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New light on the personal identification of a skeleton of a member of Sir John Franklin's last expedition to the Arctic, 1845

S. Mays [a,*], A. Ogden [b], J. Montgomery [b], S. Vincent [a], W. Battersby [c], G.M. Taylor [d]

[a] Archaeological Science, English Heritage, Fort Cumberland, Eastney, Portsmouth PO4 9LD, UK
[b] Department of Archaeological Sciences, University of Bradford, Bradford BD7 1DP, UK
[c] Cleaver Square, London, UK
[d] Division of Microbial Sciences, Faculty of Health and Medical Sciences, University of Surrey, Guildford GU2 7TE, UK

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ABSTRACT

In 1845, an expedition, commanded by Sir John Franklin, set out to try and discover the north-west passage. All 129 men on this ill-fated voyage perished. Over the years, skeletal remains associated with the final throes of the expedition have been located on and near King William Island, Nunavut, in the Canadian arctic. In general, even a tentative personal identification for these remains has proved impossible. An exception is some skeletal remains that were recovered in 1869 and brought back to England and interred beneath the memorial to the Franklin expedition in Greenwich. In the 19th century, these were tentatively identified as of one of HMS *Erebus*'s lieutenants, Henry Le Vesconte, a conclusion that has been widely accepted in studies of the Franklin voyage. Renovations to the monument in 2009 provided an opportunity for scientific examination of the remains, and to re-evaluate the personal identification made nearly 140 years before. The current work, which is the first modern scientific analysis of a fairly complete skeleton associated with the Franklin voyage, describes the remains and the artefacts interred with them, discusses the pathological conditions present, and evaluates the personal identification using osteological techniques and isotope geochemistry. Results indicate that the remains are of an adult male of European ancestry. Although some writers have suggested that scurvy or tuberculosis may have been important causes of morbidity and mortality on the Franklin expedition, osteological analysis and, in the case of tuberculosis, DNA analysis, provided no evidence for their presence in these remains. Isotopic studies indicate that the personal identification as Le Vesconte is unlikely to be correct. From the isotopic results and forensic facial reconstruction, HDS Goodsir, an assistant surgeon on the expedition, appears a more likely identification, but the results do not allow a firm conclusion.

1. Introduction

In May 1845, two ships, HMS *Erebus* and HMS *Terror*, embarked from Greenhithe, England, bound for the Canadian arctic. The expedition, from which none would return alive, was under the command of Sir John Franklin, and its purpose was to pass from the north Atlantic to the Pacific via the North-west Passage. The expedition over-wintered at Beechey Island in the Canadian high arctic (Fig. 1). The following summer, the ships sailed south and west in search of the Passage. On 12 September 1846, the ships were beset in ice north-west of King William Island. The ice failed to release them the following summer. A note left in a canister on King William Island in May 1847 indicated all was well, but an addendum of April 1848 indicated that 24 men, of whom nine were officers, had died by that time. In April 1848, the 105 survivors deserted the ships and subsequently perished whilst attempting to reach safety overland via the Back River (Cyriax, 1939; Owen, 1978; Beattie and Geiger, 1987).

In the years following the loss of the expedition, many search parties set out to try and ascertain its fate (Ross, 2002). Some of these located skeletal remains, on the southern and western coasts of King William Island and on the adjacent mainland. Subsequent expeditions researching the Franklin disappearance also sometimes encountered human remains, as occasionally did those travelling the region for other purposes. Between 1859 and 1949 skeletal remains representing at least 30 individuals were discovered (Gibson, 1932; Cyriax, 1939, 1951; Beattie and Geiger, 1987), the great majority being scattered surface finds rather than deliberate burials. Other than helping to trace the route of the final

* Corresponding author. Tel.: +44 02392 856779; fax: +44 02392 856701.
E-mail address: simon.mays@english-heritage.org.uk (S. Mays).

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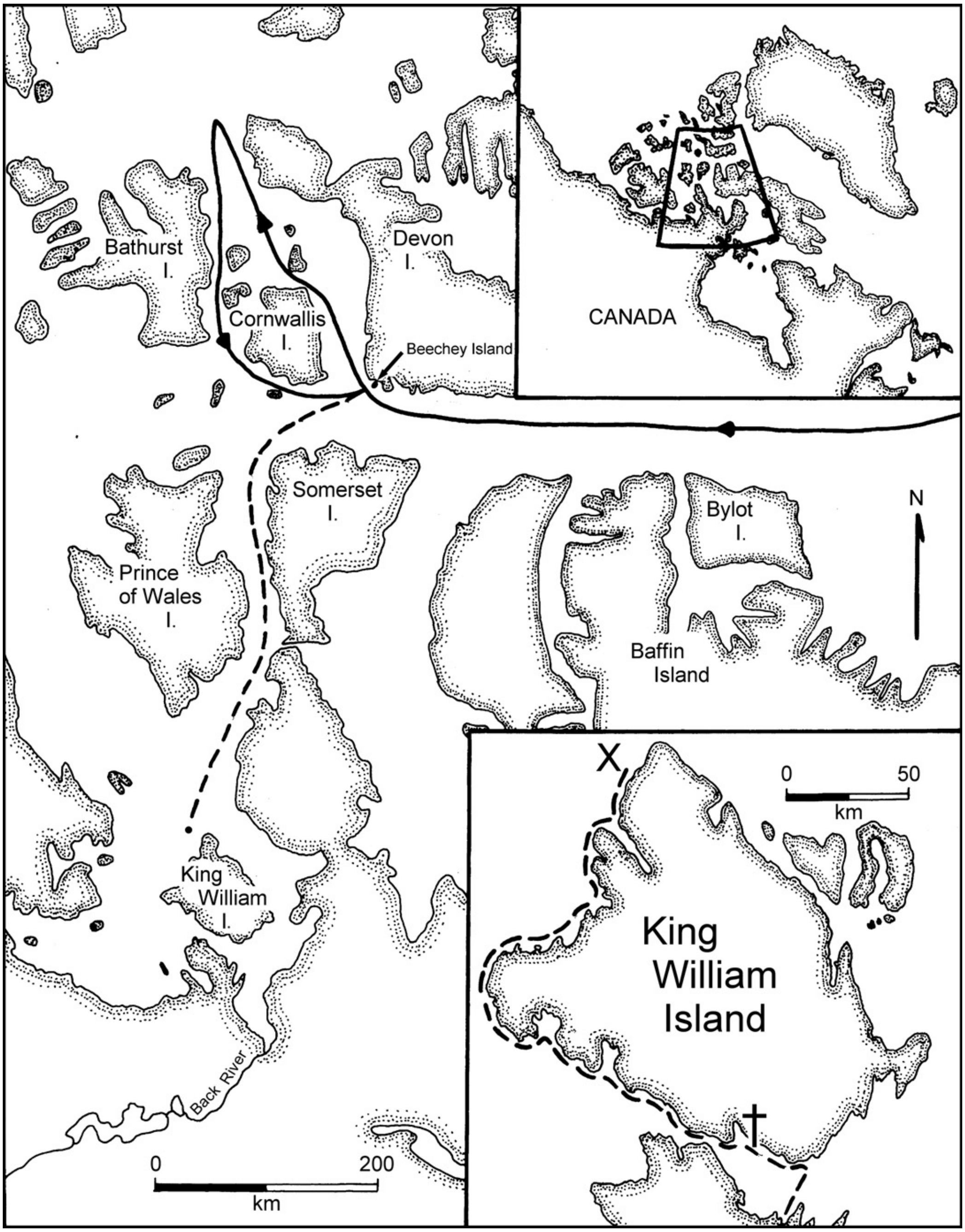

Fig. 1. Canadian archipelago, showing Franklin's 1845 route (solid line), and presumed 1846 route (dashed line). In the inset, X marks the location of the ships when deserted in April 1848, the dashed line is the presumed final journey of the expedition on foot from the ships toward the Canadian mainland. The cross marks the approximate location of the grave from whence the current remains were recovered by Hall in 1869.

march of Franklin's men, these remains were felt to have little further value. Most were simply gathered together and buried in the locale in which they were found, and in general they cannot now be located (Beattie and Geiger, 1987).

The first modern studies of human remains from the Franklin expedition took place in the 1980s. A team, led by Owen Beattie, studied the frozen bodies of John Torrington, William Braine and John Hartnell, three men who died in the first winter of the expedition and who were buried in the permafrost on Beechey Island (Amy et al., 1986; Notman et al., 1987; Beattie and Geiger, 1987). In the 1980s and 1990s, surface scatters of skeletal remains representing at least 20 individuals were located on the southern and western coasts of King William Island, apparently representing those who died following the desertion of the ships in April 1848. Osteological study of these remains (Beattie, 1983; Beattie and Savelle, 1983; Keenleyside et al., 1997) revealed that some bore cut-marks consistent with Inuit accounts of cannibalism during the final throes of the expedition. Lead levels in the bones were high (Beattie, 1985; Kowal et al., 1989, 1991; Keenleyside et al., 1996), as they were in tissue from the Beechey Island bodies (Amy et al., 1986; Kowal et al., 1991), and this has helped advance theories that lead poisoning, from canned foods (Beattie and Geiger, 1987; Kowal et al., 1989, 1991) or other sources (Battersby, 2008), contributed to the expedition's loss.

The current work focuses on a skeleton of a member of the Franklin expedition recovered from King William Island in 1869

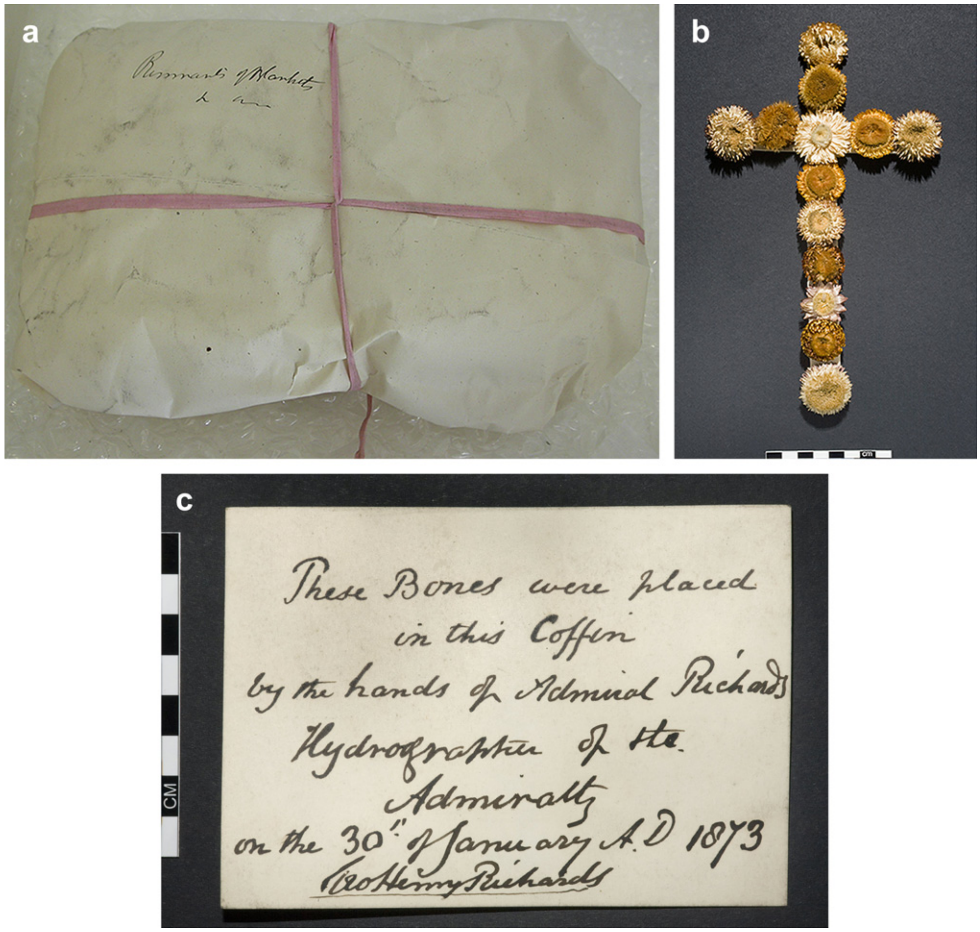

Fig. 2. Some of the artifacts interred with the bones in the Franklin Memorial. (a) Paper parcel, labelled "Remnants of blankets" containing textile fragments. (b) The floral tribute. (c) The note recording the deposition of the remains beneath the Franklin Memorial in 1873.

and interred beneath the Franklin Memorial at Greenwich Old Royal Naval College, London. The bones were recovered from the arctic by an American adventurer, Charles Francis Hall. He headed north in 1864 on a five-year mission to find traces of Franklin's men. The Inuit told him of a grave they had discovered near the mouth of the Pfeffer River on King William Island. When discovered by the Inuit, it was apparently a shallow burial beneath stones of a supine, clothed body arranged with the hands laid on the chest; the body was still fleshed. The Inuit had disturbed the grave searching for wood or metal artefacts. Guided to the find-spot by the Inuit in May 1869, Hall found the soft tissue largely gone, leaving little but bone (Woodman, 1991, p. 159). He gathered up the bones, together with fragments of textiles, and brought them to James C. Brevoort in New York, one of his expedition's patrons. He in turn consigned them to Admiral Inglefield of the British Royal Navy who brought them to England in 1872, passing them into the care of Admiral Richards, Naval Hydrographer (Owen, 1978, pp. 421–422). Both Inglefield and Richards believed the remains to be of an officer, on account of the remnants of a silk undervest in which the body had been clothed and a gold filling which they noticed in one of the teeth. In order to try and make further progress with the identification, the remains were sent to Thomas Henry Huxley, one of the foremost biologists of the age and now best known as a public defender of Darwin's ideas on evolution. In July 1872, Huxley submitted a four-page hand-written forensic report on the bones (Huxley, 1872). He identified the skeleton as a male, no less than 5′10″ (178 cm) in height and at least 30 years old, with a prominent nose and chin and square-set jaw. As well as the gold filling, he noted a missing lateral incisor in the maxilla. In a covering letter to Inglefield, Huxley expressed the hope that these observations might lead to the identification of its "unfortunate owner". Barely two weeks later, the Admiralty declared the remains as those of HTD Le Vesconte, a lieutenant aboard HMS *Erebus*. The process by which this identification was arrived at is unclear, but Richards felt able to state that he had "little doubt that it is Le Vesconte" (Owen, 1978, p. 422). The remains were interred beneath the Franklin Memorial in January 1873. Despite Richards' conviction that they were Le Vesconte's, the inscription on the memorial refers simply to "one of Franklin's companions".

In 2009, renovations to the Painted Hall at the Old Royal Naval College in Greenwich (Lewis-Jones, 2009) necessitated disinterment of the bones purported to be Le Vesconte's, and this provided an opportunity for a first modern scientific examination of a fairly complete skeleton of one of the members of Sir John Franklin's last expedition. The purposes of the current paper are threefold. Firstly, to describe the remains and the artefacts associated with them. Secondly, to evaluate any pathological lesions, and in particular to investigate any conditions that might have been associated with cause of death. Particular attention is paid toward investigating signs of scurvy and tuberculosis, as (in addition to lead poisoning) these have been suggested by previous writers as significant causes of morbidity and mortality on the expedition. Lead levels in the remains will be the subject of a future research paper. The third objective is to evaluate the likelihood that the remains are indeed Le Vesconte's.

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2. The interment beneath the Franklin Memorial

The bones were deposited beneath the Franklin Memorial in 1873 in a triple-shelled casket, made up of a pine box encased in lead and placed within an oak casket. The dimensions of the outer casket are 94 × 23 × 33 cm. Triple case coffins were common in 19th century church vault burials (Litten, 1987, p. 100), and this appears to be an imitation of a high status coffin in miniature. The bones were placed in the inner pine casket wrapped in linen. Also present in the pine casket were several other items. A paper parcel weighing 391 g labelled "Remnants of blankets" (Fig. 2a) contained fragments of textiles that Hall had collected with the bones. Fragments of textile were also found adhering to some of the skeletal remains. Adhering to some of the textile fragments were many wood shavings. These appear to represent packing material used when the remains were transported across the Atlantic in 1872 (Richards, 1872).

The textile remnants were the only items in the casket, other than the bones, to have come from the grave in the arctic; those listed below were all placed within the pine casket before its interment beneath the Franklin memorial. There was a tribute of dried flowers (*Helichrysum bracteatum*) stitched upon card (Fig. 2b). Floral tributes began to be popular in Victorian funerals from the 1860s (Litten, 1987, p. 170), but rarely survive in burial contexts. There was a section of a map, backed in linen, and apparently included as packing, of the Louisiade Archipelago in the western Pacific, measuring approximately 90 cm × 35 cm and clearly cut from a larger map. There was also a complete map in paper entitled "discoveries in the Arctic Sea up to MDCCCLIX" bearing the legend "London published according to the Act of Parliament at the hydrographic office of the Admiralty Jan 20, 1855 additions to 1860 June 69". Finally there was a note from Admiral Richards recording the deposition of the remains (Fig. 2c).

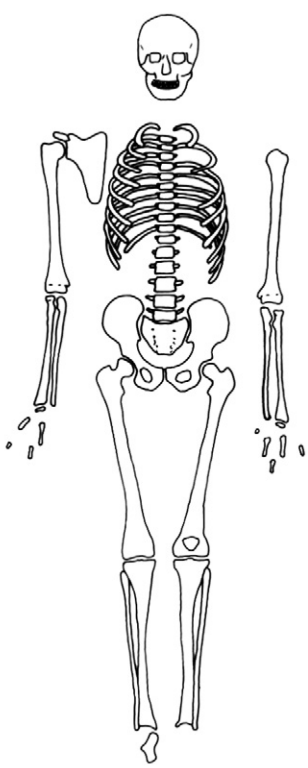

Fig. 3. Skeletal elements present.

Fig. 4. Human hair adhering to textile fragments.

3. Osteological observations

3.1. The condition of the remains

There is no duplication of skeletal elements among the remains, and the morphology and condition of the bones strongly suggests that they all come from one individual. The skeletal elements present are depicted in Fig. 3. Some bones bear soft tissue remnants. There were remnants of articular cartilage on some joint surfaces and substantial remains of disc material on most vertebral bodies. There were also minor unidentified dried soft tissue adhesions on some other bones. Some human hair was found adhering to remains of the textiles associated with the burial (Fig. 4). Some clumps of hair were bonded to the textile remains by dark brown/black concretions which appeared to represent remains of decayed soft tissue.

The gross preservation of the bone was generally good with no erosion of surfaces. Exceptions were some ribs and parts of the pelvic bones which showed surface striation and longitudinal cracking. The left 7th and 8th ribs showed puncture marks at their sternal ends, suggestive of carnivore gnawing (Fig. 5). Keenleyside et al. (1997) reported that the scattered bones they examined from King William Island that lay on the surface had a "bleached and weathered" appearance and many had suffered the attention of carnivores. In bones that were only partially exposed on the surface, those parts that were covered by soil were in excellent condition and several of them had dried soft tissue adhering to them (Keenleyside et al., 1997). The state of the current remains is therefore consistent with most of them being covered by soil with the exception of some parts, particularly the rib ends. The state of the bones is consistent with Hall's account of a shallow grave whose contents had attracted the attention of arctic foxes (Woodman, 1991, p. 159). No cut-marks or other evidence for anthropogenic

Fig. 5. Sternal end of left 8th rib, showing two puncture marks consistent with carnivore gnawing.

post-mortem modification were found on the bones. That the body was accorded formal burial suggests that the death occurred before the final throes of the expedition when the dead seem to have been left unburied and, in some cases, cannibalised (Beattie, 1983; Keenleyside et al., 1997).

3.2. Sex and age at death

Pelvic (Phenice, 1969; Brothwell, 1981) and cranial (Brothwell, 1981) morphology indicates male sex. All epiphyses were fused and the third molar roots were complete, indicating adult status. The pubic symphysis shows Brooks and Suchey (1990) phase 4, suggesting an age of about 23–59 years. The sternal end of the right fourth rib gave a combined component score of 7 using the methodology of Işcan et al. (1984), which in a 19th century group of known age at death corresponded to an age of about 20–68 years (Molleson and Cox, 1993, p. 177). The auricular surfaces show phase I as defined by Falys et al. (2006), which corresponded to an age span on 17–69 years in a 19th century skeletal sample of known age (ibid.). Dental wear is negligible, with only minor wear facets visible on the enamel. The only suggestion of degenerative joint disease is at the articulation between the odontoid process of the axis vertebra and the anterior arch of the atlas where there is minor marginal lipping. There is a little ossification of the ligamentum flavum. Arriving at any very precise estimate of age at death from these observations is difficult, but an age of about 30–40 years seems most likely.

3.3. Ancestry, stature and physique

Cranial morphology classifies the ancestry of the individual as White using the methodology of Giles and Elliot (1962), Gill (1984) and Bass (1987, p. 83). CRANID (Wright, 2009) groups the individual most closely with European crania.

The equation of Trotter and Gleser (1958) for the fibula and femur for White males gives an estimated height of 173.9 ± 3.6 cm, or approximately 5′8.5″. The estimates from the other long-bones lie within 0.7 cm of this, suggesting that the limb bone proportions resemble those in Trotter and Gleser's White male reference sample. This stature is rather tall by 19th century British standards. Measurements on living subjects showed that at that time mean male stature varied according to social class, ranging from 166.2 cm among 'habitual criminals' to 175.0 cm among 'the most favoured classes' (Morant, 1950; Johnson and Nicholas, 1995). The stature of seamen was not systematically recorded in naval records, but a private survey done by a 19th century captain of men aboard his ship gave an average of 5′5″ (165 cm) (Boston et al., 2008, p. 36). Mean stature estimated from skeletal remains of 88 seamen buried at the Royal Naval Hospital Greenwich was 167.9 cm (ibid.).

Bi-iliac breadth is a useful measure of body breadth, and one which can be directly compared in skeletal and living populations (Ruff and Walker, 1994). Bi-iliac breadth, taken using the methodology of Tague (1989), was 25.2 cm. To our knowledge, bi-iliac breadth data are not available for 19th century populations, but a study of a large sample of living US White males in 1946 gave a mean of 29 cm and a standard deviation of 2 cm (White, 1956). Allowing 0.5 cm for soft tissue (Ruff, 1991, 1994) suggests an *in vivo* bi-iliac breadth in the current case of about 25.7 cm. This is nearly 2 standard deviations below the mean of the mid-20th century US White population who were of similar stature (mean 174.2 cm – White, 1956). The bi-iliac breadth: stature ratio is 0.148. This is below the means given for various recent European populations by Ruff (1991). The stature and bi-liac breadth therefore suggest an individual who was rather tall and slender.

3.4. Skeletal anomalies

The dentition shows agenesis of the left maxillary lateral incisor, and of both mandibular third molars. In populations of European ancestry, the frequency of missing lateral maxillary incisors is about 1–2% (Polder et al., 2004; Harris and Clark, 2008). About 11% of individuals of European ancestry have one or more missing mandibular third molars (Harris and Clark, 2008), although the prevalence of missing third molars is elevated in those who have missing maxillary lateral incisors (Garib et al., 2010). Agenesis of teeth has a genetic component (Nieminen, 2009). In the cranium, the temporal styloid processes are absent bilaterally. This anomaly has a frequency of less than about 2% (Başekim et al., 2005; Onbas et al., 2005; Ramadan et al., 2007).

3.5. Pathological changes

There is a caries cavity in the mesial side of the crown of the right maxillary first premolar. It measures 2.2×1.6 mm, and is filled by gold foil which has been pressed into the cavity (Fig. 6a). The mesial face of this tooth, and the distal face of the crown of the adjacent canine, are flattened and show fine, parallel, horizontal striations. These striations suggest that an abrasive process produced the flattened surfaces here; presumably a fine file was drawn back and forth between the teeth in order to make sufficient space so that the gold foil could be tamped into the cavity in the premolar. Small files of suitable for this purpose were a common part of dentists' equipment at that time (Bennion, 1986, pp. 120–121). A radiograph (Fig. 6b) indicates that the carious decay involved the dentine but did not penetrate the pulp cavity. There is no evidence of demineralisation around the gold filling, indicating that the carious process did not restart once the tooth was filled. Gold dental fillings are known in a few other archaeological

Fig. 6. (a) Mesial view of right maxillary first premolar. (b) Linguo-labial radiograph of the same tooth.

skeletons from 19th century English burial grounds (e.g. Whittaker, 1993; Cox et al., 2000; Boyle et al., 2005; Brickley et al., 2006; Powers and Walker, 2008; Boston et al., 2009), but they are rare and, not surprisingly in view of the high cost of such treatment, they are generally restricted to high status church vault burials.

The left maxillary first molar shows a large carious cavity with no sign of treatment. It penetrates the pulp cavity, and there is a periapical void at the roots, with localised dehiscence of the lateral wall of the maxilla, indicating a non-vital pulp (Ogden, 2008). The maxillary bone at the margins of the void is pitted and there is a thin lens of woven new bone formation. The problem presumably arose during the voyage when it appears no dental treatment was available, and the presence of the woven bone shows an inflammatory response that was active at time of death. Both mandibular first molars have been lost ante-mortem.

The tip of the spinous process of T7 is present as a detached ossicle, bound to the rest of the neural spine by dried soft tissue (Fig. 7). This likely represents a fracture of the spinous process that failed to unite. The typical location for this type of injury is C7 or T1, where it is known as clay-shoveller's fracture, and is an avulsion of the tip of the spinous process due to powerful muscular contraction. In this individual, the tip of the neural spine of T7 is rather slender, and perhaps this predisposed it to injury.

Given the lack of access to fresh fruit and vegetables on 19th century arctic voyages, scurvy was always a potential problem. Although this was recognised at the time, and supplies of lemon juice were customarily taken as prophylaxis, many commentators have suggested that scurvy may have been a factor in the deaths which occurred on Franklin's expedition from 1847 onward (Cyriax, 1939; Lambert, 2009). In the current remains, the interdental septa in the posterior parts of the maxillary dental arch have flattened and occasionally concave profiles, and are porotic. These changes are indicative of periodontal disease. Although disease of the periodontal tissues occurs in scurvy (Ortner, 2003, p. 387; van der Merwe et al., 2010), it may also arise from a variety of causes which have nothing to do with scurvy (Hillson, 1986, pp. 310–312). Bony disease of the interdental septa is virtually universal in adults in British pre-modern populations (Kerr, 1998). Therefore the finding of this condition in this individual cannot be considered evidence for scurvy. This skeleton lacks the ossified subperiosteal haematomas and subperiosteal new bone formation which are the skeletal characteristics of the disease (Fain, 2005; van der Merwe et al., 2010). In arctic burial conditions, remains of the haematomas themselves may survive as dark stains on the bones (Maat, 1982); the current material shows no such staining.

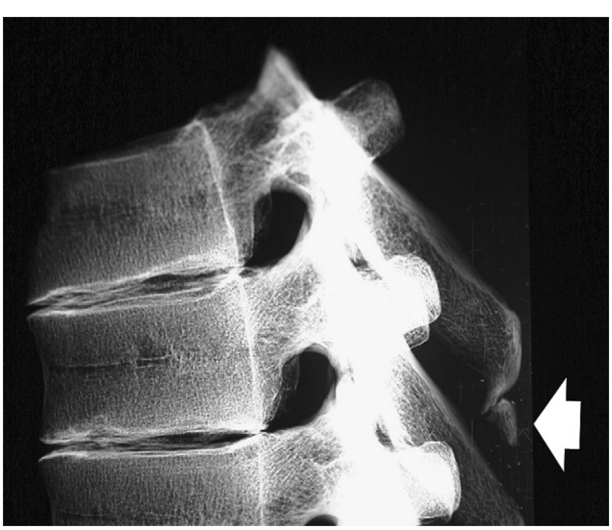

Fig. 7. Lateral radiograph of thoracic vertebrae. T7 shows an un-united fracture of the tip of its spinous process (arrowed).

Autopsy of the three preserved bodies on Beechey Island (Amy et al., 1986; Notman et al., 1987) revealed lung tissue showing changes that may have been tuberculous, and some writers (e.g. Lambert, 2009) have speculated that tuberculosis may have been an important cause of morbidity and mortality on the expedition. Although the current remains show no bony signs of the disease, a bone sample was taken from a vertebral body and analysed for the presence of *Mycobacterium tuberculosis* complex DNA. Analysis for IS*1081* was performed using the methodology of Taylor et al. (2005) with modifications. These included the use of new forward (5′-CTGAAGCCGACGCCCTGTGC-3′) and reverse (5′-TGGCGGTAGCCGTTGCGC-3′) primers to amplify extremely degraded DNA fragments (79 bp). A dual-labelled hybridisation probe (HEX- 5′-ATT GGA CCG CTC ATC GCT GCG TTC GC-3′ -BHQ1) was used to follow the formation of any product on a Corbett RotorGene™ 3000 real-time PCR platform. Results proved negative.

4. Evaluation of the personal identity of remains as Lieutenant HTD Le Vesconte

Place of birth and upbringing can be traced for some of the Franklin expedition members, including Le Vesconte. Henry TD Le Vesconte was born in Netherton, Devon in 1813 and lived as a child in Devon (http://jamcnairn.com/Genealogy/LeVesconteFamilyTree.htm). The oxygen and strontium isotopic composition of dental enamel reflects the locale in which a person lived when the enamel was forming during childhood. We therefore took isotopic measurements from tooth enamel from the current remains in order to determine whether they produced values consistent with a childhood spent in Devon.

Prior to embarkation, portraits of 14 of the 24 officers on the expedition, including Le Vesconte, were taken using the newly devised Daguerreotype process. In order to assist personal identification, we undertook facial reconstruction using the skull, and compared our results with the Daguerreotype photographs.

4.1. Methods

4.1.1. Isotopic work

A small sample of tooth enamel was removed from the upper right second premolar with a dental saw and all surfaces abraded following the procedure of Montgomery (2002). No dentine was included in the sample: although the isotopic integrity of tooth enamel has been demonstrated in many studies, this does not appear to be the case for strontium in dentine (Chiaradia et al., 2003; Hoppe et al., 2003; Trickett et al., 2003). The enamel of the upper second premolar commences mineralisation around the age of two and the crown is usually complete by the age of nine (Gustafson and Koch, 1974; Hillson, 1996). The bulk enamel sample taken in this study will therefore represent an average of dietary inputs from this period of time during childhood, although the precise age or duration of time represented is difficult to narrow further due to inter-individual variation and current unknowns about the speed, pattern and duration of the enamel maturation process. Once removed, the samples were sealed in a container and transferred to the NERC Isotope Geosciences Laboratory at the British Geological Survey, UK.

The strontium isotope composition and concentration was determined by thermal ionisation mass spectroscopy (TIMS) using a Thermo Triton multi-collector mass spectrometer. Samples were run at *c* 5V using single Re filaments loaded using TaF following the method of Birck (1986). The international standard for $^{87}Sr/^{86}Sr$, NBS987, gave a value of 0.710226 ± 0.000012 (2s, $n = 15$). All strontium ratios have been corrected to a value for the standard of 0.710250. All data are measured to better than ±0.000010 (2SE) internal precision. Strontium procedural blanks provided a negligible contribution.

For analysis of oxygen isotopes, small (15–20 mg) fragments of clean enamel were treated to extract PO_4 radicals and precipitated as silver phosphate, using the method of O'Neil et al. (1994). The fragments of enamel were cleaned in concentrated hydrogen peroxide for 24 h and evaporated until dry. Samples were dissolved in 2 M nitric acid and then treated with 2 M potassium hydroxide and 2 M hydrogen fluoride to remove calcium from the solution by precipitation. The samples were then centrifuged and the supernatant added to beakers containing ammoniacal silver nitrate solution and heated gently to precipitate silver phosphate. The silver phosphate was filtered, rinsed, dried and weighed into silver capsules for analysis. Oxygen isotope measurements on each sample were analysed in triplicate by thermal conversion continuous flow isotope ratio mass spectrometry (TC/EA-CFIRMS). The reference material NBS120C calibrated against certified reference material NBS127 (assuming $\delta^{18}O_{VSMOW2}$ of NBS127 = +8.59‰; Brand et al., 2009) gave +21.64‰ ± 0.26 (1σ, n=54) during this set of analyses. This value is within error of the mean value of the published estimates of +21.70‰ for this standard (Chenery et al., 2010). Drinking water values are calculated using Levinson's equation (Levinson et al., 1987), after correction (+1.4‰) for the difference between the value for NBS120C measured at NIGL and the value for NBS120B used by Levinson. ACC-1, a commercially available hydroxyapatite (Aldrich), converted to Ag_3PO_4, was also used as a batch control with a reproducibility of ±0.14‰ (1σ).

4.1.2. Facial reconstruction

In order to preclude the possibility of expectations influencing the results, the entire process of facial reconstruction was completed before the researcher responsible (AO) had sight of the Daguerreotypes of the expedition members.

The cranium and mandible were articulated with the mandible in its normal resting position with the dental arches separated vertically by 2 mm. The skull was then mounted on a turntable and multiple photographs taken with the Frankfurt Plane horizontal and aligned with the horizontal axis of the camera. Although the cranium and mandible were complete and undamaged, the anterior teeth had been lost from their sockets post-mortem. They were carefully built up in modelling clay using the well-preserved sockets as guidance. This showed that the upper anterior teeth were strongly retroclined, leading to a deep overbite with minimal overjet. This indicated that in life the upper lip would have been short and the upper anterior teeth would have been under the control of a large, powerful, somewhat everted lower lip (Mitchell, 2007), leading to a deep sublabial fold (Fig. 8).

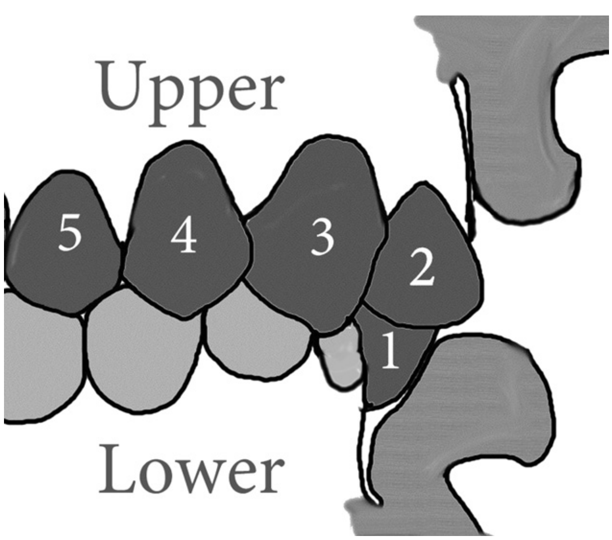

Fig. 8. Right side of the occluding jaws of an individual with a severe Class 2 division 2 malocclusion. Note that the lips do not naturally meet at rest and the individual may well be a mouth breather. The retroversion of the roots of the upper central incisors and the deep overlap of the lower incisors by the uppers indicate that the lower lip dominates the positioning of both the upper and the lower incisors.

The skull was encased in a double layer of 1 cm thick bubblewrap to act as a spacer, and a two-part supporting shell for the impression was constructed in Plaster of Paris using a thin wax layer along the antero-posterior midline to separate the two halves. This shell was left for 2 h to set and gain strength. The shell was then gently prized apart and the bubble-wrap removed. A layer of cotton wool and gauze was glued to the inner surface of both shells for anchorage of the alginate impression material. Deep cavities and undercuts on the skull that would make its withdrawal from the mould problematic or impossible were blocked out with crumpled acid-free paper and masking tape. Alginate dental impression material was then used to take an impression of the skull as its water-based formula and low tear-resistance minimised any risk of damage to the skull. The impression material was mixed with cold water to ensure slow setting, placed in the right-hand mould and the skull was then gently lowered into position, and the alginate left to set and toughen. Time restrictions on the retention of the material in the laboratory meant that only the right half of the skull was modelled.

The undamaged skull was removed from the mould and cleaned of modelling clay and paper. A cast of the right half of the skull was then poured in resin-strengthened high quality Plaster of Paris. Facial reconstruction was started using the 'Manchester Method' (Prag and Neave, 1997; Wilkinson, 2004). Tissue thickness indicators, 4 mm wooden dowels cut to the correct length for their location, were placed on skeletal landmarks (Fig. 9a), based on ultrasound data for a 35 year old European male (Helmer, 1984, modified by Wilkinson, 2004, p. 137). The muscles were then built up in modelling clay, according to the strength of their muscle markings on the skull (Fig. 9b). The anatomical modelling was covered by a layer of clay, laid over its surface to simulate the outer layer of subcutaneous tissues and skin allowing them to mirror the form underneath, but always using the markers to guide their thickness. It seems reasonable to suppose that the men were neither emaciated nor obese prior to the voyage, and the Daguerreotypes confirm this for those depicted. The tissues were therefore built up to the average depth (Fig. 9c).

4.2. Results

4.2.1. Isotopic data

Strontium and oxygen isotope data are presented in Table 1. The tooth enamel contained 83.4 ppm of strontium which had an isotope ratio of 0.70935. This concentration of strontium is typical for omnivorous humans originating from temperate climates such as Britain. For example, human enamel strontium concentrations of ~40–150 ppm are usually found in British archaeological and modern populations whereas higher concentrations of several hundred ppm are found in coastal and island populations (Montgomery, 2002; Brown et al., 2004; Evans and Tatham, 2004; Montgomery et al., 2005; Evans et al., 2006; Montgomery et al., 2009). The strontium isotope ratio is indicative of regions of relatively young (i.e. Mesozoic) sedimentary silicate rocks which crop out over wide regions of the British Isles, particularly in the south

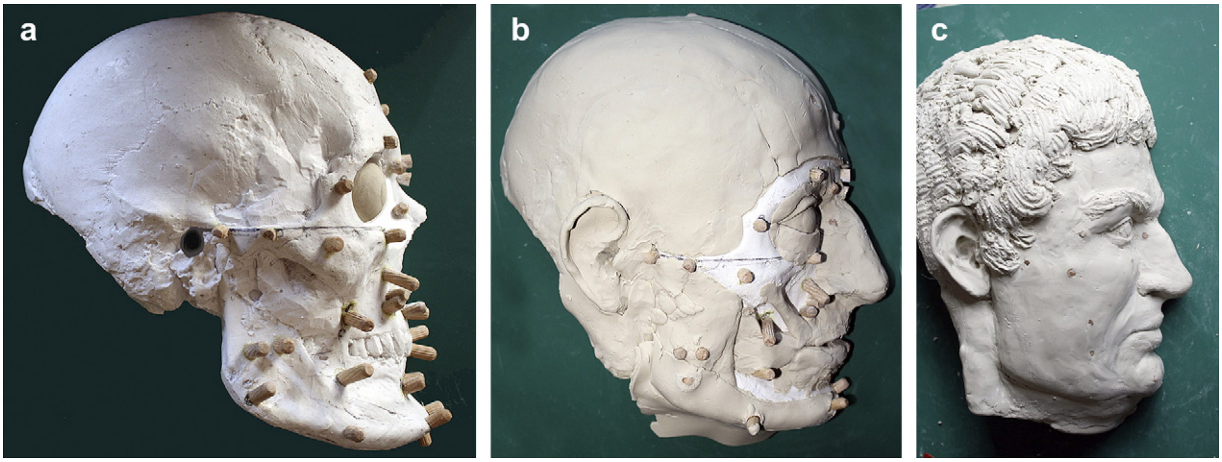

Fig. 9. The facial reconstruction. (a) The tissue-depth markers overlying anatomical landmarks glued to the plaster cast of the skull. (b) The clay reconstruction in progress, with muscles and the parotid salivary gland being modelled. (c) The finished reconstruction, representing a man in his thirties, with the anatomical structures covered by a layer representing the subcutaneous soft-tissues and skin. Note that the tissue-depth markers are just visible, confirming that the tissue depths are correct at each point. The lips are held together as they would probably be in an official photograph. In rest or boredom however it is more likely that they would be slightly apart.

and east (Evans et al., 2010). However, such ratios are also found in people living in regions of older rocks (e.g. Palaeozoic) and granites which are near the coast and significantly affected by strontium of marine origin ($\sim$0.7092) and in regions of high rainfall such as the western seaboard of Britain where the bioavailable strontium in the soil can be biased towards 0.7092 (Whipkey et al., 2000; Montgomery et al., 2007; Raiber et al., 2009; Evans et al., 2010). It is possible however to rule out origins in regions of basalts or chalks which provide ratios below 0.7092. On this basis, the enamel strontium composition is consistent with origins in much of Britain and is not particularly diagnostic with regards to identifying the place of origin.

The oxygen isotope ratio of the enamel phosphate was measured as 16.8‰ ±0.3 (2sd). There is currently no reference map for the geographical distribution of human phosphate oxygen isotope ratios. However, there are several published equations for converting the measured oxygen isotope ratio in skeletal phosphate to the estimated equivalent value for the water the individual would have been expected to have drunk whilst alive (Longinelli, 1984; Levinson et al., 1987; Daux et al., 2008). This can then be compared with oxygen isotope contour maps for precipitation or groundwater in the region of interest (e.g. Darling et al., 2003; Darling and Talbot, 2003; Diefendorf and Patterson, 2005). Here, we have used two equations that are currently being used in British and European studies of human migration. They produce similar results: −8.2‰ ± 0.5 (2sd) (Daux et al., 2008, Eq. (4)) and −8.6‰ ± 0.6 (2sd) (an adjusted version of Levinson et al., 1984 outlined in Chenery et al. (2010)). There is little evidence that the mean annual value of precipitation or groundwater currently falls below −9.0‰ in Britain or Ireland (e.g. Darling et al., 2003; Darling and Talbot, 2003; Diefendorf and Patterson, 2005). Values between −7.5 and −9.0‰ are found only in eastern Britain and those between −8.0 and −9.0‰ have a fairly limited distribution in Yorkshire and Scotland.

However, there are many processes that can alter the oxygen isotope ratio of the water people drink. For example, ratio of rainwater varies considerably from winter to summer and it is possible that this can introduce variability within a population living in the same place if they drank rainwater rather than well or spring water. Natural processes such as heat and wind can evaporate a standing water source such as a lake and alter the oxygen isotope ratios of the water it contains. In addition, humans can alter the oxygen isotope ratio of the water they drink by processes such as boiling. None of these will make the isotope ratio of the water more negative however, i.e. it is highly unlikely that the oxygen isotope ratio of the Franklin sailor could have been obtained in western Britain as almost all the processes that can alter the value of rainwater after it has fallen will make its isotope ratio less not more negative. This cannot of course rule out spring water sources that tapped a deep and ancient aquifer containing rain that fell during a much colder period but the balance of probability would suggest that if this was an individual of British origin, he spent his early childhood in central or eastern Scotland or England, or possibly the Welsh Borders. Whilst the combination of strontium and oxygen isotopes still leave a large number of places to choose from and include major cities such as London, York and Edinburgh it does preclude the western seaboard, most of southwest England and regions of marine carbonates such as chalks and limestones. Given that Le Vesconte spent his childhood in Devon, the results indicate that the current remains are unlikely to be his.

4.2.2. Facial reconstruction

On the basis of the type of clothing on the body and the presence of the gold dental filling, the 19th century naval authorities concluded that the current remains were those of an officer. We see no reason to doubt this assessment. If this is accepted, then, because the isotopic measurements effectively eliminate Le Vesconte, there remain up to a further 23 possible candidates. The facial reconstruction was photographed from similar angles to those used in the Daguerreotypes of the officers (Fig. 10) in order to facilitate comparison (Maples, 1993; Işcan, 1993; Helmer et al., 1993). The remains exhibited an unusual dental conformation (Angle's (1899) Class 2, division ii), which had a prevalence in the late 19th century of about 4% (Angle, 1899). This narrowed the

Table 1
Strontium and oxygen isotopic composition of dental enamel.

Tooth	Tissue	Sr ppm	$^{87}Sr/^{86}Sr$	Mean $\delta^{18}O$ PO_4	1sd	Mean $\delta^{18}O$ DW Levinson	1sd	Mean $\delta^{18}O$ DW Daux (Eq. (4))	1sd	*n*
URPM2	Enamel	83.4	0.70935	16.8	0.15	−8.6	0.33	−8.2	0.26	4

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Fig. 10. Daguerreotypes of 14 officers from the Franklin expedition. ©National Maritime Museum, Greenwich, London.

range of possible candidates, and suggested HDS Goodsir as a likely identification as his lower lip appeared the most bulky and prominent of the photographed officers with a deep sublabial groove. A high-resolution image of Goodsir's Daguerreotype was obtained, as an evaluation or comparison of poor quality photographs is of little value (Taylor, 2001). This was then superimposed with the facial reconstruction, confirming the excellence of fit (Fig. 11).

HDS Goodsir was born and raised in Anstruther, Fife, eastern Scotland (Cyriax, 1939, pp. 210–212; www.scotlandspeople.gov.uk), a location which would provide strontium and oxygen

Fig. 11. The facial reconstruction of the right side superimposed on a high-resolution copy of the Daguerreotype which shows, as predicted, the lips not meeting at rest and a deep sublabial groove. Note the very good agreement between the two pictures. Daguerreotype ©National Maritime Museum, Greenwich, London.

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isotopic ratios consistent with those found in dental enamel of our skeleton. HDS Goodsir was described by one of his shipmates, Fitzjames (1845) as “long and straight” (i.e. tall and slender), and this is consistent with the observations on stature and bi-iliac breadth made on the skeletal remains. He was born on 3 November 1819 (www.scotlandspeople.gov.uk), which, if we assume a date of death in 1846–1848, would make him 26–29 years old. This is somewhat younger than the overall impression gained from the skeleton, although it is within the (very broad) age ranges suggested by the individual age indicators.

Goodsir's official position on the expedition was assistant surgeon aboard HMS *Erebus*, but he was also an accomplished naturalist, and he clearly also served in that capacity on the voyage (Fitzjames, 1845; Franklin, 1845). He received his medical training at Edinburgh, and was conservator at the museum of the Royal College of Surgeons of Edinburgh from 1843 until his resignation in 1845 to join the expedition (Kaufman, 2004). He had publications in both anatomy and natural history (Kaufman, 2004), and his work as a naturalist attracted the attention of Charles Darwin (Darwin, 1850).

It is important to emphasise that facial reconstruction can eliminate possible candidates, but cannot prove identity: it can only indicate a high probability of a match. Indeed photo-to-photo comparison “is not appropriate or legally valid for determination of a positive identification” (Taylor, 2001). In addition, there are ten officers for which there are apparently no extant depictions. For at least some of these, birth places are known, and some are locations (Scotland, north-east England) that would be consistent with the strontium and oxygen isotopic determinations in the current remains. Therefore firm identification is not possible.

5. Conclusions

Osteological examination of the skeletal remains from the Franklin Memorial, Greenwich, indicated they comprise the well preserved and fairly complete skeleton of a young adult male of European ancestry. The individual was of tall and slender build by 19th century standards. Although some have speculated that tuberculosis or scurvy were important causes of morbidity and mortality on the Franklin voyage, the remains showed no signs of these diseases. There was no evidence of cause of death, although the active dental infection noted in the maxilla may conceivably have contributed.

The Admiralty's identification in 1872 of the remains interred beneath the Franklin Memorial as those of Henry Le Vesconte has been accepted in most major works on the Franklin voyage (e.g. Beattie and Geiger, 1987; Woodman, 1991; Lambert, 2009). The isotopic analyses of the dental enamel show that this is unlikely to be correct. The isotopic results and the forensic facial reconstruction are consistent with an identification as HDS Goodsir, assistant surgeon aboard HMS *Erebus*. However, a firm conclusion has not been possible. In part this is because of the limited nature of supporting biographical and photographic evidence concerning members of the expedition. However, it is also inherent in the nature of the scientific evidence: both forensic facial reconstruction and isotopic analyses are more suited to elimination of candidates rather than positive identification. DNA evidence differs in that a match with a living descendant would potentially permit positive identification. For this to be feasible, there would need to be adequate survival of DNA in the skeletal tissues. We would also require Y chromosomal DNA from a direct descendant in the male line from one of Goodsir's four brothers (HDS Goodsir himself had no known offspring), or mitochondrial DNA from a direct descendant in the female line from his sister. Tissue samples have been retained from the remains in case such descendants can in future be traced.

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