Scientia Canadensis
Canadian Journal of the History of Science, Technology and Medicine
Revue canadienne d'histoire des sciences, des techniques et de la médecine

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Volume 34, numéro 1, 2011

URI : https://id.erudit.org/iderudit/1006927ar
DOI : https://doi.org/10.7202/1006927ar

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Éditeur(s)

CSTHA/AHSTC

ISSN

0829-2507 (imprimé)
1918-7750 (numérique)

Découvrir la revue

Citer cet article

Pryke, K. (2011). The Woolwich Arsenal and Acadian Mines. *Scientia Canadensis*, *34*(1), 25–50. https://doi.org/10.7202/1006927ar

Résumé de l'article

En 1856, le Royal Arsenal britannique se lance à la recherche d’une source de ravitaillement en minerai de fer de grande qualité. Bien que des rapports préliminaires suggèrent qu’un acier de Nouvelle-Écosse présente une qualité comparable à l’acier suédois, les autorités de l’Arsenal, dans le cadre d’une politique rigide de modernisation, exigent que tous les aciers considérés répondent aux exigences de leurs spécialistes en chimie analytique. Devant le rejet de l’acier acadien, des critiques avancent que ces chimistes obéissent à des dogmes plutôt qu’à la science. Les procédures employées par les chimistes étant assurément inadéquates, cet incident illustre le fait que la chimie analytique de l’époque a peu à offrir au commerce des métaux.

The Woolwich Arsenal and Acadian Mines[1]

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Abstract: In 1856 the Royal Arsenal undertook to locate a British source for high grade ore that would be suitable for purposes of ordnance. Early reports indicated that one of the irons being evaluated, an iron from Nova Scotia, was comparable to Swedish iron. Having adopted a rigid policy of modernization, the Arsenal insisted that all irons had to meet the standards established by the analytical chemists. When the Acadian iron was subsequently rejected, critics claimed that the chemists were promoting dogma, not science. The procedures being used by the chemists were certainly flawed, and the Arsenal project incident illustrated that at that time analytical chemistry had relatively little to offer the metal trades.

Résumé : En 1856, le Royal Arsenal britannique se lance à la recherche d'une source de ravitaillement en minerai de fer de grande qualité. Bien que des rapports préliminaires suggèrent qu'un acier de Nouvelle-Écosse présente une qualité comparable à l'acier suédois, les autorités de l'Arsenal, dans le cadre d'une politique rigide de modernisation, exigent que tous les aciers considérés répondent aux exigences de leurs spécialistes en chimie analytique. Devant le rejet de l'acier acadien, des critiques avancent que ces chimistes obéissent à des dogmes plutôt qu'à la science. Les procédures employées par les chimistes étant assurément inadéquates, cet incident illustre le fait que la chimie analytique de l'époque a peu à offrir au commerce des métaux.

> "It is most desirable that means be taken to secure a proper supply from the vast resources of our colony of Nova Scotia, which contains mountains of this precious material." Colonel F. Eardly-Wilmot, Superintendent, Royal Gun Factories, Woolwich Arsenal, December 1855.

In 1856 the British War Office decided to use the Woolwich Arsenal to manufacture war materials because the long-standing policy of depending on private sources had proven to be quite unsatisfactory during the Crimean War. An important part of this decision involved the expansion

1. I am grateful for the helpful and constructive comments provided by the editor and the anonymous reviewer.

of the Royal Gun Factory. Responsibility for implementing the new policy fell to Colonel F. Eardly-Wilmot, R.A., who was appointed as the Factory's Superintendent in July 1856. He was committed to an extensive mechanization of the development and manufacture of ordnance, as well as the application of scientific procedures to the entire process of manufacturing iron. These were to be applied to all aspects of the Factory's modernization and would replace the reliance on the experience and skill of craftsmen.[2]

Eardly-Wilmot was convinced that it was vital for the country's security to find a British source of high grade iron for ordnance purposes in order to end the existing dependence on Swedish iron. By 1856 he and officials at the War Office were able to declare that they had located an iron ore from Nova Scotia that equalled, or even surpassed iron from Sweden. This ore was supplied by the Acadian Charcoal Iron Company,[3] a British company which in January 1854 had acquired the recently developed Acadian Mines in Colchester county. Two years later, however, Eardly-Wilmot reported that, on the basis of rigorous chemical testing, it was clearly evident that the Nova Scotian iron was of very poor quality and quite unsuited for use in the manufacture of ordnance.[4]

The rejection in 1858 of the Nova Scotian iron raised obvious questions about why Eardly-Wilmot and the Woolwich Arsenal officials had previously had such high expectations of the Nova Scotian product. One possible explanation was that the initial evaluation had been based on the traditional methods which had been used for decades by iron masters and others in the iron trade. Perhaps those methods were as flawed as the Superintendent believed. Another possibility was that the Nova Scotian iron was of high quality but the analytical chemical procedures being used at Woolwich Arsenal were seriously flawed. Yet another possibility was that some of the iron subjected to the chemical analysis was of a different type and quality than that originally sent to Britain.

It did become evident that the original positive reports by the Woolwich Arsenal and by various other authorities as to the high quality of iron from Acadian Mines were well founded. However, some of the iron supplied by the ACIC had been obtained from a separate operation developed by the ACIC at Nictau, Annapolis county and was of poor quality. The critical

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2. O.F.G. Hogg, *The Royal Arsenal: Its Background, Origin, and Subsequent History*, vol. II (London: Oxford University Press, 1963), 775-9; 787-9.

3. Between 1853 and 1856 the name of this company changed three times but for the sake of convenience the company will be identified in this paper as the Acadian Iron Charcoal Company (ACIC).

4. Public Record Office (hereafter PRO), War Office: Reports, Memoranda and Papers (WO 33), Papers 1857 (4A), Paper #1, *Experiments Connected with the Comparative Strength of Iron*, 6-7.

issue remained that Eardly-Wilmot insisted on a rigid, narrow application of the doctrine that only scientific principles should be used in the evaluation of the iron. As a result he refused to accept evidence from mechanical experiments that suggested that the Acadian iron was of high quality. Instead he relied on the results of a fundamentally flawed chemical analysis. Thus the ultimate reason for the rejection of the Acadian iron by Woolwich Arsenal was that it adhered to a narrow, restricted view of science.

The balance of this paper is divided into two parts. The first begins with an examination of the conduct of the Superintendent of the Royal Gun Factories, Colonel F. Eardly-Wilmot and his demand that the British iron industry should abandon its traditional craft basis in favour of applying scientific principles to its production. In order to provide some context for his position, contemporary views of modernity, science, and technology will be noted and the state of iron manufacturing will be reviewed. Eardly-Wilmot was primarily concerned with the provision of high grade iron ore and the manufacture of high grade iron. Attention therefore will be paid to Eardly-Wilmot's specific charges against the British iron industry and how it had failed to produce high grade iron. His concerns were shared by the Sheffield steel interests and some of these companies played a secondary, but nonetheless a significant role in the course of the project to find a high grade iron. An important element of Part 1 concerns the steps taken by those associated with Woolwich Arsenal to evaluate the Acadian iron prior to the application of chemical and mechanical testing.

Part 2 describes the actual process of the testing by chemical and mechanical means of a large number of irons, including those from the ACIC. This section also contains a discussion of the difficulties faced by the ACIC in supplying the Gun Factory with the contracted amount of iron. This section deals with four chemical tests of the ACIC iron, each of which resulted in the rejection of the Acadian iron. Finally, after much resistance from the Woolwich Arsenal officials, testing by both chemical and mechanical methods was carried out under the supervision of two referees, with the final rejection of the iron being made by an umpire. This decision was then reviewed by an engineer and an iron master noted for his experimental approach to iron making.

Science and Technology

Eardly-Wilmot's conviction that the iron industry had to be based first on science and second on mechanization reflected in part the critical debate as to the proper relationship between science and technology. There was a long established cultural tradition that placed science, as a profession of pure thought, above technology which was regarded as tainted by economic and other social factors.[5] This tradition was strongly reinforced by modernity's focus on "methodism," which, as one commentator has argued, put stress on the proper method in all its doings, with the end justified only by the means used to attain it.[6] Thus, high cultural values informed Eardly-Wilmot's belief that Britain could only maintain its position in the world by adopting scientific principles in the production of iron. He had no doubt that analytical analysis would provide a clear, rational explanation for the particular behaviour of iron.

In 1855 the War Office appointed Eardly-Wilmot as Superintendent of the Royal Gun Factory in order to fulfill plans to modernize the operations of the Royal Arsenal. He was faced with the immediate challenge of meeting the demand for brass cannons created by the Crimean War, which occurred between October 1853 and February 1856. He also had the task of implementing the 1855 decision to manufacture iron guns at the Gun Factory, which involved the construction of a large foundry and boring mill. The official records reveal little about Eardly-Wilmot as a person, but they do reveal that he was totally dedicated to the modernization of the iron industry.[7] To this end he insisted on following scientific principles, such as utilizing specific procedures derived from analytical chemistry and he denied any credibility to the methods currently being used in the iron trade. He wanted, in brief, to utilize the principles of the Enlightenment and thereby make the iron industry truly a part of the modern age. Later developments suggest that the War Office was not always comfortable with his zeal.

The Rise of British Iron and Steel Industry

Eardly-Wilmot's demand for a new approach in metallurgy did not necessarily mean that the methods used by the iron and steel trades were without merit. Indeed, one authority on the steel trade has argued that "perfectly satisfactory steel was produced reliably, and reproducedly, well before theoretical investigations even commenced. Such practices were based on a combination of innate genius, care, patience and close

5. Some relevant works on science and technology would be: Andrew Webster, *Science, Technology, and Society: New Directions* (New Brunswick, N.J.: Rutgers University Press, 1991); Steven Yearly, *Making Sense of Science: Understanding the Social Study of Science* (London: Sage, 2005); Paul Forman, "The Primacy of Science in Modernity, of Technology in Postmodernity, and of Ideology in the History of Technology," *History and Technology* 23, 1-2 (2007): 1-152; Ursula M. Franklin, *The Real World of Technology* (Toronto: Anansi Press, 1999).
6. Forman, 70-1.
7. Hogg, *Royal Arsenal*, vol. II, 778-9.

observation of trial and error methods and the painstaking repetition of detail when once a satisfactory method had been established."[8] Similar comments were made respecting the manufacture of iron, especially up to the early 1850s.[9] This reliance on the experience and judgement of the individual artisan, however, contrasted sharply with Eardly-Wilmot's demand for scientific objectivity which would provide an explanation for the particular results.

The rise of the British iron and steel industry began when British artisans developed new techniques involving first the use of coke, and then coal, rather than charcoal, to smelt iron ore into pig iron or cast iron. However, charcoal with its 95 per cent carbon content was much more suitable for smelting iron than was either coke or coal. In smelting iron ore, carbon was an essential alloying element and the carbon content in British coal was not only noticeably less than in charcoal, but it also varied with different types of coal. British iron masters compensated for the deficiency in carbon by lengthening the blast by using the waste heat from the furnace. Thus, while in 1830 the usual furnace temperature was 1130ºF, by 1855 it had been raised to 1550º. The higher temperatures also brought about a more complete combustion of the fuel which also reduced the cost of production. The result of these and other developments was that a well-designed furnace, using a hot blast, could produce approximately nine times more iron than a charcoal furnace, thus significantly reducing capital costs.

Although many were proud of the achievements of the craft based iron industry, Eardly-Wilmot focussed on how these changes affected the quality of high grade iron. He particularly singled out the use of coal, rather than charcoal. He complained that where the object was quantity, and recourse was made to using a hot blast with a fuel of raw coal glistening with sulphur, the result was a weak iron. In addition, the sulphur could make iron brittle when hot, or "hot short" as it was then known. He was particularly disturbed by the practise of some manufacturers who tried to pass off inferior iron that had been mixed with better grades of iron as suitable for ordnance purposes. Eardly-Wilmot was insistent that existing practises would have to change. He stated that for the manufacture of mortars and cannons in the future it would be necessary to "introduce a system of manufacture different from, and in

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8. K.C. Barraclough, *Steelmaking before Bessemer, Crucible Steel*, vol. II (London: The Metals Society, 1989), 7.
9. Charles K. Hyde, *Technological Change and the British Iron Industry* (Princeton: Princeton University Press, 1977), 146-47; H.R. Schubert, *History of the British Iron, and Steel Industry from c.450 B. C. to A. D. 1775* (London: Routledge & Kegan Paul, 1957), ix.

many respects the opposite of that pursued in England, this system embracing every detail of manipulation of the Iron and the Fuel."[10]

Eardly-Wilmot's belief that the British iron industry was manufacturing an inferior, low grade iron was heightened by several incidents that occurred during the Crimean War. One notable case occurred during the siege of Swearborg [Sveaborg] in August 1855 when three out of sixteen five-ton mortars had exploded, killing their gun crews. The Superintendent saw this as further proof that British iron was unsuited for ordnance since all three had been cast in 1855. However, he was quite perplexed that the remaining mortars had bottomed out, and thus ceased to function, since they had been built to criteria that predated the Napoleonic Wars.[11] One immediate result of the disaster with the British mortars was the appointment of Sir William Fairbairn,[12] an eminent engineer of the period, to develop a new design for mortars. In setting out on this task, one of the first things he had to do was to find a suitable iron.

In addition to the complaint that the British iron industry was not manufacturing high grade iron, only limited sources of high grade iron ore were available in Britain. Throughout the nineteenth century Britain had relied on foreign sources, and Swedish charcoal iron from the Gästrikland district remained the standard by which other iron was judged.[13] It therefore was not surprising that Swedish iron always commanded a premium in Britain. Apart from ordnance purposes, however, this type of iron had only limited uses although it was essential for the manufacture of steel produced mainly in Sheffield. In the mid-1850s, however, the impact of the demand created by the Crimean War and a sharp rise in British domestic consumption of steel resulted in a shortage of Swedish iron for

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10. PRO, WO 33/4A, Paper #1, *Experiments Connected with the Comparative Strength of Iron*, 6-7.

11. PRO, WO 33/4A, Paper #1, *Experiments Connected with the Comparative Strength of Iron*, 6-7. See http://www.histdoc.net/lauttasaari/crimean.html for information concerning the events at Swearborg.

12. See William Fairbairn, *The Life of Sir William Fairbairn, Bart: Partly Written by Himself*, ed. and comp. by William Pole (London: Longman and Green, 1877), a reprint with an introduction by A.E. Musson (Newton Abbot: David & Charles Reprints, 1970); James Burnley, rev. by Robert Brown, "Fairbairn, Sir William, First Baronet (1789-1874)," in *Oxford Dictionary of National Biography*, eds. H.C.G. Matthews and Brian Harrison (Oxford: Oxford University Press, 2004), online edition, edited by Lawrence Goldman, May 2008, http://www.oxforddnb.com/view/article/9067, accessed February 20, 2009.

13. Information concerning the Swedish iron industry will be found in Göran Rydén, "Skill and Technological Change in the Swedish Iron Industry, 1750-1860," *Technology and Culture* 39, 3 (1998): 383-407. See also Göran Rydén and M. Agren, eds., *Ironmaking in Sweden and Russia: A Survey of the Social Organization of Iron Production before 1900* (Uppsala: Uppsala University, 1993), 7-42.

both ordnance purposes and the steel makers of Sheffield.[14] It was thus not surprising that some of the Sheffield steel masters took some part in Eardly-Wilmot's attempts to break the Swedish monopoly of high grade iron in the British market.

The Reliance on Chemical and Mechanical Testing

Eardly-Wilmot was quite emphatic that before any iron was accepted for ordnance purposes chemical analysis had to establish its suitability for the intended purpose. If the iron did meet the required standards, it would then be subjected to mechanical experiments to establish its specific qualities, such as compression. It was thus clear that chemical analysis played the primary role in the evaluation of the iron and the mechanical experiments, which would probably be conducted by engineers, were of secondary importance. The task assigned to mechanical experimentation was, at that time, customarily performed by practical men and they did use some very exacting methods.[15] Eardly-Wilmot, however, justified the use of machinery by arguing that the usual methods were inadequate for ordnance purposes. Mechanization of this particular aspect of the evaluation process would have an obvious appeal to Eardly-Wilmot because it produced objective, quantitative results and did not depend on subjective opinion or experience. The resort to mechanization was thus one element of Eardly-Wilmot's plan to modernize the process of iron manufacturing. What he ignored was that at mid-century, mechanization had notable limitations and handicraft methods remained critical to the industrial modernization in Britain.[16]

If conducting mechanical experiments was a means of reducing the role of practical men, it also could potentially enhance the role of others, such as engineers, who were seen as belonging to technology, not science. Such persons did not necessarily support the craft tradition nor did they necessarily agree with the type of claim that Eardly-Wilmot was making for science. As we shall see, this occurred during the mechanical tests in 1858 at the Royal Gun Factory. Eardly-Wilmot's policy of reinforcing the position of scientists by eliminating the role of the craftsmen overly simplified the existing situation because it ignored the role of others in the modernization of the iron industry.

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14. Barraclough, *Steelmaking before Bessemer*, vol. II, 63, 84, 105.
15. W.K.V. Gale, "The Technology of Iron Manufacture in Britain in the Decade 1850-1860," in *The Sorby Centennial Symposium on the History of Metallurgy*, ed. C.S. Smith (New York: Gordon and Breach Science Publishers, 1966), 464-5.
16. For a study of the importance of handicraft methods and the limitations of mechanization see Raphael Samuel, "Workshop of the World: Steam Power and Hand Technology in Mid-Victorian Britain," *History Workshop* 3, 1 (1977): 6-72.

Before the mechanical testing could begin, however, Eardly-Wilmot had to arrange for the design and construction of the required equipment. For this task Eardly-Wilmot again turned to Sir William Fairbairn, who was an enthusiastic supporter of Eardly-Wilmot's campaign to modernise Woolwich Arsenal and had long believed that the iron industry should be based on scientific principles. The development of equipment proved to be more difficult than expected, however, and as a result, the testing, planned to take place in 1856, was delayed until the following year. Even then, some equipment was still not functioning properly when the testing was carried out in 1858.

In contrast to the difficulties encountered in arranging for equipment to conduct the mechanical experiments, Eardly-Wilmot had a much simpler time with arranging for chemical analysis because staff and facilities already existed at the Woolwich Arsenal. A chemical laboratory had been established at the Woolwich Arsenal following the appointment of Frederick Abel as Ordnance Chemist in July 1854.[17] He was part of the senior staff at the Woolwich Arsenal since he held a rank equivalent to that of the superintendents of the various sections.

Abel discussed the purpose of analysis in a well-received handbook on chemistry that he and his assistant published in 1853.[18] For some time it had been recognised that good cast iron should have limited quantities of various foreign elements, but the chemists produced more precise observations and constructed quantitative analytical tables that established the permissible amounts for the various foreign elements found in an iron.[19] The purpose of the tables was thus to provide a reliable means of determining the difference between good and bad iron. One result of this statistical process was to transform an open question into one that was numerically limited and thus reframe the situation.[20]

A key point in the analytical tables was the levels considered acceptable for the various foreign elements. Abel's handbook did not provide any

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17. Robert Steele, rev. by K.D. Watson, "Abel, Sir Frederick Augustus, First Baronet (1827-1902)," in *Oxford Dictionary of National Biography*, eds. H.C.G. Matthews and Brian Harrison (Oxford: Oxford University Press, 2004), online edition, edited by Lawrence Goldman, May 2008, http//www.oxforddnb.com/view/article/30319, accessed 28 January 2009. Abel was appointed as chemist to the War Office in 1856.
18. Frederick A. Abel and C.L. Bloxam, *Handbook of Chemistry, Theoretical, and Practical*, with a preface by Dr. Hoffmann (Philadelphia: Blanchard and Lea, 1854). A second edition of the British edition was published in 1858.
19. Cyril Stanley Smith, *A History of Metallography: The Development of Ideas on the Structure of Metals before 1890* (Chicago: University of Chicago Press, 1960), xviii; R. Bud and G.K. Roberts, *Science versus Practise: Chemistry in Victorian England* (Manchester: Manchester University Press, 1984), 15-16.
20. Soraya Boudia, "Global Regulation: Controlling and Accepting Radioactive Risks," *History and Technology* 23, 4 (2007): 411.

information as to how such amounts were arrived at, although the preface did point out that many of the analytical methods used by chemists were flawed, and therefore the various analytical tables would have to be regarded as provisional. He did seem to suggest, however, that it was up to the chemists to detect and correct any flaws in their procedures.[21] It might be asked that if the results of one of their chemical procedures were questioned, whether they might consider the possibility that there was indeed a flaw in their procedures. As far as the evaluation of iron at Woolwich Arsenal was concerned, however, both Abel and Eardly-Wilmot considered chemical analysis to be the keystone of the entire evaluation process, and they refused to accept any criticism.

It might well have been expected that analytical tables for iron would be widely used in light of the widespread respect for science in mid-Victorian Britain and the perception that chemistry was the most important of the sciences.[22] However, at that time, chemical analysis of iron was relatively new and not widely used, even in technical reports. This was probably due, in part, to the difficulty of conducting such an analysis. The process for identifying phosphorous, for example, was described in 1869 as "both difficult and tedious, involving numerously repeated precipitations, filtrations, and washings, and in some cases requiring between thirty and forty determinations of weight in the examination of a single ore."[23] Certainly the Woolwich Arsenal assumed a considerable challenge when it undertook to analyse the approximately seventy types of iron that were submitted to it by various companies.

Eardly-Wilmot perhaps exaggerated when he claimed that science played no part in the production of iron. Some large firms, particularly toward the close of the decade, had invested in laboratories and hired analytical chemists.[24] Much of the actual work done by these chemists, however, was limited to carrying out assays on iron ore. This process was used to determine the commercial value of an ore by establishing the percentage content of metallic iron and the approximate constitution of associated materials, such as clay, magnesia, and water, with respect to their fusibility.[25] Chemists were thus employed more to perform routine analyses than to conduct research into developing scientific techniques for

21. Abel and Bloxam, ix.
22. Bud and Roberts, 14-6.
23. Hilary Bauerman, *A Treatise on the Metallurgy of Iron: Containing Outlines of the History of Iron Manufacture, Methods of Assay, and Analysis of Iron Ores, Processes of Manufacture of Iron and Steel, Illustrated with Numerous Woodcuts* (New York: Virtue and Co., 1868), 79 and 97.
24. Smith, *A History of Metallography*, 88-9.
25. Abel and Bloxam, 355, 606-7.

manipulating the process of manufacturing iron.[26] Eardly-Wilmot's determination to follow only what he regarded as scientific practice was thus a departure from existing practices in the iron trade.[27]

Mechanical engineers and iron masters were often sceptical of the chemists' conclusions because they knew that the criteria established by the chemists did not guarantee the manufacture of satisfactory iron. For his part Eardly-Wilmot was aware that the chemists had only a partial knowledge of the chemistry of iron. He illustrated this point by citing the case of two mortars which in terms of specific gravity and mechanical and chemical results appeared to be similar in composition. However, in field tests one burst in 64 rounds, and the other apparently stood 201 rounds without bursting.[28] Despite this awareness of the limitations of the analytical method Eardly-Wilmot remained confident that it was the only reliable method for evaluating the quality of iron.

The significant point remained, however, that the chemists' reliance on analytical tables to determine the quality of iron was a dead end. It took thirty years before microscopic examination shifted attention away from the composition of iron to the internal structure of the metal and metallurgists were able to deal with the problem that had puzzled Eardly-Wilmot. Rather than focus on the quantity of individual foreign elements, such as silica, they examined the manner in which elements were combined with each other.[29] The fact that the quantity of foreign elements in an iron did not determine the quality of an iron showed that the analytical tables relied on by Eardly-Wilmot had no factual basis and raised question as to how the chemists had originally constructed the statistical tables. Moreover it was clear that any verification of the tables was impossible. During the mechanical experiments that finally did take place on the Acadian iron some who supported the modernization of the iron industry emphasized the need for verification. Indeed, as we shall see, the argument was advanced that the analytical chemists were not following science but were preaching dogma.

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26. Hyde, 119-165.
27. Gale, 451-65; D.C. Coleman, "Gentlemen and Players," *Economic History Review* 36, 1 (1973): 92-116; Bud and Roberts, 35; Robert R. Locke, *The End of the Practical Man: Entrepreneurship and Higher Education in Germany, France, and Great Britain, 1880-1914* (Greenwich, Conn.: JAI Press, 1984).
28. PRO, WO 33/4A, Paper #1, *Experiments Connected with the Comparative Strength of Iron*, 6-7.
29. Norman Higham, *A Very Scientific Gentleman: The Major Achievements of Henry Clifton Sorby* (Oxford: Pergamon Press, 1963).

Fairbairn and Acadian Mines

Actually by the time of the Crimean War various persons connected with the Woolwich Arsenal project concluded that the high quality iron that they had been seeking had been found. The iron in question came from Acadian Mines which was located in Colchester County in Nova Scotia and which for some years had been promoted by Charles Dickson Archibald.[30] He was originally from Truro, Nova Scotia, but he moved to England in 1831 and the following year married the heiress to Rutland Hall in North Lancashire. This estate was near the mining district of Ulverston as well as the Backbarrow Iron Company, which had operated a charcoal blast furnace for some two hundred years and was reputed to be the only full time charcoal blast furnace then operating in England. Relying in part on the assistance of this company Archibald proceeded to send first iron ore and then pig iron and bar iron to many of the most important firms and individuals connected with high grade iron, including several steel firms in Sheffield.[31] Some Sheffield companies did purchase ACIC iron and three representatives of prominent Sheffield companies became members of the board when the ACIC was established in 1854.[32] The Sheffield masters' support for the ACIC was important because they carried considerable influence in the metal trades. However, the person who would come to play a determining role in the Acadian Mines' fate was Sir William Fairbairn.

In the early 1850s Fairbairn experimented at his factory in Manchester with pig irons and iron ores from a number of British sites, and especially from Wales. He also tested the iron that Archibald had forwarded from Acadian Mines and soon concluded that it had greater strength than any of the British irons. He made this opinion very clear in a major article on the iron trade that he prepared for the 1856 edition of the *Encyclopaedia Britannica*. In this article he noted that "In Nova Scotia some of the richest ores yet discovered occur in exhaustless abundance. The iron manufactured from them is of the finest quality, and is equal to the finest Swedish metal." He continued by indicating that "several specimens of iron from those mines have been submitted to direct experiment, and the

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30. William B. Hamilton, "Charles Dickson Archibald," in *Dictionary of Canadian Biography*, eds. Francess G. Halpenny and Jean Hamelin, vol. 9 (Toronto: University of Toronto Press, 1976), 7-8.
31. *The Novascotian* (Halifax), 28 October 1850.
32. Thomas Mathews of Turton & Mathews and Thomas Jessup of Jessup & Sons, were on the board and their respective companies were leaders of the expansion of the Sheffield steel industry in the 1850s. The third Sheffield representative was Frederick Thorpe Marpin, a master cutler. See Barraclough, *Steelmaking before Bessemer*, vol. I, 105.

results prove its high powers of resistance to strain, ductility, and adaptation to all those processes by which the finest description of iron and steel are manufactured."[33] In an earlier paper dealing with Acadian iron, he indicated that it would exceed 30,000 psi, whereas the best record for British iron was 27,000 psi and the average for British iron was 22,000 psi.[34]

In March 1856 a member of the government cited Fairbairn's findings concerning the merits of Acadian iron during a debate on the War Office in the House of Commons.[35] The possibility that Nova Scotia, a British colony, could supply a much needed commodity, undoubtedly appealed to both the government and business sectors of the iron industry. It certainly echoed the mandate of the recently established Government School of Mines and Science Applied to the Arts[36] to exploit the minerals of Britain and its colonies for the benefit of the mother country.

The War Office Considers Acquiring Acadian Mines

In his 1856 article Fairbairn cited national interests when he referred to the recent problems in securing Swedish iron. "The difficulties which the Government have had to encounter during the last two years," he wrote, "in obtaining a sufficiently strong metal for artillery, are likely to be removed by the use of the Acadian pig-iron." For his part the Superintendent adopted a more trenchant approach. In his opinion the only two irons which met his specifications for quality and method of smelting by charcoal came from Sweden and Nova Scotia. He indicated that it might be proper to get iron from Sweden occasionally, but asked "would the British government condescend to be indebted to another nation for such an article of manufacture when their own colony of Nova Scotia is teeming with ore and wood suited for the purpose?"[37]

The strong support being given to Acadian iron by government officials apparently encouraged the ACIC to approach the War Office with an offer to sell or lease Acadian Mines to the British government. The War Department was sufficiently interested in the proposal to have the Colonial Office

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33. William Fairbairn, "Iron," *Encyclopaedia Britannica, or Dictionary of Arts, Sciences, and General Literature*, 8th ed., vol. 12 (Edinburgh: Ad. and Charles Black, 1856), 29-31.
34. Excerpts from a paper on Acadian iron presented to the Philosophical Society of Manchester in 1854 may be found in ACIC, *Reports and Testimonials Relating to the Iron Mines of Nova Scotia: With the Charter of the Acadian Iron and Steel Company* (Halifax: J. Bowes, 1855).
35. *London Times*, 8 March 1856, 7, cols. 4/6.
36. In 1863 the name was changed to the Royal School of Mines.
37. PRO, WO 33/4A, Paper #1, *Experiments Connected with the Comparative Strength of Iron*, 8.

request the governor of Nova Scotia to provide information on all aspects of the ACIC operations in the colony.[38] In response, the governor, who was a recent arrival in the province, indicated that he could not offer any opinion on the subject because of the controversy that existed in the province as to the value of the two mines operated by the ACIC.[39] In the following weeks supporters of the iron works managed to convince the governor to inform the Colonial Office that the colony had sufficient supplies of iron and charcoal to justify a full scale iron works in the province.[40]

There was no further reference at this time to the matter of leasing or purchasing the Acadian Mines. The matter was likely held in abeyance until completion of the proposed tests at the Royal Gun Factory. There certainly was no indication that the political controversy over Acadian Mines caused any concern in either the War Office or the Royal Gun Factory. Indeed, in February 1856 the Gun Factory officials sought to gain evidence of the quality of the ACIC iron by test firing a two pound cannon that had been cast at the expense of Charles Archibald.[41] The Gun Factory officials were sufficiently pleased with the results to begin negotiations with the ACIC for the purchase of two thousand tons of ACIC iron to be used in the proposed chemical and mechanical testing of iron.[42]

The Manufacture of Ordnance with Acadian Iron

The acceptance of ACIC iron extended to its use in the manufacturing of mortars. Fairbairn, following instructions to develop new designs, cast five mortars according to his own specifications. One of these was made from Welsh iron and the remainder from ACIC iron. The cessation of the Crimean War may have ended any sense of urgency and there is no evidence that the mortars were ever tested.

38. Library and National Archives of Canada (hereafter LNAC), RG 10, CO 217/218, Nova Scotia and Cape Breton Original Correspondence, Secretary of State for the Colonies, mfm B1096, War Department to the Undersecretary of State for the Colonies, 19 November 1856, p. 273; G. LeMerchant to Henry Labouchere, 19 December 1856, p. 346.
39. LNAC, RG 10, CO 217/218, mfm B1096, G. LeMerchant to Henry Labouchere, 19 December 1855, p. 346-7.
40. LNAC, RG 10, CO 217/218, mfm B1096, G. LeMerchant to Henry Labouchere, 30 January 1856, p. 58-9. See also G. LeMerchant to Henry Labouchere, 3 January 1856, p. 371; 17 January 1856, p. 47; J.W. Johnston to E.M. Archibald, 16 January, 1856, p. 60-3. Edward Mortimer Archibald, a younger brother of C.D. Archibald, who had served as LeMerchant's attorney general in Newfoundland, was instrumental in changing the governor's mind. E.M. Archibald was at that time the general agent for the ACIC in Nova Scotia. See also PRO, Ordnance Office and Office of the Commander in Chief: Reference Books to Correspondence (WO 45), Board of Ordnance, 1856 (vol. 280/10), Z169/75, February 4th, 1856; and PRO, WO 45, vol. 280/26, Z169/75, November 22nd, 1856.
41. PRO, WO 45, vol. 280/9, Z169/75, February 1st, 1856; PRO, War Office: Correspondence Subject Indexes, 1857-1865 (WO 139/1), Z169/44, 46, 48.
42. PRO, WO 45, vol. 280/18, Z169/75, February 27th, 1856.

It was customary at the Gun Factory to test new materials to determine what particular type of ordnance they would serve best. Some iron was well suited for heavy weapons with a large propellant, and others might be best used in lighter weapons. Fairbairn was of the opinion that the ACIC iron would be particularly suited for heavy ordnance. Accordingly in 1857 when the Gun Factory officials decided to have two 68- pounders built, it shipped ten tons of ACIC iron to Fairbairn with instructions to design and supervise the weapons that would be tested to destruction.[43] The two 68- pounder guns were sent for field testing in September 1857, but the firing range was not yet ready, so no testing took place.[44] They presumably were never tested because there was no further reference to them in the correspondence.

In the fall of 1857 Fairbairn again turned to ACIC iron when authorization was given for the casting of a nine-pounder cannon at the Royal Gun Factory that would be tested to destruction in comparison with two foreign made cannons.[45] As was the case with the other weapons, there was no testing of the nine-pounder before the Gun Factory officials ruled in January 1859 that Acadian iron was unacceptable for ordnance purposes.

Eardly-Wilmot was replaced as Superintendent in the winter of 1859, and in the following summer the Ordnance Select Committee issued instructions to carry out field testing on the nine pounder. There was no indication who had initiated the decision to reopen the question of cannon made with Acadian iron or why they did so. Nonetheless, an order was issued in June 1859 that the cannon be tested to bursting. One possibility was that the new Superintendent of the Gun Factory, Sir William Armstrong wanted a field testing of the Acadian iron because he had less confidence in chemical analysis than had Eardly-Wilmot.

The actual field testing of the nine-pounder did not occur until August 1860. The cannon burst after 70 rounds and there was no indication as to whether this was considered a satisfactory result.[46] In the event that it was deemed to be satisfactory, then a question could be asked whether it would have affected the final assessement by Woolwich of the Acadian iron if the field testing of this cannon, as well as the mortars and the 68 pounder, had been conducted prior to the chemical analysis. It was not

43. PRO, WO 45, vol. 280/24, Z169/75, June 3rd, 1857. The two guns were cast in Lancashire in one of the principal British ordnance manufacturers on a core by a process originally developed in the United States and modified by Fairbairn. Such weapons were usually associated with the navy but in 1857 authorization had been given for land use.

44. PRO, Abstract of Proceedings, Reports, and Memorandum 1855-1859, Ordnance Select Committee (WO, SUPP. 6, vol. 1), #1068, September 25th, 1857, p. 89.

45. PRO, WO, SUPP. 6, vol. 1, #1068, October 20th, 1857 and November 13th, 1857, p. 88-9.

46. PRO, WO, SUPP. 6, vol. 1, #1068, June 15th, 1859, p. 179; September 3rd, 1859, p. 14; and vol. 2, #1068, August 1st, 1860, p. 277. The field testing was scheduled for a maximum of 100 rounds and the cannon burst with cylinders that were equal to seven solid shot.

likely, however, that it would have made any difference at all, in view of the focus that the Woolwich officials placed on chemical analysis.

The Woolwich Arsenal Project Officially Begins

The long proposed chemical and mechanical testing of various irons became official on 9 June 1856 with the publication of a notice inviting iron masters to submit tenders to provide a minimum of 500 tons. A contract with the ACIC, however, had already been signed on 5 June 1856. By this contract the company agreed to supply the British government within one year with 2,000 tons of grey and white pig iron that would produce a strain of 3,000 pounds per square inch for £8.15s a ton.[47] The ACIC iron was preferred to that from Sweden and Wales and the contract price appeared to be higher than the current price of £7 to £8 a ton for Acadian pig iron.[48] The final list of firms contracting to supply the Gun Factory for its testing programme included eighteen British, six foreign and two specialty firms.

Although the ACIC iron received preferential treatment and positive comments were made that Nova Scotia was a British colony, the inclusion of the ACIC iron in the list of foreign irons suggests a certain ambiguity as to its status. Was this an indication that Nova Scotia was in a sense an outsider and not really part of Britain and, if so, was such an opinion widely shared? Further, what would be the effect of such an opinion when questions were raised as to the quality of the Acadian iron?

The ACIC took the successful signing of the contract with the Gun Factory as justification for continuing with its ambitious development in Nova Scotia. The expansion of the ACIC operations in the colony had actually begun in 1854 with the construction of a blast furnace at Nictau in Annapolis County. This furnace went into blast in the fall of 1855 and construction of a second furnace at Nictau[49] was begun in the following

47. Nova Scotian Archives (hereafter NSA), RG 1, Mines and Minerals, vol. 462, Articles of Agreement between Secretary of State for the War Office, and the ACIC, July 1856. There was a delay in signing the formal contract. The contract stipulated that the iron should not have been subject to more than two meltings.

48. Cumbria Record Office, Barrow, Hart Jackson & Son Papers, box 117, bundle 13, Prospectus of the ACIC Company, 15 February 1856. See also LNAC, RG 10, CO 217/219, 205/6, mfm B1097. In October 1856 the weekly quote for ACIC was £8.15. The estimated cost of pig iron from Acadian Mines, including shipping to St. Johns, was £4.17.81/4 a ton and £3.11.91/2 a ton for pig iron from Nictau. Shipping costs to Liverpool, and insurance, would be additional charges. See Cumbria Record Office, Barrow, Hart Jackson & Sons Papers, box 117, bundle 1, Report of Edward Wadham to the Directors of the ACIC, 9 September 1856.

49. NSA, Akins Library, Books on Geology, "Report on the Nictau Iron Mine," *Prospectus of the ACIC and Charcoal Steel Company, 1855*. The site of the mines was on property leased by C.D. Archibald in 1849. See NSA, RG 76, vol. 76, Annapolis County Registry of Deeds, vol. 42, 1849, mfm 17031, p. 20, 40.

year, with others to follow in the succeeding years. The decision to develop facilities at Nictau was linked to plans to develop trade with the United States. Moreover, development and operation costs were much easier and notably less costly at Nictau than in the frontier conditions of Acadian Mines.[50] As for Acadian Mines, the ACIC expected to sell it to the British Government.

The company was undoubtedly enthusiastic about its contract with the War Office to provide the Gun Factory with 2,000 tons of iron within a twelve month period. In agreeing to such a contract, however, the company directors may have assumed too quickly that with two furnaces, one at Nictau and the other at Acadian Mines, that the required amount of pig iron could be provided within the stipulated time period. It would seem that the directors disregarded the difficulties inherent in establishing new works in Nova Scotia. The Nictau furnace, for example, produced only some 190 tons in its first year of production, and in its second year its furnace was difficult to operate and when it was in blast it averaged only four tons a day.[51] In terms of meeting the contract with the Woolwich Arsenal it became apparent that the Nictau operation could provide only limited quantities of iron.[52]

The situation at Acadian Mines was only marginally better than that at Nictau. Since it had begun operating in 1853, it had produced less than a thousand tons in a year, and the average daily rate of production was five tons. The major problem was with the furnace which was more often out of blast than in. Thus, although the furnace went into blast in August 1856, it had to be shut down in September and again in November because the hearth was completely worn out. When the furnace was about to go into blast in February 1857 a new manager arrived from Britain. He suspended operations until new equipment arrived from Britain that would convert the furnace to a cold blast system. It was thus July 1857 before the furnace was in production again. As a result the total output at Acadian Mines from August 1856 to July 1857 was 214 tons.[53]

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50. Id.

51. NSA, Manuscript Group, Business Records, vol. 246, Acadian Mines, Produce Book, 1853-1857. See also Cumbria Record Office, Barrow, Hart Jackson & Sons Papers, box 117, bundle 1, Edward Wadham, Report to the Directors of the ACIC, 9 September 1856. The produce book indicated that the furnace was very fractious throughout 1856.

52. Kris Inwood, *The Canadian Charcoal Iron Industry: 1870-1914* (New York: Garland Pub., 1986). Professor Inwood indicates that the average output of Canadian charcoal furnaces ranged from four to seven tons a day.

53. Cumbria Record Office, Barrow, Hart Jackson & Son Papers, box 117, bundle 2, E.M. Archibald to Edward Wadham, 20 February 1857.

Fortunately for the company the machinery for the mechanical experiments being developed by Fairbairn was not yet ready, so the contract deadline was extended to June 1858.[54] This extension was certainly needed since by the close of the 1857 shipping season the ACIC had managed to send only some 450 tons for which it received payment of £3,643.[55] It was obvious that the company had difficulty in providing even that amount because it shipped six varieties of pig iron, not only the white and grey varieties stipulated in the contract.

It was not until about August 1858 that the ACIC made a further delivery of 600 tons of iron. Instead of a payment for this shipment, however, the company received a peremptory notice from officials at the Gun Factory stating that the chemical analysis had shown that three-quarters of the first shipment was unacceptable and therefore the new shipment would be used as a replacement. The officials also indicated that no mechanical experiments had been conducted on the iron provided by the ACIC because it had not met the required standards set by the chemical tables.

In their report the chemists noted several failings of the ACIC iron. The most serious, and one that was quite unexpected, was that there were relatively large amounts of phosphorous and sulphur in some of the samples tested. Certainly none of the various firms that had worked with ACIC during the previous few years had encountered any such problem. The ACIC had no explanation for this and could only complain that some other iron must have been mixed in with their shipment.[56]

Another finding from the chemical analysis was that some samples contained amounts of silicon above the level of two per cent which was regarded as acceptable for ordnance purposes. Silicon was said to weaken or deteriorate cast iron. Further complaint was made that it was difficult to determine the average quality of iron because the shipment included several varieties of iron. This comment served to illustrate the gap between the chemists and common foundry practice because to a chemist this mixture of types of iron was an inconvenience but to a gun manufacturer it would have been a serious problem.[57]

54. NSA, RG 1, vol. 462, E.M. Archibald to the Provincial Secretary, 21 November 1856, p. 2-13 and also 7 April 1857, p. 2-20.
55. PRO, WO 45, vol. 280/24, Z169/75, June 3rd, 1857.
56. Cumbria Record Office, Barrow, Hart Jackson & Sons Papers, box 117, bundle 13, Acadian Charcoal Iron Company Limited, "Reports and Opinions in the Reference Between H.M. Government and the Acadian Company as to the Quality of its Iron for the Purposes of Cannon," London, 1859, p. iv. Under the agreement the ACIC would receive £6 15s a ton for the 1857 shipment of iron and an additional £2 a ton if the iron met the required chemical standards.
57. Personal communication from the late Dr. J. Parr.

ACIC's immediate response to the Woolwich Arsenal officials' decision to deny payment for the shipment received in 1858 was to insist that the iron delivered in 1857 had been bought and paid for and that the Woolwich Arsenal officials had violated the contract by not carrying out the stipulated mechanical testing. The question of payment for the ACIC was critical because the company was seriously short of funds. It was only after considerable negotiations, however, that it was agreed that the ACIC would initially receive some payment for the 1858 shipment but would receive the balance only if the iron proved to be of acceptable quality. Significantly, however, the officials at Woolwich Arsenal made no concessions concerning the primacy accorded to chemical analysis.

As was probably expected, Woolwich Arsenal officials refused to carry out mechanical tests on iron shipped in 1858 because it also failed to meet the required chemical standards. On this occasion, however, the rejection of the iron was based solely on what was considered to be an unacceptably high level of silicon because the analysis showed only moderate amounts of sulphur and phosphorous. This result might not have been a surprise since by this time the company had probably concluded that the objectionable iron had not come from Acadian Mines but rather from Nictau.

It was also possible that officials at the Gun Factory and interested parties such as Fairbairn had come to a similar conclusion. Fairbairn, in particular, would have sought some reconciliation between his personal experience with ACIC iron and the very dismal results of the original chemical analysis. It would surely not have taken him long to decide that the Acadian iron was indeed of high quality and that the problem iron came from Nictau. Henry Bessemer supplied indirect support for this view.

In 1856 Bessemer announced a new method of processing iron. This process, which involved making mild steel from iron ore, was seen as a major breakthrough, but its potential was seriously limited by the fact that it required iron that contained neither phosphorous nor sulphur. Bessemer's new procedures attracted considerable attention from both the Superintendent at the Gun Factory, and Fairbairn. It was significant that in his search for a phosphorous free iron Bessemer first experimented with Acadian iron. On three separate occasions, in 1858, 1860, and 1862, he made a commitment to the Nova Scotian legislature that he would build an iron works in the colony within two years. It was unlikely that Bessemer would have maintained his interest in Nova Scotian iron had Fairbairn continued to suspect that the Acadian iron contained unacceptable levels of phosphorous.[58]

58. NSA, RG 5, General petitions to the Governor/Lieutenant Governor, vol. 13, no. 3, Petition of Henry Bessemer, 1 May 1860; and no. 22, Petition of H. Bessemer, 26 February

The results of the second set of tests from one perspective were an improvement over the previous results. The ACIC, however, was unlikely to find any comfort in such a conclusion because it lacked any confidence in the evaluation methods used by the officials at the Woolwich Arsenal. After the Woolwich Arsenal officials had made their final decision as to the quality of Acadian iron, the ACIC put forward its own position. This amounted to the simple claim that field testing, and not science, was the only reliable method of determining the suitability of iron for ordnance purposes.[59] But despite this, the company pointed out, by the spring of 1859 no such testing had yet been conducted on any cannon made from Acadian iron.[60] The company's approach was thus the antithesis of Eardly-Wilmot's focus on method.

The company's position was a straightforward defence of the craft tradition. Or, as it might be summarized, no one knew how to make iron who had not burned his hands and singed his beard at a blast furnace. As Eardly-Wilmot had pointed out, many in the iron trade continued to support the craft tradition and this was particularly true for the steel makers in Sheffield. Thus it was not surprising that the ACIC, with three representatives from Sheffield on its board, should hold such a position. At the same time the company was also aware that technology had a subordinate cultural rank to science and that the scientist would always prevail over the practical man.

Following the results of the second set of tests at Woolwich Arsenal the ACIC obviously concluded that there was no further point in dealing with Woolwich Arsenal and turned to the War Office with a request that Woolwich Arsenal conform to the 1856 contract. In approaching the War office the ACIC had the advantage of having three representatives of prominent Sheffield firms on its board. Without their influence the War Office might not have overruled Eardly-Wilmot. In any case Eardly-Wilmot was ordered to carry out both sets of tests on iron drawn from the 1858 shipment. Eardly-Wilmot was so firmly entrenched in his position that the quality of iron could only be determined by chemical analysis that

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1862. See also Henry Bessemer, *An Autobiography, with a Concluding Chapter* (London: Offices of Engineering, 1905), reference is to the reprinted edition (London: Institute of Metals, 1989), 213. See also Fairbairn, "Iron," *Encyclopaedia Britannica*, 143.

59. Cumbria Record Office, Barrow, Hart Jackson & Sons Papers, box 117, bundle 13, "J.V. Bazalgette's remarks upon the Mr. W. Fairbank's decision as Umpire, between Dr. Noad and Mr. Bramwell," 8 April 1859, in Acadian Charcoal Iron Company Limited, "Reports and Opinions in the Reference Between H.M. Government and the Acadian Company," 31-4. Bezalgette was secretary to the board.

60. Cumbria Record Office, Barrow, Hart Jackson & Sons Papers, box 117, bundle 13, Acadian Charcoal Iron Company Limited, "Reports and Opinions in the Reference Between H.M. Government and the Acadian Company," v.

when the Acadian iron again failed to meet the established standard he refused to carry out the mechanical experiments.

When the War Office again repeated its order to carry out both tests, Eardly-Wilmot remained adamant. He was able to do so apparently because, although a serving officer, the post of superintendent at Woolwich Arsenal was classed as "civilian."[61] However, whatever standard practises may have been, the War Office was not prepared to accept a third refusal from Eardly-Wilmot. Moreover the ACIC, which neither appreciated nor understood the objectives of the officials at Woolwich Arsenal, appeared convinced that the officials would do whatever was necessary to support their rejection of the Acadian iron. Accordingly the War Office not only ordered Eardly-Wilmot to carry out both forms of testing but stipulated that the testing be carried out under the supervision of two referees, one to be chosen by the government and the other by the ACIC. In the likely event that the two referees were unable to agree, they would select a third person whose decision would be binding.

The latest agreement between the War Office and the ACIC was quickly implemented, even though the Woolwich Arsenal officials were probably humiliated by the charges against both their professional and personal integrity. Predictably the Woolwich Arsenal officials selected a chemist and the ACIC a mechanical engineer. Woolwich Arsenal officials first attempted to recruit a chemist from the Royal Military College but finally chose Dr. Henry Noad, a chemist at the Medical School at St. George's Hospital in Knightsbridge, who had had no prior contact with the iron industry. The ACIC in its turn selected F. Bramwell, a consulting engineer who had considerable experience with foundry work.

The chemical analysis took place in November 1858, and the mechanical tests began in December. Castings of bars from the pig iron took place on the afternoons of the 21st, 24th, and 31st of December. On the 24th and the 31st December, when the castings were completed in the late afternoon, the various officials were able to hop into their carriages and return home to enjoy the festivities, leaving the workmen to cool the castings and to clean the furnace. The next stage, which took several days, was to subject the iron bars to a number of tests to determine their tensile, transverse, and crushing strength. However, the test for hardness was delayed because of difficulties with the equipment and no attempt was made to determine torsional strain, which was the ability to resist twisting. As Fairbairn had learned, developing the required machinery was no easy task and it would

61. Hogg, *Royal Arsenal*, vol. II, 828.

be some years before the necessary equipment for quality controls was developed.[62]

In terms of the chemical analysis, the questions concerning the silicon content of the Acadian iron remained the critical issue. The mean silicon rate of eleven samples of iron was 2.124%, and one sample contained 5.280%, while the established standard set by chemists was 2.0%. When Bramwell initially subjected the pig iron to mechanical testing, it appeared to be of only fair quality. Bramwell then followed standard foundry practice for that type of iron which was probably similar to that used by Fairbairn in the manufacture of mortars, since both were using iron from Acadian Mines. The subsequent mechanical testing indicated that the iron, which still contained 5.280% of silicon, had a remarkably high degree of transverse and tensile strength and compared favourably with six irons which had been judged suitable for ordnance purposes. Rather than consider whether their own procedures were affected by unknown factors, the Woolwich Arsenal officials tried to find flaws in those used by Bramwell.

Bramwell, like the ACIC, was quite opposed to the approach adopted by the officials at Woolwich Arsenal but he based his criticism on entirely different grounds from those used by the steel masters. Bramwell was sympathetic to the application of scientific principles to metallurgy but did not believe that the chemical analysts had a sufficient knowledge of metallurgy to establish the quality of iron. He agreed with them that the elements of iron were important but argued that without verification by mechanical experiments their views were mere conclusions. Indeed, he argued, the practice of chemists of accepting each other's conclusions without anyone verifying them were problematic. Deductions from a chemical analysis might be erroneous, he concluded, but the results from properly conducted mechanical experiments could not be wrong.[63]

As an alternative to the approach adopted by the chemical analysts he proposed that the appropriate level of elements in iron should first be established by mechanical experiments. Once this was done, use should then be made of chemical analysis because such tests were, in his view,

62. Gale, 464-65.

63. Cumbria Record Office, Barrow Hart Jackson & Sons Papers, box 117, bundle 13, Acadian Charcoal Iron Company Limited, "Reports and Opinions in the Reference Between H.M. Government and the Acadian Company," F.J. Bramwell to J.V.N. Bazalgette, Secretary, ACIC, 30 April 1859, 35-4. The incident concerned an iron identified as No.1 pig which at first was of only average strength and had a high level of silicon. Bramwell, following standard foundry procedure for this type of iron, remelted the iron and added scrap iron. When this iron was subjected to further mechanical testing the iron proved to be of very high quality and subsequent chemical analysis showed that the silicon content had not been reduced. Woolwich Arsenal officials then objected to the remelting of the scrap metal and pointed to the variations in the specific gravity of the pig iron and the modified iron.

easier to carry out than were the mechanical experiments. Bramwell's notion that engineers, rather than scientists, should take the lead in establishing standards for iron may have been intended to be provocative, but it would have been interesting to see the reactions had it been carried out.

Bramwell's approach was similar to that of Robert Mushet who was one of the few iron masters in Britain at the time who regularly carried out research on iron.[64] Mushet was opposed to the reliance on the craft tradition and, like Bramwell, was sympathetic to the general objectives of the officials at the Woolwich Arsenal. He had taken an interest in the project from its commencement but he disagreed with the claims of analytical chemists that it was possible to determine the quality of iron solely on the basis of its elements. Like Bramwell he regarded the claims of the analytical chemists as having no factual basis, and he charged that their assertions were not science but mere dogma.[65]

Both Bramwell and Mushet recognised that the approach by the analytical chemists was too simplistic and, if applied generally, would result in the rejection of satisfactory practices of the metal trade. Both appeared to recognize that developing scientific principles was desirable but that this could only take place after there was a much better understanding of metallurgy. The analytical chemists were, thus, in the view of Bramwell and Mushet, obstacles to the modernization of science.

A decision as to the quality of the Acadian iron involved several complex questions but dealing with them was beyond the scope of the two referees. Not surprisingly Bramwell indicated that he found the iron acceptable and Noad, the other referee, found the silicon content unacceptable. Bramwell later stated that he had never believed that a chemist would accept an engineer's opinion and had only agreed to be a referee after Noad had assured him that he would ignore the chemical results should the mechanical tests prove to be satisfactory. Since the two referees disagreed, as was probably expected, it was then necessary to appoint an umpire

Noad and Bramwell chose William Fairbairn as an umpire. In view of the latter's close connection with both the Woolwich Arsenal and Acadian Mines, his selection was an obvious tribute to his integrity. There was no indication which side had first suggested Fairbairn's name and whether anyone else had been proposed. Fairbairn had to decide, as Bramwell had already indicated, whether mechanical experiments could be used to verify the conclusions drawn from chemical analyses.

64. Fred M. Osborn, *The Story of the Mushets* (London: Thomas Nelson & Sons, 1952).
65. Cumbria Record Office, Barrow, Hart Jackson & Sons Papers, box 117, bundle 13, ACIC Limited, "Reports and Opinions in the Reference Between H.M. Government and the Acadian Company," 26-29. I am indebted to the late Dr. J. Parr for his comments on the reports prepared by Woolwich Arsenal officials, as well as on the pamphlet published by the ACIC.

In his ruling as referee Fairbairn indicated that the ACIC iron was of very high quality and thus, by inference, he set aside the negative findings of the 1857 report. In view of his previous enthusiastic support for the iron from Acadian Mines it was probably the least that he could do. It would perhaps have been better if he had stated clearly that there never had been a question as to the quality of iron from Acadian Mines. Despite his support affirming the quality of the iron, however, he aligned himself with the chemists. "I am still of the opinion," he concluded in his report, "on a careful examination of its chemical constitution that the large proportion of silicon, amounting to from two to two and a half per cent, would be fatal to its use in the manufacture of guns."[66]

Actually there was no indication as to why he made a ruling that contradicted his previous support for the Acadian iron. Whatever his reasons might have been, his actions lent support to the claims of the analytical chemists that they had the only valid approach to metallurgy. Through his actions Fairbairn also ensured that Eardly-Wilmot achieved his objective of using only scientific methods in determining the quality of iron. On the other hand, would there have been any consequences if Fairbairn, one of the eminent engineering names of his day, had ruled in favour of the Acadian iron? It was not likely, however, that anything Fairbairn would have done would have affected the claim by the analytical chemists that they had a monopoly of knowledge of metallurgy.

At mid nineteenth century chemists enjoyed considerable influence and the standards established by them had some creditability.[67] There was one strong challenge to the analytical chemists in 1864 when John Percy, a prominent metallurgist of the period, suggested that none of the existing analytical methods was sufficient to explain the reasons for the differences in steel. As an alternative to chemical specifications, he proposed that attention should turn to the work of Henry Clifton Sorby who had studied the structure of iron under a microscope.[68] However, it was not until some twenty years later that metallurgists actually began to examine the structure of the metal under a microscope and then relate their observations to the measured mechanical properties. For the first time metallurgists were able to explain the causes of such problems as brittleness in iron.[69]

Although the final rejection of the ACIC iron was based on the amount of silicon in the Acadian iron, the suspicion lingered that the Acadian iron

66. Cumbria Record Office, Barrow, Hart Jackson & Sons Papers, box 117, bundle 13, ACIC Limited, "Reports and Opinions in the Reference Between H.M. Government and the Acadian Company as to the Quality of its Iron for the Purposes of Cannon," London, 1859, 29.

67. Smith, *A History of Metallography*, xviii.

68. John Percy, *Metallurgy: The Art of Extracting Metals from their Ores, Iron and Steel* (London: John Murray, 1864), 765.

69. See Smith, *History of Metallography*, 180-4; Higham, 128-30, 151

contained phosphorous and sulphur.[70] The operators of Acadian Mines made various attempts to prove that its iron did not contain these elements and at one point sent two samples of its iron ore for analysis. The subsequent report strongly indicated that the ore was of high quality. It also indicated that their iron ore sample contained only 0.67% of silicon, which was well within the standards set by the analytical chemists.[71]

The argument that phosphorous and sulphur were the reason for the loss of the contract was repeated many years later by Edward A. Jones, who had managed Acadian Mines from February 1857 until 1870. In his account he reduced the problem to simple carelessness on the part of the developers to have the Nictau iron ore tested for phosphorous.[72] Apart from anything else, he overlooked the fact that testing iron for phosphorous only became customary after the development of the Bessemer process. The Nictau mine predated that event.

The rejection of the iron from ACIC had repercussions for all of the major participants. The Woolwich Arsenal, which for several years had indicated that the only suitable replacement for Swedish iron was iron from Acadian Mines, was now left without an alternative. Instead, in the fall of 1858, the decision was made by a committee of the House of Commons to abandon cast iron for ordnance and adopt a gun with wrought iron rings shrunk on a steel core developed by Sir William Armstrong. Eardly-Wilmot, however, was convinced that Bessemer's technique would benefit ordnance more than would the cannon developed by Armstrong and began arrangements for Bessemer to use the facilities at the Gun Factory. The War Office took exception to these plans and as a result removed him as Superintendent and appointed Armstrong in his place.[73]

As for the ACIC, it faced financial ruin and was forced to reorganize. The reputation of the company probably never did recover in Britain. This became obvious when Acadian mines sent some ore samples to the Nova Scotian exhibit at the International Exhibit in 1863. In a hostile article, the columnist for the London Times who covered the iron industry, not only

70. Henry How, *The Mineralogy of Nova Scotia: A Report to the Provincial Government* (Halifax: William Annand, 1869).

71. Percy, 540. He reported that the two types of iron ore from Acadian Mines showed 0.19 and 0.28 of phosphorous and 0.02 and 0.02 of sulfur which were comparable to those of Noad at the Woolwich Arsenal in 1858.

72. NSA, MG 100, vol. 177, no. 16, Edward A. Jones to Joseph Plummel Edward, Letter on the History of Londonderry Mines, 17 April 1914. Also printed as an appendix to Public Archives of Nova Scotia, *Report*, 1960, 43-6.

73. John Batchelor and Ian Hogg, *Artillery* (London: Macdonald, 1972), 8-12. The process of manufacturing wrought iron eliminated much of the phosphorous in the pig iron and thus made it possible to use British iron for ordnance purposes. See Jeanne McHugh, *Alexander Holly and the Makers of Steel* (Baltimore and London: Johns Hopkins University Press, 1980), 108-9.

complained about the extremely poor quality of the ACIC iron but also took strong exception to the manner in which the ACIC had "somewhat ostentatiously obtruded its iron upon the British public as of surpassing excellence." He concluded with the suggestion that "Give a dog a bad name, etc., may apply to an iron company as well as our domestic friend."[74] A question remained as to whether the bad reputation was due in part to the fact that the iron came from a colony.

As for Acadian Mines itself, it had been seized by the sheriff in December 1858 for debts, and it had taken considerable effort on the part of the local supporters to get the mines out of bankruptcy proceedings. The works did not reopen until May 1859. Although more furnaces were needed to improve efficiency and reduce costs, the operation remained dependent on the one furnace in the 1860s. As for the works in Nictau they were abandoned by 1860, and the investment made since 1854 had to be written off.[75] In retrospect it would seem that the development at Nictau was a mistake. The Nictau venture raised unnecessary questions as to the quality of Acadian iron and used funds that would have put Acadian Mines in a more viable position. As for the promised Bessemer converter, it was never built. The crippled Acadian Mines thus faced an uncertain future with inadequate financial backing and limited markets.

A postscript to the attempt to promote Acadian iron in Britain appeared in 1861 when Fairbairn had his article on iron in the *Encyclopaedia Britannica* reprinted under separate cover. Perhaps he had not read his comments on Acadian iron before sending the work to the publishers for they appeared as written six years earlier. Thus his comments included the statement that "The difficulties which the Government have had to encounter, during the past two years, in obtaining sufficiently strong metal for artillery, are likely to be removed by the use of the Acadian pig-iron."[76]

Conclusion

The central problem with the Woolwich Arsenal's attempt to find an iron suitable for ordnance purposes arose from Eardly-Wilmot's commitment to modernize the manufacture of ordnance by relying on the scientific principles of the analytical chemists. By adhering to this premise, Eardly-Wilmot managed to reject an iron that might have met the exacting standards demanded for ordnance purposes.

74. London *Times*, 24 July 1863, 12, col. 1-3. For a response to the article see *London Morning Star*, 6 September 1863, 5. Also How, *Mineralogy of Nova Scotia*, 91-2.
75. As holder of the leases to the mining properties, the Nictau operation reverted to C.D. Archibald in 1862.
76. William Fairbairn, *Iron: Its History, Properties, and Processes of Manufacture* (Edinburgh: Adam and Charles Black, 1861), 30.

One major difficulty with Eardly-Wilmot's reliance on analytical chemists was that they had a limited knowledge of metallurgy. A second difficulty was that Eardly-Wilmot shared the cultural belief of the time that science was a superior form of knowledge. As a result Eardly-Wilmot minimized, or entirely disregarded, the achievements of the craft tradition. Thus, in order to eliminate the role of the practical men, Eardly-Wilmot turned to mechanical experiments conducted by engineers. The work of an engineer, although it was based on technology, was satisfactory to the extent that it produced objective, quantitative results.

A further difficulty with the approach adopted by the Woolwich Arsenal officials was that the analytical chemists maintained that the only way to identify the quality of iron was through its elements. This approach did have a certain utility, such as determining whether iron ore was suitable for the Bessemer process. Also, gun manufacturers might benefit from knowing the scatter of elements in an iron. It could not, however, determine the quality of an iron. The chemical analysts, however, were not prepared to accept any challenge to their belief in chemical analysis. Thus, when the mechanical tests at the Woolwich Arsenal raised questions as to the creditability of the chemical analysis, the officials at the Woolwich Arsenal responded by rejecting the validity of well established foundry procedures used in the preparation for the mechanical testing.

The claim by the analytical chemists that they alone were able to determine the quality of iron was challenged by both Bramwell and Mushet. Both were interested in modernizing the iron trade and both accepted the claim of the chemists that the elements of iron were an important index of the quality of iron. They took strong exception, however, to the failure of the chemists to provide any verification for the analytical tables that they used to establish the quality of an iron. Their critique of the chemists raised a question as to just what the analytical chemists were doing in the name of science.

In their comments neither Bramwell nor Mushet indicated that their problems with the methods used by the analytical chemists at the Woolwich Arsenal were new or unexpected. It was obviously their view that Eardly-Wilmot, in insisting that only scientific principles be used, was iterating the position of contemporary analytical chemists that they should be the ones to determine the procedures used in the iron trade. Thus, it would be useful to reconsider Eardly-Wilmot's original complaint that the iron trade was refusing to adopt scientific procedures. The question might be raised as to whether this resistance was simply because the analytical chemists had relatively little to offer to the iron trade.