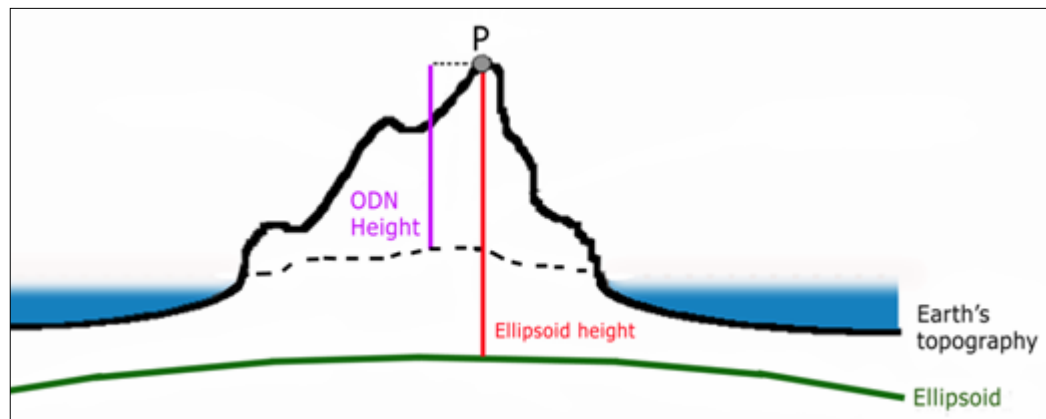


Figure 7: Representation of ellipsoidal height in relation to the ODN (after Ordnance Survey ©Crown Copyright 2002. All rights reserved. License 100015565).

For a detailed explanation to Great Britain co-ordinate system consult: <http://www.gps.gov.uk/guidecontents.asp>

## 4.2 GPS co-ordinates systems: WGS84 and ETRS89

Data received from GPS is related to a global co-ordinate system known as WGS84 or World Geodetic System 1984. GPS position will be expressed in latitude, longitude and ellipsoid height.

However, the WGS84 co-ordinate system will become unacceptable when using fixed points for land surveying. This is caused by the constant motion of continents with

respect to the WGS84 co-ordinate system: in Great Britain, it moves on a rate of 25mm per year away from the WGS84, meaning that in reality there are no fixed points.

For this reason, the European Terrestrial Reference System 1989 (ETRS89) is used as the standard precise GPS co-ordinate system throughout Europe. The ETRS89 is tied to the European continent, and hence it is steadily moving away from the WGS84 co-ordinate system.

If co-ordinates are required in a local mapping system, a transformation from GPS WGS84 or ETRS89 is needed.

For Great Britain, the most accurate transformations are the Ordnance Survey's OSTN02 and OSGM02 (available free from their website [www.gps.gov.uk](http://www.gps.gov.uk)). The OSGM02 geoid model will transform the ellipsoid height onto orthometric height, above sea level.

Furthermore, Great Britain's Ordnance Survey enables GPS users to tie their positions with the National Grid through the use of the National GPS network. The Ordnance Survey active GPS network consists of 32 permanently installed geodetic quality GPS receivers throughout Great Britain. Most locations in Great Britain are within 75 km of at least one active station, and several serve major urban areas. These active stations record dual-frequency GPS data 24 hours a day and their position is in relation to the ETRS89 co-ordinate system.

Additionally, there are 900 passive stations but with the disadvantage of having to be occupied by the user's own GPS receiver.

ETRS89 co-ordinates and full information from both active and passive stations are supplied by Ordnance Survey through their website ready to use for post-processing.

## **5. Use of GPS in Archaeology**

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GPS proves to be an excellent tool for surveying. In archaeological fieldwork, Global Positioning Systems may well be used for mapping find-spots, earthworks and other archaeological features without the need of conventional techniques (i.e. triangulation, off-set grids). The correct choice of GPS for a job depends upon the acceptable level of accuracy.

Many archaeologists are happy with the level of accuracy obtained by hand-held GPS (navigation grade) for archaeological field-work. Whilst this is an increasingly indispensable (and inexpensive) item of equipment for field reconnaissance and

walkover surveys- especially in the more remote regions (e.g. uplands) of the UK- it is clearly inappropriate for positioning evaluation trenches or conducting field-walk surveys, where tighter controls are required over each transect to be walked.

The level of accuracy may be hugely variable from one point to the next within a space of minutes. Experience in central and southern Britain shows that, at best, with fairly average satellite reception, the accuracy may be in the range between 5 to 8 metres. Not only this, but the operator will have no means of determining in which direction the point actually lies, and moreover, no means of re-calibrating the discrepancy. The consequence being a trench or transect in an entirely different place than required- often critical when attempting to target plotted cropmark features or geophysical anomalies. The potential loss of archaeological information rather goes without saying.

Where accuracy within a metre is acceptable, such as trench stake-outs, field-walking transects or recording sites at scales up to 1:2500, a Differential GPS is suitable. For more detailed recording, however, such as topographical surveys, excavation plans or grid layouts, a Carrier-Phase GPS is preferable. This will assure millimetric accuracy.

These are not the only applications of GPS in archaeological survey, but perhaps the more commonly used.

## **5.1 GPS versus Total Station**

Over the last decade, the Total Station Theodolite (TST) has become increasingly the preferred tool of archaeologists for setting out trenches, surveying sites or undertaking topographical surveys. Frequently in archaeological work, the TST becomes the less attractive option when compared to GPS:

- Where sites are remote or hard detail is poor, positioning may be unreliable.
- Two people are required unless a robotic system is used.
- Line of sight must be maintained between the instrument and prism.

On the contrary, the use of Global Positioning Systems in archaeological field-work has distinct advantages:

- There is no dependency on permanent landscape features.
- A single operator may carry out the survey.
- There is no dependency on a maintained line of sight between the base receiver and rover.

Additionally, both setting up and surveying time is considerably reduced. For example, two operatives using TST to set out 50 standard length archaeological trenches, to provide conventional ground coverage in rural conditions, may take two days to complete. The same coverage may be achieved by a single operative using GPS in half the time.

There are, however, some limitations with GPS that should be taken into account. As GPS receivers listen to signals from satellites they must have a clear view of the sky at all times. In proximity to tall buildings or in dense forest satellite signal may be poor.

## **5.2 Considering a GPS**

It's worth mentioning that accuracy comes with a price tag. The more expensive the GPS, the more accurate it will be.

Buying a hand-held GPS does not seem to be much of a problem, as nowadays prices are very reasonable and are widely available in most outdoor leisure stores. But if an accurate survey is needed then the use of a higher precision GPS should be considered.

As the purchase cost of a precision GPS may be outside the budget range of many companies, the alternative is to sub-contract a specialist. Most GPS surveying contractors are engineering-based, although there are a few companies that specialize in archaeological requirements.

There is also the possibility of hiring GPS equipment, but rates are still relatively high and its use by skilled operators is strongly recommended.

Whether subcontracting another company, buying your own equipment or hiring it, the use of GPS is an option to consider on an archaeological field survey.

## **6. Additional Information**

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For any additional information on GPS visit:

<http://www.trimble.com/gps>

<http://www.garmin.com/aboutGPS/manual.html>

[http://www.gmat.unsw.edu.au/snap/gps/gps\\_survey/principles\\_gps.htm](http://www.gmat.unsw.edu.au/snap/gps/gps_survey/principles_gps.htm)

For case studies applications of GPS on archaeological field work visit:

[http://www.english-](http://www.english-heritage.org.uk/Filestore/publications/pdf/free/GPS_archaeological_fieldsurvey.pdf)

[heritage.org.uk/Filestore/publications/pdf/free/GPS\\_archaeological\\_fieldsurvey.pdf](http://www.english-heritage.org.uk/Filestore/publications/pdf/free/GPS_archaeological_fieldsurvey.pdf)

For a detailed glossary, visit:

<http://www.garmin.com/aboutGPS/glossary.html>

For GPS archaeological contractors visit:

<http://www.souterrain.biz>

<http://www.northantsarchaeology.co.uk/>

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**How to take NGRs with two popular handhelds.** (from the Portable Antiquities Scheme Guide)

***How to plot a findspot or site using the Garmin Etrex:***

Once the receiver is switched on (power button) you will see the 'satellite page'.

When the receiver is ready to use (i.e. once it has tracked satellites) it will display the message 'ready to navigate'.

Next use the 'page' button to get to the 'menu' (4 clicks of the button).

Then select 'mark' using the 'enter' button.

The NGR of the findspot or site (e.g. TQ 12345 67890) will be shown below a man holding a flag.

Use the 'enter' button when 'ok' is highlighted if you want to save this 'waypoint'.

***How to plot a findspot or site using the Garmin Geko 201:***

Once the receiver is switched on (red button) you will see the 'satellite page'.

When the receiver is ready to use (i.e. once it has tracked satellites) it will display the message 'ready to navigate': it is best to wait until the 'accuracy' rating is 10 metres or lower before you try to plot a findspot or site.

Next use the 'page button' (two rectangles overlapping each other) to get to the 'menu page' (4 clicks of the button).

Then select 'mark' using the 'ok' button.

The NGR of the findspot or site (e.g. TQ 12345 67890) will be shown below a man holding a flag.

Press 'ok' if you want to save this.