The current state of non-destructive analysis

13 November 2016

David Saunders

The current state of non-destructive analysis

Why do we conduct analyses?

Basically – to understand better the materials from which objects are made in order to:

1. Shed light on their provenance, manufacture, use, social and cultural context, or collection history

2. Inform our approaches to future conservation treatment and our decisions concerning storage or display

The current state of non-destructive analysis

Shedding light on provenance, manufacture, context, etc.

to understand how something was made and the relation of making to appearance and function

to understand what the materials tell us about trade, exchange, beliefs and customs

to understand the extent to which the materials are a product of the social, political and physical environment in which the object was made or used

to understand whether an object really is what we believe it to be

The current state of non-destructive analysis

Informing our approaches to future conservation, etc.

to understand how they have deteriorated and might deteriorate in the future

to understand how we can store, display and transport them to minimize deterioration

to understand how we can treat them for the future

to understand how they have been treated in the past

The current state of non-destructive analysis

Terminology

We are generally dealing with valuable and often irreplaceable objects. In many cases even small changes to the object caused by analysis are deemed unacceptable

The descriptions, non-destructive, non-invasive and non-contact are often used, but what exactly do we mean by these terms?

The current state of non-destructive analysis

- Non-contact
  - The instrument does not need to make any contact with the object
- Contact
  - Non-invasive
    - No sample taken from the object, but instrument may touch object
    - (Usually) no damage to the area examined
  - Invasive
    - Non-destructive
      - Sample removed from object for analysis
      - Sample not destroyed during analysis and thus available in future
    - Destructive
      - Sample removed from object for analysis
      - Sample destroyed in the process

The current state of non-destructive analysis

Terminology

However, the term non-destructive is widely used to refer to non-invasive techniques in the previous analysis

We will use this definition –

i.e. a technique that does not involve the removal of a sample

The current state of non-destructive analysis

Direct and indirect analysis

Most investigations that investigate provenance, manufacture, use, etc. involve **direct** examination or analysis of the object (either through invasive or non-invasive methods)

For the conservation and future preservation of objects, we can divide investigations in to those that require **direct** interaction with objects and those that are **indirect**, examining the objects' past or future environment, or general methods of treatment

The current state of non-destructive analysis

Direct analysis

Examination and analysis of original and added components

Identification of changed or deteriorated materials

Investigating the effect of previous treatments

The current state of non-destructive analysis

Indirect analysis

Investigations of the susceptibility of objects to their environment (humidity, light, pollutants, etc.)

Analysis and monitoring of the environment surrounding objects

Analysis of materials for storage, display and packing

Analysing and testing conservation materials and techniques

The current state of non-destructive analysis

Selecting techniques

Over what area of the object does the technique operate?

What type of information is produced?

How representative are the results?

What is the cost of equipment or analysis?

The current state of non-destructive analysis

Over what area of the object does the technique operate?

Across a whole objects – or at least a large area / proportion

Point analyses

The current state of non-destructive analysis

Over what area of the object does the technique operate?

Whole object methods: imaging techniques

Visible light

Infrared reflectogram

'The Arnolfini Portrait', Jan van Eyck [NG 186]

Monday(am): analytical imaging

The current state of non-destructive analysis

Over what area of the object does the technique operate?

Whole object methods: imaging techniques

Visible light

UV-induced luminescence

Early Western Zhou bronze Fang Ding

Monday(am): analytical imaging

The current state of non-destructive analysis

Over what area of the object does the technique operate?

Whole object methods: imaging techniques

Visible light

Visible-induced luminescence

Fowling in the Marshes (*c.* 1350 BC) [BM EA 37977]

Monday(am): analytical imaging

The current state of non-destructive analysis

Over what area of the object does the technique operate?

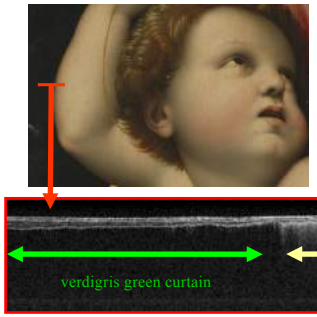
Whole object methods: scanning techniques

Thursday(am): XRF

The current state of non-destructive analysis

Over what area of the object does the technique operate?

Whole object methods: scanning techniques



The Madonna and Child, after Raphael [NG 929]

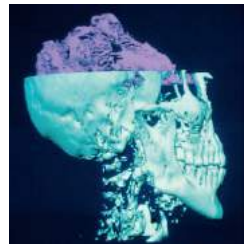
OCT depth profile

Monday(pm): OCT

The current state of non-destructive analysis

Over what area of the object does the technique operate?

Whole object methods: three-dimensional capture



Mummy, painted cartonnage and gilded mask of the priestess Tjentmutengebtiu [BM EA 22939]

Wednesday(pm): computed tomography (CT)

The current state of non-destructive analysis

Over what area of the object does the technique operate?

Whole object methods: three-dimensional capture

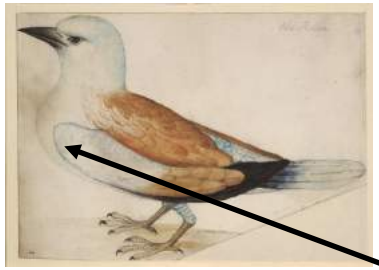
Hoa Hakananai'a [BM 1869,1005.1]

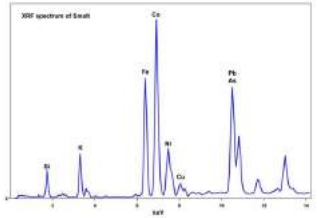
Wednesday(am): 3D imaging

The current state of non-destructive analysis

Over what area of the object does the technique operate?

Point analyses





Smalt

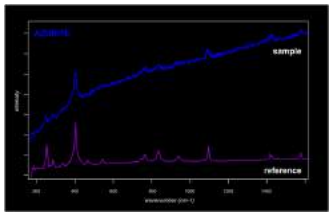
John White *Common roller* [BM1906,0509.1.64]

Thursday(am): XRF

The current state of non-destructive analysis

Over what area of the object does the technique operate?

Point analyses



Azurite

John White *Common roller*
[BM1906,0509.1.64]

Thursday(am): Raman

The current state of non-destructive analysis

Over what area of the object does the technique operate?

Point analyses

The Crucifixion of Christ
[BM Af1893,1112.1]

Thursday(am): FTIR

The current state of non-destructive analysis

Over what area of the object does the technique operate?

Point analyses

Monday(am): FORS

The current state of non-destructive analysis

What type of information is produced?

Structural information (biological/petrographic/metallurgical microscopy, boroscopy, imaging techniques, radiography, SEM, computed tomography)

Elemental information (SEM/EDX, XRF, PIXE, AAS, etc.)

Molecular information (Raman or FTIR spectroscopy, XRD, GC-MS, HPLC or other chromatographic techniques)

Dating (radiocarbon dating, stable isotope analysis, etc.)

The current state of non-destructive analysis

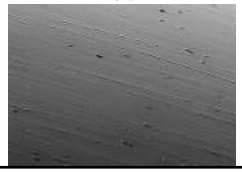
What type of information is produced?

Structural information

Crystal skull (first documented in New York in 1897)

Hand tool polishing marks on Mixtec crystal goblet

Wheel-made marks on the crystal skull



The current state of non-destructive analysis

What type of information is produced?

Structural information

Visible light

Infrared reflectogram

Leather manuscript in Coptic containing magical spells for favour, honour and passion [BM 10434]

The current state of non-destructive analysis

What type of information is produced?

Elemental information

The Sedgeford Torc, gold/silver, Iron Age 200–50 BC
Found May 1965

The Sedgeford Torc Terminal gold/silver Iron Age 200–50 BC
Found March 2004

The current state of non-destructive analysis

What type of information is produced?

Elemental information

Torc	Gold %	Silver %	Copper %
Terminal	53	45	2.2
Collar	49	50	1.5
Wire	54	46	0.5

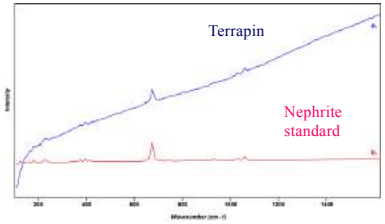
Terminal	Gold %	Silver %	Copper %
Terminal	53	46	1.5
Collar	49	50	1.0
Wire	53	45	2.3

The current state of non-destructive analysis

What type of information is produced?

Molecular information

Terrapin found in 1803 in cistern within Mughal palace at Allahabad, probably early seventeenth century

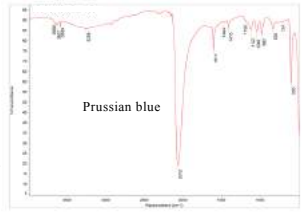


Raman spectroscopic analysis confirms that the terrapin is made of nephrite, one of the two varieties of true jade

The current state of non-destructive analysis

What type of information is produced?

Molecular information



The Crucifixion of Christ
[BM Af1893,1112.1]

The current state of non-destructive analysis

How representative are the results?

Point information on the surface (Raman or FTIR spectroscopy, XRF, XRD, PIXE)

Stratified point information (biological/petrographic/metallurgical microscopy, SEM, XRD, FTIR, GC-MS, HPLC and other chromatographic techniques)

Surface imaging or mapping (microscopy, ultraviolet fluorescence and other imaging techniques including hyperspectral imaging)

Collapsed 3D information (X-radiography, neutron radiography)

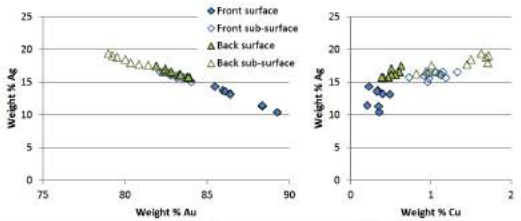
3D information (computed tomography, laser scanning, OCT)

The current state of non-destructive analysis

How representative are the results?

Point information on the surface

Inscribed strip K550 from the Staffordshire Hoard



Area analysed	No of analyses		Wt% Au	Wt% Ag	Wt% Cu
Front decorated sheet surface	8	Average	87.1	12.6	0.3
		Standard Deviation	1.40	1.40	0.09
Front decorated sheet sub-surface	12	Average	83.0	16.0	1.0
		Standard Deviation	0.56	0.47	0.16
Back base sheet surface	8	Average	83.2	16.3	0.5
		Standard Deviation	0.74	0.67	0.09
Back base sheet sub-surface	10	Average	80.8	17.8	1.4
		Standard Deviation	1.41	1.09	0.36

The current state of non-destructive analysis

How representative are the results?

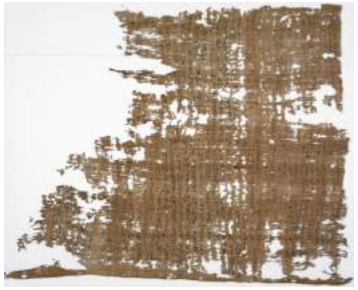
Stratified point information

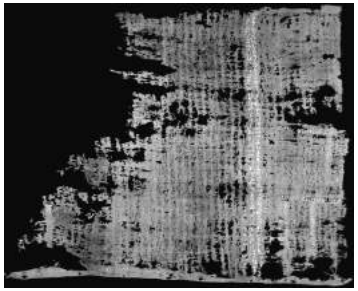
The Raising of Lazarus,
Sebastiano del Piombo
[NG 1]

The current state of non-destructive analysis

How representative are the results?

Surface imaging or mapping





Visible light

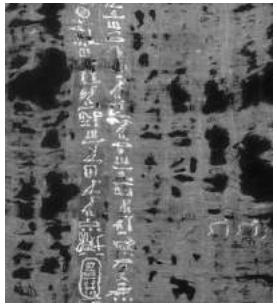
After image processing

The Norwich Shroud
Castle Museum, Norwich
[1927,31,50]

The current state of non-destructive analysis

How representative are the results?

Surface imaging or mapping



Visible light

After image processing

The Norwich Shroud
Castle Museum, Norwich
[1927,31,50]

The current state of non-destructive analysis

How representative are the results?

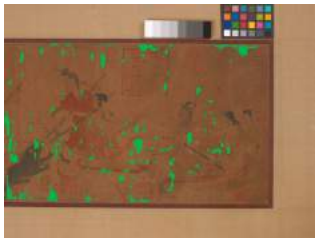
Surface imaging or mapping

The Admonitions Scroll (main painted scenes)
Tang dynasty (CE 618–906)

The current state of non-destructive analysis

How representative are the results?

Surface imaging or mapping



Large silk repair areas

Small silk repair areas

The Admonitions Scroll (main painted scenes)
Tang dynasty (CE 618–906)

The current state of non-destructive analysis

How representative are the results?

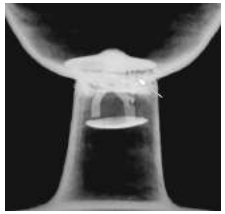
Collapsed 3D information

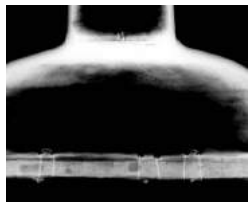
Mid-sixteenth century ewer, enamelled in black,
white and blue [BM1885,0420.17]

The current state of non-destructive analysis

How representative are the results?

Collapsed 3D information





Detail of hidden wires

Mid-sixteenth century ewer, enamelled in black,
white and blue [BM1885,0420.17]

The current state of non-destructive analysis

How representative are the results?

Collapsed 3D information

Mid-sixteenth century ewer, enamelled in black,
white and blue [BM1885,0420.17]

The current state of non-destructive analysis

How representative are the results?

Stratified or 3D information

Nineveh, *c.* 645 BC
Hunting with hounds
[BM ME118915]

The current state of non-destructive analysis

How representative are the results?

Stratified or 3D information

Nineveh, *c.* 645 BC
Hunting with hounds
[BM ME118915]

The current state of non-destructive analysis

How representative are the results?

Stratified or 3D information

Nineveh, *c.* 645 BC
Hunting with hounds
[BM ME118915]

The current state of non-destructive analysis

How representative are the results?

Stratified or 3D information

Nineveh, *c.* 645 BC
Hunting with hounds
[BM ME118915]

The current state of non-destructive analysis

How representative are the results?

Stratified or 3D information

Mummy and painted cartonnage of the priest Nesperennub [BM EA 30720]

Image: ©National Hospital for Neurology and Neurosurgery

The current state of non-destructive analysis

How representative are the results?

Stratified or 3D information

Mummy and painted cartonnage of the priest Nesperennub [BM EA 30720]

The current state of non-destructive analysis

How representative are the results?

Stratified or 3D information

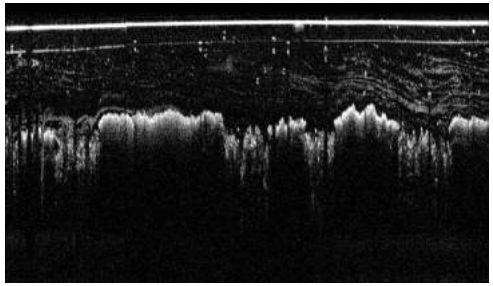
Persian tile [BM G.313]

The current state of non-destructive analysis

How representative are the results?

Stratified or 3D information

Persian tile [BM G.313]

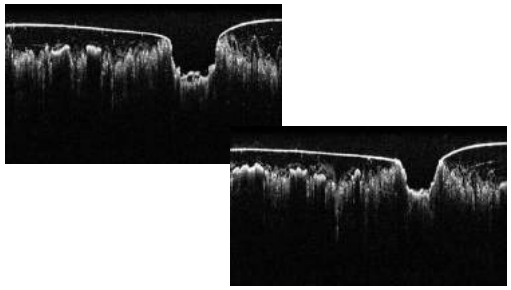


OCT image of a glazed area on tile G.313 (horizontal axis exaggerated)

Note mixing of the glaze and body colour

The current state of non-destructive analysis

Persian tile
[BM G.313]



OCT image of a glazed area on tile G.313
(horizontal axis exaggerated)

Scans across a 'hole' in the glaze

The current state of non-destructive analysis

What is the cost of equipment or analysis?

The current state of non-destructive analysis

What is the cost of equipment or analysis?

Routine low-cost methods (microscopy, ultraviolet fluorescence and some other imaging techniques)

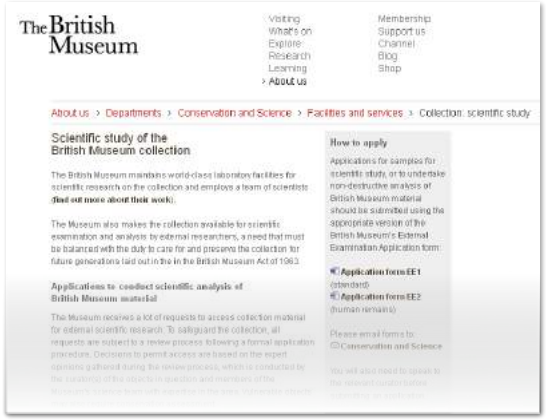
Basic museum 'toolkit' (biological/petrographic/metallurgical microscopy, FTIR, SEM/EDX, Raman spectroscopy, XRF, XRD, GC-MS, HPLC, X-radiography) [EU-ARTECH MOLAB initiative]

Specialist techniques through collaboration (PIXE, computed tomography, neutron radiography, SIMS, PGAA, etc.)

Bought in services (radiocarbon dating, stable isoptope analysis, etc.)

The current state of non-destructive analysis

Non-destructive versus destructive: a risk vs benefit analysis



The current state of non-destructive analysis

Non-destructive versus destructive: a risk vs benefit analysis

Sample size / visibility / aesthetic impact

Quality of questions

Amount of information or knowledge gained

Significance / representativeness of results

Researcher experience

Certainty of obtaining a result

Novelty of method

Long term impact on object (positive and negative)

Effect on future research

The current state of non-destructive analysis

Non-destructive versus destructive: a risk vs benefit analysis

Sample size / visibility / aesthetic impact

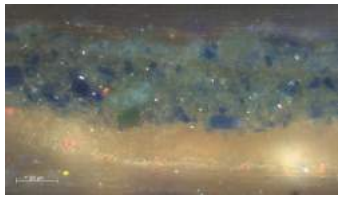
The current state of non-destructive analysis

Non-destructive versus destructive: a risk vs benefit analysis

Quality of questions

Amount of information or knowledge gained

Significance / representativeness of results



The current state of non-destructive analysis

Non-destructive versus destructive: a risk vs benefit analysis

Significance / representativeness of results

The Large Dort, Aelbert Cuyp [NG 961]

Surface XRF analysis

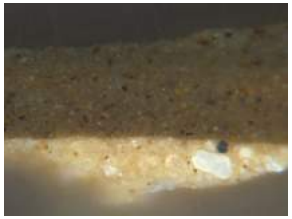
Ca, Fe, P, Si, Al

The current state of non-destructive analysis

Non-destructive versus destructive: a risk vs benefit analysis

Significance / representativeness of results

The Large Dort, Aelbert Cuyp [NG 961]



Yellow lake with a chalk substrate	Ca
Vivianite (blue hydrated iron phosphate)	Fe, P
Yellow and brown earths	Fe, Si, Al …
Bone black (mainly calcium phosphate)	Ca, P

The current state of non-destructive analysis

Non-destructive versus destructive: a risk vs benefit analysis

Researcher experience

Certainty of obtaining a result

Novelty of method

The current state of non-destructive analysis

Non-destructive versus destructive: a risk vs benefit analysis

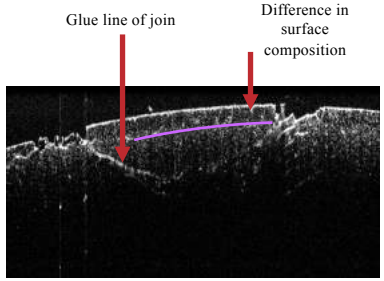
Long term impact on object (positive and negative)

Effect on future research

The current state of non-destructive analysis

Beyond single techniques

Blue glass scarab inlay, New Kingdom [BM 1891,0509.35]

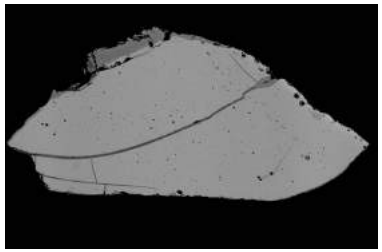


OCT image across re-attached section of scarab
10 mm x 1.6 mm
(horizontal axis exaggerated)

The current state of non-destructive analysis

Beyond single techniques

Blue glass scarab inlay, New Kingdom [BM 1891,0509.35]



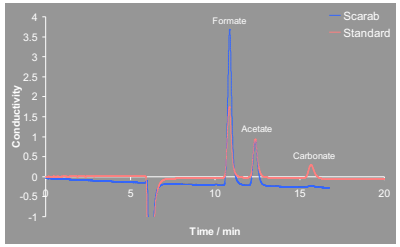
Back scattered SEM image of mounted glass fragment

The current state of non-destructive analysis

Beyond single techniques

Blue glass scarab inlay, New Kingdom [BM 1891,0509.35]

Ion Exclusion Chromatography: heptafluorobutyric acid eluent

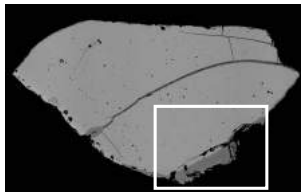


The current state of non-destructive analysis

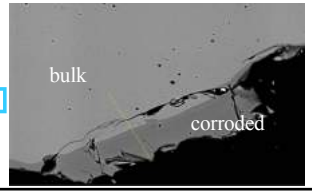
Beyond single techniques

SEM-EDX analysis of scarab inlay

	Corroded Glass	Bulk Glass
SiO_2	83.5	68.1
Na_2O	5.83	23.6
K_2O	1.53	0.87
CaO	1.72	1.25
MgO	1.08	0.72
Al_2O_3	0.56	0.42
Fe_2O_3	0.15	0.34
Mn_2O	0.38	0.22
CuO	2.24	2.05



Scanning electron microscope image of mounted glass fragment



The current state of non-destructive analysis

Beyond single techniques

	Scarab Bulk Glass	Nesikhons * Bulk Glass
SiO_2	68.1	62.6 – 69.1
Na_2O	23.6	18.2 – 23.4
K_2O	0.87	0.6 – 0.9
CaO	1.25	1.3 – 4.8
MgO	0.72	0.3 – 1.2
Al_2O_3	0.42	2.1 – 3.1
Fe_2O_3	0.34	0.5 – 1.0
Mn_2O	0.22	–
CuO	2.05	0 – 1.7
SO_3	1.29	2.6 – 3.2
Cl	1.10	1.9 – 2.3

Schlick-Nolte, B. and Werthmann, R., 'Glass Vessels from the Burial of Nesikhons', *Journal of Glass Studies* 45 (2003) 11–34.

The current state of non-destructive analysis

Beyond single techniques

"A pretty little vase of mottled black and white glass (British Museum 17043) which formed part of the funerary equipment of Nesi-khensu, fell to pieces in consequence of the salt which it had by some means absorbed"

Budge, E.A.W., *The Mummy*, 2nd edn, Cambridge University Press, Cambridge (1925).

故宮博物院
THE PALACE MUSEUM