Identification of the Probable Source of the Lead Poisoning Observed in Members of the Franklin Expedition

by William Battersby

Abstract

Since 1982, signs of a high exposure to lead have been identified in the human remains of members of John Franklin's expedition to the Arctic, 1845–8. Tinned food has been suggested as the source of this lead. This paper provides evidence that the primary source of this lead was not tinned food, which was in widespread use in the Royal Navy at the time, but the unique water system fitted to the expedition's ships.

Introduction

The Franklin Expedition[1] was one of the biggest disasters in exploration history. Led by Captain Sir John Franklin, the expedition's objective was to pass from the Atlantic to the Pacific through the North West Passage. The 134 men of the expedition sailed from Greenhithe in HMS *Erebus* and HMS *Terror* at 10:30 am on 19 May 1845. After stopping briefly at Stromness, they transhipped stores from a transport ship at Disko Bay in Greenland from 4 July to 12 July 1845. Five men had already been sent back to England by the time the expedition left Greenland. Passing into Lancaster Sound, the expedition overwintered from 1845 to 1846 at Beechey Island, then sailed west and south to attempt the Passage. The ships were trapped in ice off King William Island on 12 September 1846 until, still trapped, the crews abandoned them on 22 April 1848. Sir John Franklin died on 11 June 1847 of unknown causes. The entire crew died while attempting to reach safety and both ships disappeared.

Between 1818 and 1845, the Admiralty instigated ten ship-borne Arctic and Antarctic expeditions, either to attempt to sail the North-West Passage or to reach the poles.[2] After Franklin's disappearance, some thirty-six separate search expeditions were sent to the Arctic.[3] While ships and men were lost, none of these expeditions suffered losses approaching those of Franklin. So anomalous is this total loss that it has long been suspected that there was some unique and fatal flaw in the expedition.

1 Probably the best overall description of the expedition is Richard J. Cyriax, *Sir John Franklin's Last Arctic Expedition*, London, 1939; facs. edn, Plaistow, 1997. This expedition, from 1845 to 1848, was actually the third led by Franklin to the Arctic. For simplicity this paper refers to this third expedition as 'the Franklin Expedition'.

2 HMS *Dorothea* & HMS *Trent*, Buchan, 1818; HMS *Isabella* & HMS *Alexander*, John Ross, 1818; HMS *Hecla* & HMS *Griper*, Parry, 1819–20; HMS *Fury* & HMS *Hecla*, Parry, 1821–3; HMS *Griper*, Lyon, 1824; HMS *Fury* & HMS *Hecla*, Parry, 1824–5; HMS *Blossom*, Beechey, 1825–6; *Victory*, John Ross, 1829–33 (a private expedition but closely aligned with the Royal Navy); HMS *Terror*, Back, 1836–7; HMS *Erebus* & HMS *Terror*, James Ross, 1839–43.
Two of these ships were lost: HMS *Fury* and the *Victory*. See, for a good general discussion: Ann Savours, *The Search for the North West Passage*, London, 1999.

3 W. Gillies Ross, 'The Type and Number of Expeditions in the Franklin Search 1847–1859', *Arctic*, 55, 1, March 2002, pp. 57–69. This number includes supply and reinforcement expeditions and those for which the Franklin search was a secondary role. Another three failed to reach Arctic waters.

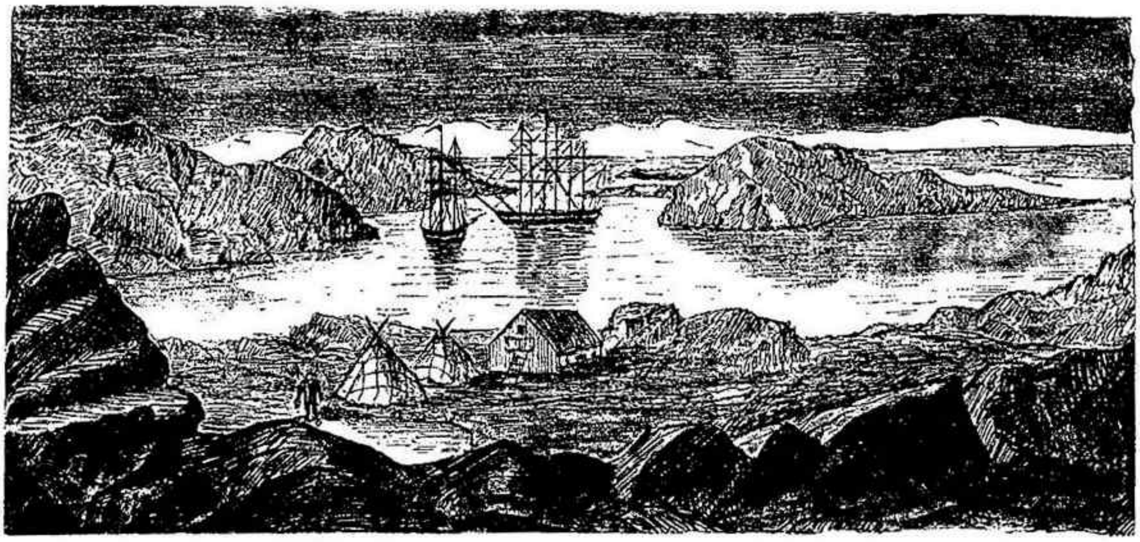

Figure 1. HMS Erebus and HMS Terror at anchor in Disko Bay

Possible explanations for the failure of the Franklin Expedition

Several hypotheses have been advanced for the expedition's failure, with attention focused on its tinned provisions. As early as the 1850s it was suggested that these were tainted. More recently Owen Beattie[4] and others have suggested that these tins were the source of the lead observed in the human remains of expedition members. In 1990 Scott Cookman[5] suggested that the tinned food contained botulism. The firm of Goldner supplied 33,289 lb of canned meat to the Franklin Expedition.[6] Goldner supplied the Royal Navy with 2,741,988 lb of canned meat between 1845 and 1851.[7] The contract to supply the Franklin Expedition was one of its first commissions and represented less than 2% of the total amount of canned meat it supplied to the Royal Navy. Although meat supplied in 1850–51 was certainly substandard, by then Franklin had been dead for three years and there is no evidence that the meat the expedition took with it was tainted in any way. If Goldner had been producing tainted meat in 1845, it is hard to see how the firm could have won repeated orders for the next seven years.

Captain Sir James Clark Ross and Captain Francis Crozier commanded HMS *Erebus* and HMS *Terror* respectively during the ships' earlier and highly successful 1839–1843 Antarctic expedition[8] and took similar tinned food.[9] They reported no dietary problems and suffered only four casualties, all attributable to accident.[10] Their death rate after three years was 3%, in marked contrast with the death rate of almost 19% for the Franklin Expedition at the same point. This is documented in Crozier's and Fitzjames's 'Victory Point' note of 22 April 1848[11] which states that by then only 105

4 Owen Beattie & John Geiger, *Frozen in Time: The Fate of the Franklin Expedition*, London, 1987, 2004; Saskatoon 1988.

5 Scott Cookman, *Ice Blink: The Tragic Fate of Sir John Franklin's Lost Polar Expedition*, New York & Chichester, 2000.

6 Admiralty Records, ADM 114/17/1.

7 *Fraser's Magazine*, April 1852, p. 415.

8 Rear Admiral M. J. Ross, *Ross in the Antarctic: the Voyages of James Clark Ross in Her Majesty's Ships Erebus & Terror: 1839–1843*, Whitby, 1982.

9 Canned provisions were supplied on a large scale: '13,500 pounds of meat, 15,000 pounds of vegetables, 6,000 pounds of soup and 5,000 pounds of gravy' (M. J. Ross, *Polar Pioneers*, p. 217, below).

10 Rear Admiral M. J. Ross, *Polar Pioneers, John Ross and James Clark Ross*, Montreal & London, 1994, p. 250.

11 Richard J. Cyriax, *Sir John Franklin's Last Expedition*, pp. 159–60.

of the 129 men who set out had survived. The death rate reported for officers was almost three times higher than that for the crew. Nine officers out of twenty-four had died, a death rate of almost 40%, while fifteen men out of 105 had died, a death rate of 14%.

Modern evidence for disease in members of the Franklin Expedition

Archaeological evidence exists for tuberculosis, scurvy and lead poisoning afflicting the Franklin Expedition. Archaeological digs by Anne Keenleyside and others at two sites on King William Island (Nunavut)[12] have recovered bone fragments from expedition members which show signs of scurvy. Scurvy, although dreaded and not fully understood at the time, was commonplace on nineteenth-century Royal Naval expeditions and would have been expected. We now know that the vitamin C in the lemon juice supplied would have decomposed after about three years.

Tuberculosis was common in nineteenth-century society. At least two of the five members sent back before the expedition left Greenland were recognised to be ill.[13] This illness is likely to have been tuberculosis. The three men who died in the winter of 1845–46 all showed symptoms of tuberculosis.[14] While scurvy and tuberculosis would have debilitated the expedition and killed individual members, their effects applied equally to other expeditions, so neither can represent a *unique* cause for the loss of the Franklin Expedition.

Bone fragments and other human remains of almost a quarter of all expedition members have now been analysed for lead content. These include the well preserved bodies of the three men who died in the winter of 1845–46 at Beechey Island and bone fragments from an estimated nineteen to twenty-two further members of the expedition who died in 1848, or possibly later, on King William Island.[15] When he died on 1 January 1846, Petty Officer John Torrington, of HMS *Terror* had levels of lead in his bone ranging from 110 to 151 parts per million (ppm) and 'astoundingly high' lead levels in his hair of 600 ppm.[16] The bodies of the two other members of the expedition to die that winter, Private William Braine, Royal Marines, HMS *Erebus*, and Able Seaman John Hartnell, HMS *Erebus*, also show very high levels of lead in both bone and soft tissue. Lead can remain in bone for many years, but soon passes out of the vascular system and soft tissues unless it is replaced.[17] Given that all three men had been aboard the ships for a minimum of seven months by the time they died, they had clearly been exposed to very high levels of lead while on the expedition. Without exception every member of the expedition whose bone has been analysed shows very high levels of lead contamination. Theoretically, every member of the expedition could have suffered from extremely high lead exposures independently before joining the expedition. This, however, seems most unlikely and their extremely varied backgrounds prior to joining the expedition militate against it.[18] Even if this were true, it would not explain the high levels of lead seen in soft tissues, which could only have been deposited during the expedition. The unavoidable

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12 Anne Keenleyside, Margaret Bertulli & Henry C. Fricke, 'The Final Days of the Franklin Expedition: New Skeletal Evidence', *Arctic*, 50, 1, March 1997, pp. 36–46; Anne Keenleyside, X. Song, D. R. Chettle & C. E. Webber, 'The Lead Content of Human Bones from the 1845 Franklin Expedition', *Journal of Archaeological Science*, 23, 1996, pp. 461–65.

13 Captain Francis Crozier, letter to Captain James Clark Ross, 9 July 1845, Scott Polar Research Institute, University of Cambridge.

14 Owen Beattie & John Geiger, *Frozen in Time*, p. 241.

15 Anne Keenleyside et al. (note 12); Owen Beattie & John Geiger, *Frozen in Time*.

16 Owen Beattie & John Geiger, *Frozen in Time*, p. 194.

17 For an authoritative general discussion of the health aspects of lead, see: US Department for Health and Human Services, Agency for Toxic Substances and Disease Registry, http://www.atsdr.cdc.gov/toxprofiles/tp13-c3.pdf.

18 See Ralph Lloyd-Jones, 'The Men who Sailed with Franklin', *Polar Record*, 41, 219, 2005, pp. 311–18; Ralph Lloyd-Jones, 'The Royal Marines on Franklin's last Expedition', *Polar Record*, 40, 215, 2004, pp. 319–26; Richard J. Cyriax, *Sir John Franklin's Last Expedition*.

conclusion is that the Franklin Expedition 'must have suffered from severe lead poisoning'[19] and that this very high exposure to lead must have occurred during the voyage.

The effects of this level of lead poisoning are severe. At lead levels in the blood of 40–80 µg/dL 'neurobehavioral effects including malaise, forgetfulness, irritability, lethargy, headache, fatigue, impotence, decreased libido, dizziness, weakness, and paresthesia'[20] can be expected. 'Exposure to high amounts of lead resulting in PbBs of 100–120 µg/dL in adults produce encephalopathy, a general term that describes various diseases that affect brain function. Symptoms develop following prolonged exposure and include dullness, irritability, poor attention span, epigastric pain, constipation, vomiting, convulsions, coma, and death.'[21] The levels of lead in the bodies of all Franklin Expedition members tested were over the higher limits at which these symptoms could be expected. 'It is apparent that members of the Franklin expedition exceeded the upper limit [for occupational exposure to lead, put at 40–60 µg/dL] by a factor of 3 to 10 and must have suffered from severe lead poisoning.'[22]

The source of the lead

Beattie and others[23] have proposed that the source of this lead was the tinned food supplied to the expedition. K. T. H. Farrer[24] has documented some problems with this. He says:

> It is impossible to see how one could ingest *from the canned food* [Farrar's italics] the amount of lead, 3.3 mg *per day* over eight months, required to raise the PbB to the level 80 µg/dL at which symptoms of lead poisoning begin to appear in adults and the suggestion that bone lead in adults could be 'swamped' by lead ingested from food over a period of a few months, or even three years, seems scarcely tenable.

There is also the quite fundamental problem that tinned food was in widespread use in the Royal Navy and elsewhere, and had been for over thirty years. There is no significant evidence of lead poisoning on any other expedition attributable to tinned food, *even when the same ships*, HMS *Erebus* and HMS *Terror*, were used during the 1839–43 Antarctic Expedition. Furthermore, if the tinned food was the source of the lead, does it make sense that the death rate for officers was three times higher than men? Is there an alternative source of lead which might affect officers to a greater extent than men?

This paper seeks to demonstrate that there was another, much more significant source of lead on HMS *Erebus* and HMS *Terror*. Crucially, this source of lead was unique to this Expedition and could help explain why it alone suffered a 100% casualty rate.

Until 1845, HMS *Erebus* and HMS *Terror* were pure sailing vessels fitted with the Royal Navy's standard equipment for cold climate ships from the 1820s to the 1860s: a 'Sylvester's Patent Furnace' and a 'Fraser Patent Furnace.' The Sylvester Patent Furnace was a coal-fired space heater which convected heat throughout the ship via 12-inch square section hot air ducts which ran under the lower deck. The Fraser Patent Furnace was a ships' galley. A coal-fired cooker patented in 1822,[25] it used steam produced from seawater as a medium for transmitting heat within its casing. As well as its use for cooking, it also output distilled water. Metal tanks were suspended from the

19 Anne Keenleyside et al., 1996, p. 465.
20 US Department for Health and Human Services, Agency for Toxic Substances and Disease Registry, pp. 22–3.
21 Ibid.
22 Anne Keenleyside et al., 1996, p. 465.
23 Owen Beattie & John Geiger, *Frozen in Time*.
24 K. T. H. Farrer, 'Lead and the Last Franklin Expedition', *Journal of Archaeological Science*, 20, 1993, pp. 399–409.
25 UK Intellectual Property Office no. 4706.

upper decks of the ships immediately above the galleys[26] so that ice or snow could be melted by the heat of the galley. A small tap was fitted on the aft side of the tank to drain melt-water.

Uniquely, and for this expedition only, this standard fit of equipment was extensively changed:

- Both ships were converted into auxiliary steamers. They were fitted with refurbished ex-railway locomotive engines, mounted sideways in the after hold, with a direct drive from the driving axle of the engine to the propeller shaft.[27] The engine fitted to HMS *Erebus* was from a Robert Stephenson designed 'Planet' locomotive.

- Both engines drove 'Smith' patent propellers which could be lifted out of the water to reduce water drag and the possibility of ice damage.

- The sternposts of both ships were completely rebuilt, so that the propellers could be mounted vertically, with a well sunk through the ship up which the propellers could be lifted from the water[28].

- The existing Fraser galleys appear to have been replaced with new Fraser galleys.[29]

- The Sylvester space heaters were removed and replaced with steam-based heating systems supplied by Fraser, the same firm which produced the ships' galleys. These used 12-inch (30.5 cm) circular section pipes in place of the square-section hot-air ducting and were fed with steam produced by a Fraser patent 'tubular furnace'.[30] The tubular furnaces followed the design of Fraser's 1826 patent[31] and were mounted on the deck below the existing Fraser galleys. On each ship the tubular furnace shared a common flue with the galley.

- The ships plans appear to show lagged steam pipes rising from the tubular furnace directly to the tank above the galley with stop-taps either side so that, instead of heating the ships, steam from the tubular furnace could be directed into the ice tank. This steam would melt the ice, and in turn the ice would condense the steam, to produce quickly large quantities of fresh water, some of it freshly distilled.[32]

- A new pipe was fitted to drain water from the tank above directly into the condenser of the Fraser galley. A new, large, tap was fitted to the forward side of the condenser from which fresh water could be drained from the whole system.[33]

- A hand pump was installed next to the Fraser tubular furnace with a pipe leading down through the hull of the ship directly to sea the below, so that seawater could be pumped up directly into the tubular furnace.[34]

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26 These can be seen on the Admiralty plans for HMS *Terror* for 1839 and 1845 held by the National Maritime Museum.

27 Benjamin Bell (ed.), *Lieutenant John Irving, RN, of H.M.S. "Terror" in Sir John Franklin's last Expedition to the Arctic Regions: a Memorial Sketch with Letters*, Edinburgh, 1881, pp. 117–18.

28 *Illustrated London News*, May 24, 1845.

29 Comparison between the Admiralty plans for HMS *Terror* in 1839 and 1845, held by the National Maritime Museum, indicates this.

30 Admiralty plan for HMS *Terror*, 1845.

31 A comparison between Admiralty plan for HMS *Terror* for 1845 and James Fraser Patent no. 6421 for 1833 makes this clear.

32 Admiralty plan for HMS *Terror*, 1845.

33 Ibid.

34 Ibid.

Rationale for these modifications

The decision to send HMS *Erebus* and HMS *Terror* to the North West Passage was taken in mid-January 1845, and the expedition would have to leave England by May to have a chance of entering Lancaster Sound in July.[35] The dockyard had to carry out a great deal of work to prepare the ships and equip the expedition within this tight schedule.[36] Why did the Royal Navy feel it necessary to add to this workload the massive task replacing the well-proven Sylvester space heater with a Fraser steam heating system never used before on Arctic ships of the Royal Navy? It is very likely that this was related to the decision to install auxiliary power plants. These engines were intended for use only intermittently when winds were flat or contrary and steam would enable the ship to pass through leads in the ice. Lieutenant Irving wrote of the engine installed in HMS *Erebus*: 'we can carry 12 days' coal for it; but it will never be used when we can make progress at all by other means'[37]. Early locomotive engines were inefficient by modern standards and consumed large quantities of coal and water. Although the original locomotives consumed coke, we know how much coal equivalent and water the engine fitted to HMS *Erebus* consumed because a replica of it exists. Its engine was a Robert Stephenson designed 'Planet' locomotive[38]. The Friends of the Museum of Science and Industry in Manchester have constructed a replica of this design, shown in figure 2. Their tests show that it can consume up to 340 lb (154 kg) of coal and over 2000 lb (908 kg) of water – almost a ton – an hour.[39] The engine fitted to HMS *Terror* would have had similar characteristics.

Figure 2. Replica 'Planet' locomotive

The boilers of railway locomotives were designed only to be filled with fresh water, not sea-water. Dr Michael Bailey confirmed to the author: 'Salt water would not have been suitable at all for a boiler as the build up of salts would be fast, which in turn would have led to the tubes and foundation ring 'burning out''.[40] This would be an unacceptable risk for the boilers of engines which would have to operate for up to three years away from any dockyard. In addition, because of the extreme cold in the Arctic, the boilers of these engines would have had to be drained when not in use to prevent them cracking when the water froze. The demands made by these engines on the ship's fresh water reserves would be high. Since the ship's total fresh water tankage was only 38 tons[41], a week's steaming would entirely drain

35 Richard J. Cyriax, *Sir John Franklin's Last Arctic Expedition*, has much of the correspondence.

36 See for example Captain Francis Crozier's comment in his letter to Captain Sir James Clark Ross dated 9 July 1845: 'What I fear is that from our being so late we shall have no time to look around and judge for our selves'. The letter is held at the Scott Polar Research Institute, University of Cambridge.

37 Benjamin Bell (ed.), *Lieutenant John Irving, RN*.

38 'Researches demonstrate that the two 'Planet'-type locomotives, dating from the mid-1830s, were actually a Robert Stephenson & Co. built 0-4-0 Samson-type, sold second-hand by the London & Birmingham Railway (one of its 'ballast' engines, not listed in the capital stock), and a 2-2-0 Planet-type built by Marshall & Co. and sold second-hand by the London & Greenwich Railway (its No. 4, called *Twells*, the surname of the railway's Deputy Chairman). They were each fitted as auxiliary engines, minus their wheels, to drive propellers to provide some manoeuvrability around the ice flows in northern Canada. The search for the two vessels on the sea-bed around King William Island continues, ironically potentially aided by the presence of the locomotives, their iron theoretically responding to magnetometer searches.' Dr Michael Bailey, Former President of the Newcomen Society, personal communication.

39 Michael Bailey, 'The Planet Locomotive project', *Transactions of the Newcomen Society*, 68, 1996–7, pp. 108–36.

40 Michael Bailey, personal communication.

41 Scott Cookman, *Ice Blink: The Tragic Fate of Sir John Franklin's Lost Polar Expedition*.

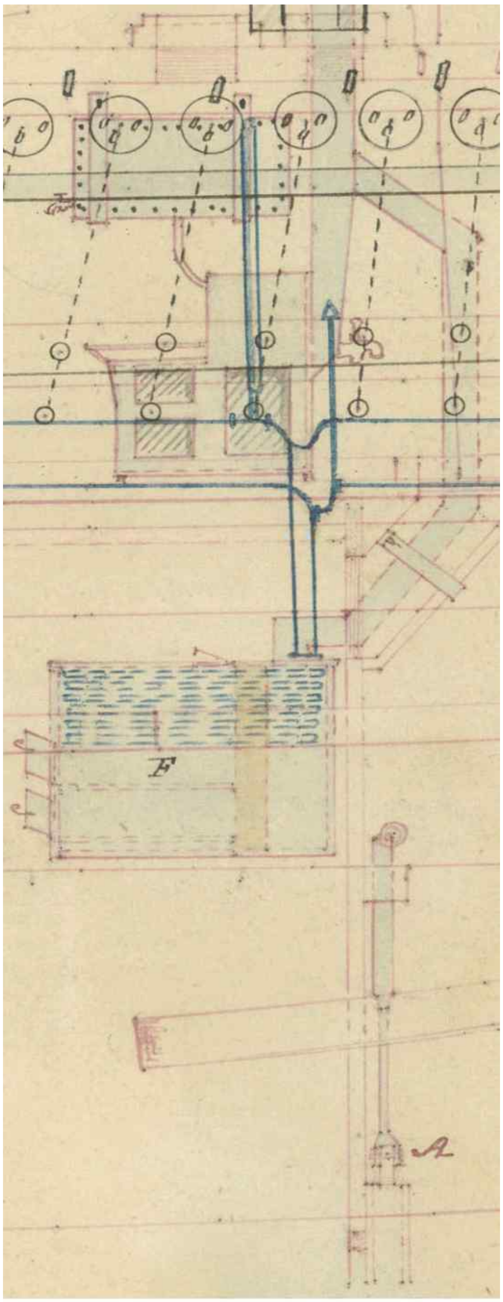

Figure 3. HMS Terror 1845, Profile

their fresh water tanks. To be able to use the steam engines, the ships must have needed a way to replenish their water supply *while under way*.

The Sylvester was a hot air heater and had no capability to produce fresh water. The combination of the Fraser galley and tubular furnace could distil large quantities of fresh water from seawater. It is difficult to see any motive for these extensive modifications other than to provide the ships with the capacity to distil large amounts of fresh water. The firm of Fraser, run in 1845 by John Fraser, was well placed to provide this equipment. John Fraser's father James had from 1818 to 1833 patented a range of inventions which included water boilers, steam heaters, distillation systems and combined distillation and cooking equipment for ships[42]. The firm also produced steam-based hot-house heaters. James Fraser was an acknowledged expert in ship-board distillation. Fraser designs tended to be complicated and were motivated by a desire to maximise use of energy. For example, the galley functioned by heating seawater to produce steam, which was used to transmit heat throughout the galley itself and then condensed as fresh distilled water. As well as its dedicated condenser, the galley also used the cooking kettles and hotplates as additional condensers, thus maximizing the use of energy but at the cost of a more complex design.

The new Fraser heating and cooking systems are shown in detail on the 1845 ships' plans, which are reproduced in figures 3 and 4, with the Fraser galley installed in 1839 shown for comparison in figure 5. Comparing figure 3 with figure 5 indicates that the Fraser galley fitted in 1845 was probably new, as it appears differently proportioned from the 1839 model. Even if it was the same galley, figure 3 shows that a new water pipe was fitted connecting the ice tank directly with the Fraser galley's condenser. This means that, apart from pre-existing small tap on the ice tank, all the fresh water from this combined system, whether produced by melting ice or distillation, flowed out of a new, large tap mounted on the forward side of the Fraser galley. This large tap was not fitted prior to the Franklin Expedition. Cold water piping may also have been fitted to drain water from this tap into the ships' tanks and to lift water from the ships' tanks to the engines' boilers. The fact that none is shown on the 1845 plans is not conclusive either way because the plans do not show the ships' water tanks or indeed their engines, which we know *were* fitted.

42 HM Intellectual Property Office, no. 4201, 4310, 4706, 5338, 5341, 5446, 5447, 5762 and 6421.

Effect of these modifications

In all Fraser's patents, piping and taps are shown made from lead. Lead was the universal material for plumbing hot and cold water piping at the time. It is reasonable to assume that the plumbers who fitted the water systems to HMS *Erebus* and HMS *Terror* would have incorporated substantial amounts of lead piping and lead soldered joints. Whether or not cold water piping was fitted, these plans show that by the time warm, distilled water emerged from the tap on the Fraser galley, it had had ample opportunity to come into contact with freshly installed lead and lead solder. The amount of lead absorbed by water from lead pipes or solders increases where:

- Water is soft, such as when freshly distilled.
- An installation is new and has not built up a layer of scale. Scale insulates water in older systems from direct contact with lead.
- Water is warm or hot. This dramatically increases the amount of lead which water can carry[43].

All these conditions applied to these installations in HMS *Erebus* and HMS *Terror*. They were new and unique and, given the materials used at the time, it is difficult to see how they could *not* have produced water with a heavy lead burden.[44]

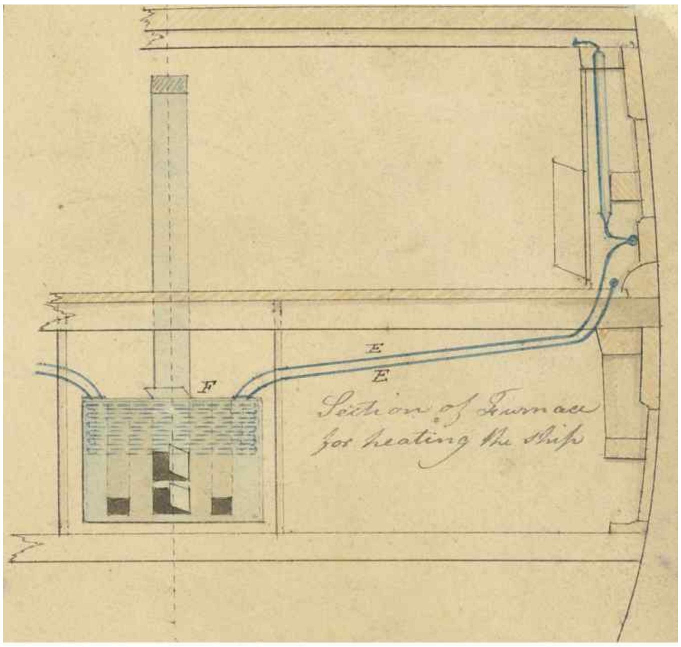

Figure 4. HMS Terror 1845, detail

The ships would have started their voyage with their water tanks filled from a dockside water supply. They stopped at Stromness, on the first leg of their journey, partly to take on additional water.[45] Knowing that any use of their new engines would make great demands on their water supplies, it is likely the crews took steps to keep the water tanks as full as possible. Given that their Fraser galleys could produce distilled water whenever they were fired, and the ships' cooks produced at least one hot meal a day, it would be surprising if this system was not employed and did not have the effect of progressively increasing the lead content of the water in the ships' tanks. Once iced in for the winter, most ships had to melt ice to produce fresh water, but HMS *Erebus* and HMS *Terror* could pump seawater straight up from the sea beneath the ships and distil it using their Fraser systems. They surely took advantage of this technology, which would appear a more convenient, more fuel-efficient and apparently safer source of fresh water. All of this represents a highly probably source for the observed lead poisoning.

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43 'Lead in Drinking Water', World Health Organisation, Geneva, 1996: http://www.who.int/water_sanitation_health/dwq/chemicals/lead.pdfxxx; US National Safety Council statement 'Lead in Water': http://www.nsc.org/resources/issues/articles/lead_in_water.aspx.

44 A significant source of lead poisoning in the USA today comes from 'moonshine' – illicitly distilled spirits. Home-made distillation systems frequently use car radiators as condensers, or lead-soldered pipework. The freshly distilled warm fluid, coming into contact with lead, can pick up huge quantities of lead, with lead concentrations known to have risen as high as 600 ppb. See for example: http://www.spectroscopynow.com/coi/cda/detail.cda?id=11404&type=Feature&chId=1&page=1.

45 Benjamin Bell (ed.), *Lieutenant John Irving, RN*.

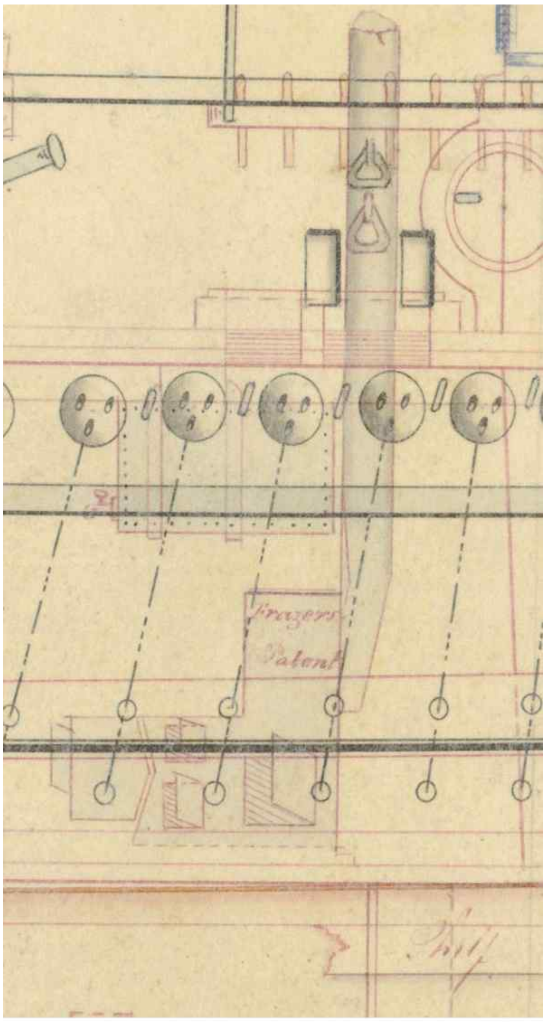

Figure 5. HMS Terror 1839, Profile

Lead from this water system could also enter the men's bodies indirectly. Both ships carried 136,656 lb (62,041 kg) of flour to be baked into ship's biscuit or bread while on the voyage, to supplement the 36,487 lb (16,565 kg) of biscuit also carried.[46] Earlier expeditions tended to carry more pre-baked biscuit. Assuming biscuit or bread baked on board was made 50/50 by weight with flour and water, this means nearly 90% of the bread or biscuit eaten on board was baked using water from the ships' tanks. When hot food is prepared using water which contains lead, some water is boiled off as steam but all the lead and any other residue remains in the food. This means that bread and biscuit prepared on board could have had a high lead content.

Can this provide a possible explanation for the higher death-rate among officers? Officers would surely be served freshly distilled water rather than increasingly stale water from the ships' tanks. They would probably have eaten more freshly baked bread than the men, for whom biscuit was a staple. The ships carried 3052 lb (1386 kg) of suet, 23,576 lb (10,703 kg) of sugar, 1008 lb (458 kg) of raisins and 170 gallons (773 litres) of cranberries.[47] Officers' letters from the first part of the voyage stress how varied and good their food was. As well as freshly baked bread, some of these raisins and cranberries may have been used by their stewards to make flans, pastries and cakes for officers. Officers may consequently have ingested more lead than the men and this may help explain the much higher death rate among officers.

Conclusion

Bone from every crew member so far analysed, almost 25% of the crews of both ships, shows that they definitely suffered from a massive and sustained intake of lead while on the Franklin Expedition. It is unlikely they ingested all this lead from tinned food, and other ships' crews eating similar food did not suffer significant lead poisoning. For this expedition, HMS *Erebus* and HMS *Terror* had unique water systems which, given the materials in use at the time, almost certainly produced drinking water very high in lead. This represents a much more likely source for the high levels of lead observed in the remains of expedition members than the tinned food. While the tinned food may have contained some lead, it seems overwhelmingly probably that the Franklin Expedition suffered severe lead poisoning not from tinned food but from their ships' water systems. Absolute proof will have to await the discovery and inspection of the wrecks when they are finally located.

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46 Richard J. Cyriax, *Sir John Franklin's Last Arctic Expedition*, p. 41.
47 Richard J. Cyriax, loc. cit.

Illustrations. Notes and acknowledgments

Figure 1: HMS *Erebus* and HMS *Terror* at anchor in Disko Bay. The ships are shown prior to their attempt to sail the North West Passage. This sketch was made by Lt Irving of HMS *Erebus* and sent back aboard the transport ship which accompanied the Expedition to Greenland. Lt Irving's body was recovered from the Arctic and is now buried in Edinburgh.
Benjamin Bell, *Lieutenant John Irving, RN*, Edinburgh, 1881.

Figure 2: Replica 'Planet' locomotive. A working replica of Robert Stephenson's 1830 locomotive 'Planet', seen here at the Manchester Science Museum. Similar engines were fitted to HMS *Erebus* and HMS *Terror* in 1845.
Image in public domain.

Figure 3: HMS *Terror* 1845, Profile. Showing from bottom to top, the hand-powered seawater pump, the Fraser tubular furnace with its flue and steam pipe-runs, the Fraser galley with the large tap on the forward (right hand) side of its condenser. The ice tank is bolted to the underside of the deck. Note that the whole installation is closely integrated. The principal outlet for drinking water appears to be the large tap on the galley's condenser.
Courtesy of the National Maritime Museum, Negative no. J1406.

Figure 4: HMS *Terror* 1845, detail. Showing the Fraser tubular furnace on the lower deck. E-E are the steam-heating pipes. The rising thicker pipes appear to be to direct steam into the ice tank.
Courtesy of the National Maritime Museum. Negative no. J1406.

Figure 5: HMS *Terror* 1839, profile. This shows the Fraser galley in 1839. It appears to be a different galley and lacks the piping and large tap of the 1845 installation. The Fraser tubular furnace was not fitted. Instead the ship was heated with a Sylvester furnace stove in the after hold (not shown here).
Courtesy of the National Maritime Museum. Negative no. J6132A