The Building of the First Ship Virginia

Edge Tools and Contact Period Ferrous Metallurgy in 1607

In 1605, George Waymouth made his famous expedition to the Maine coast and explored the area around Pemaquid Point, Cushing, and the Penobscot Bay region. Two years later Raleigh Gilbert and George Popham, under the sponsorship of Sir Ferdinando Gorges sought to begin a permanent settlement in Maine at the mouth of the Kennebec River as part of the North Virginia Company, authorized by King James I in 1606. A particularly brutal winter, the death of Governor George Popham, difficulties with the indigenous community of Native Americans, particularly with respect to establishing a fur trade, and the need of Raleigh Gilbert to return to England to settle family affairs after the death of his father, put a quick end to the settlement. Before the Popham colonists returned to England, they constructed the first vessel known to have been built in America and subsequently make a transatlantic voyage, the pinnace Virginia.

Traditionally the shallops used by Basque fisherman and by Champlain and other French explorers and traders, were brought to North America as breakdown kits and assembled on shore for in shore fishing, coastal exploration, or fur trading. The pinnace Virginia, slightly larger than the undecked single sail shallop was probably constructed entirely from wood harvested from or near the shore of the Kennebec River. The Virginia was built during the summer and fall of 1607 and was used to convey the surviving colonists back to England in 1608. It returned at least once to the Maine coast after 1608, as a component of the nearly undocumented series of visits made by Sir Francis Popham, George Popham's brother, to Monhegan Island and the Maine coast in the years before John Smith's 1614 explorations. Neither the tools nor the ironwork used to build the Virginia were produced at the site of its construction.

The Tools Themselves

The tools used to build the pinnace Virginia either as a breakdown kit in England, or at the Sagadahoc settlement of Fort Popham, would have been the traditional tools of the English shipwright of the period: adz, pit saw, whip saw, frame saw, broad ax, pod auger, mast shave, draw knife, mortising ax, mortising gauge, and mallet. Of these tools, the most important was the adz; no wooden ship was ever constructed without the use of a stone, bronze, or steeled iron adz. Nearly as essential was the pod auger for cutting the holes for the treenails (wooden pegs), which held the infrastructure of a wooden ship together. In some cases, the whip saw, a long thin flexible two man saw for cutting the curved edges of a ship's keel and ribs, served as the pit saw. The frame saw was, however, the traditional pit saw used for cutting large beams and planks in pits at least as early as the Roman Republic. During the 18th century, it was supplanted by the "modern" pit saw, which looks similar to an ice saw, but is made with a lower handle attachment not used on an ice saw.

A nearly unexplored subject pertaining to the construction of colonial era ships, beginning with the pinnace Virginia, is the source of the iron and steeled edge tools used in their construction. Wrought iron was too soft and ductile for most tools used by a shipwright. Only steel was useful for the cutting edges of adzes, augers, saws, shaves, and axes. But where did the steel used on the edge tools, which constructed the Virginia, originate? It was 135 years in the future (1742) when Benjamin Huntsman revived the ancient process of making high quality crucible steel for his watch spring business, and almost 80 years in the future when the first documented blister steel furnace was constructed on the river Derwent in northwest England near Newcastle. Steel and toolmaking strategies and techniques dating before the widespread use of converting furnaces to make blister steel are a nearly undocumented chapter of our colonial and industrial history.

When the Massachusetts Bay colonists came to New England before and during the great migration (1630 – 40), after food, their most pressing need was for ironware for ship building and horticultural tools. New England's resource based economy was a triad: fish, timber (and furs until 1650), and shipbuilding, which necessitated steeled edge tools and ironware for ship construction. Successful survival of the communities of the early settlers was contingent upon a reliable supply of functional edge and agricultural tools. These were first imported from England, but in 1646, one of the world's most modern integrated ironworks was constructed at Saugus, MA. A blast furnace, Walloon style finery, chafery, blacksmith's forge, and the ready availability of knowledgeable immigrant forge masters, blacksmiths, and toolmakers characterized this early endeavor at ferrous metallurgy. Iron manufacturing and toolmaking on a relatively large scale had begun in North America at this facility within 26 years of the arrival of the first Plymouth colonists. The steel and toolmaking strategies and techniques available at Saugus in 1646 were unchanged from those available to English and European blacksmiths who made the tools used to build the pinnace Virginia. The widespread availability of blister steel from converting furnaces where there was no fuel-ore contact to contaminate the steel with unwanted phosphorus or sulfur was an event that took place in colonial America in the early years of the 18th century. We have forgotten to ask how steel(ed) edge tools so essential for Renaissance shipwrights, Italian condottiers, or Elizabethan merchant adventurers were produced in the years before the settlement of North America.

The first documented production of blister steel was in Nuremburg in 1601. Ironically, use of the cementation furnace to produce blister steel never became widespread in Europe. The various writers on European ferrous metallurgy in the early modern era are uncertain as to the first use of this early modern furnace in England but K. C.

Barraclough (1984) in his definitive study *Blister Steel* places its first use on the river Derwent in northwest England. In part due to the chemistry of the iron ores available to English toolmakers, once the efficiency of the converting furnace was noted, it quickly spread to all English steel producing centers (the midlands including Birmingham, Newcastle, and later Sheffield). It was also quickly adopted in the American colonies but not until the end of Queen Anne's War and the Treaty of Utrecht in 1713. German and French forge masters and toolmakers already had a long established tradition of making steel from fined blast furnace derived (decarburized) cast iron. This tradition originated in the early Iron Age, when, before the appearance of the larger blast furnaces, raw steel made in direct process bloomery hearths was one of several steel making options. In 1607, forge masters and edge toolmakers in England were using the continental techniques long established in Germany and northern Europe.

When the blast furnace became the dominant mode of iron production in continental Europe in the late 14th century due to its larger capacity and efficient use of fuel and ore, the pig iron it produced had to be reprocessed into wrought iron. This was more complicated but also more efficient than producing wrought iron directly from the bloom, which had been done since the early Iron Age. To make steel from cast iron (3.0 – 3.5% carbon content) a finery furnace was needed, where during the decarburization of the cast iron to make wrought iron, the process was halted prematurely. The result was the production of an iron alloy with an intermediate range of carbon from malleable iron (0.08 – 0.5% carbon content) to raw steel (0.2 – 0.7% carbon content), rather than low carbon content wrought iron (0.02 – 0.08% carbon content). This "continental method" was also the technique used in southern England to produce steel in the 16th century in England's most important iron and steel producing region of the time, the Weald, in Sussex, directly south of London. As in Europe, with the advent of the blast furnace and the reprocessing of pig iron, steel in greater quantities and of a more uniform quality could be produced in contrast to the hit or miss production of raw steel from the bloomery or the tedious production of sheet steel from carburized sheet iron.

During the fining of cast iron, which was perfected in Germany before it was used in England, the decarburization of cast iron in a finery furnace could be controlled to produce a wide variety of steel types depending upon the use intended. For centuries, malleable iron, now called low carbon steel (0.08 – 0.5% carbon) was the most important product of the smaller continental shaft furnaces, which refined cast iron into malleable iron suitable for agricultural tools. German and then English forge masters would have known by the texture of the bloom in the furnace during the refining process when to halt the decarburization of the iron, to obtain steel with higher carbon content for edge tool and sword production, and when to let the decarburization process continue to produce low carbon wrought iron for hardware and other utensils. They were also able to accurately determine the quality of the steel they were producing by looking at the fracture of the bar stock to see how much of the crystalline structure was "sap" and what percentage was in the fine crystal patterns characteristic of tool steel (0.5 – 1.0% carbon content). From 1350 to 1650, this "continental" method of producing iron and steel was the source of the edge tools used not only by the shipwrights who built the pinnace Virginia, but also by the early colonists and their shipwrights of New England and the colonies to the south before 1700. This is true of both the edge tools imported from England and continental Europe and the scattered and nearly undocumented toolmakers active in the colonies, especially New England, New York, and Pennsylvania, in the early colonial period (before 1713). In Austria and southern Germany, in part due to the availability of high manganese content iron ore not available in England or Sweden, steel production by fining cast iron dominated steel producing strategies until the mid-19th century.

No implements other than weapons (swords and guns) were more important to agrarian Europe than agricultural implements. Ductile wrought iron was too soft for hoes, hay forks, mining picks, shovels, or ox and horse harness hardware, which required ironware with a higher carbon content. Some agricultural implements required a steel cutting edge, especially sickles, scythes, and hay knives. Austrian scythe makers were already famous in 1607 for the quality of their steel scythes when the Virginia was constructed with steeled edge tools. When European toolmakers made steel using the continental method, which we now call German steel, to differentiate it from what later evolved as the English method of making cast steel from melting blister steel, the lack of knowledge of the chemistry of steelmaking and the role of carbon was compensated for by the finesse of the forge masters in their ability to determine the quality of the steel they produced by its color, texture, and fracture.

In the case of a continental or English forge master fining cast iron to produce steel or wrought iron during the 16th century, correct analysis of the texture of his bloom was essential. High carbon solid cast iron melts at a relatively low temperature compared to low carbon wrought iron. As the cast iron melts, carbon is removed from the iron by the oxidizing fire, gradually increasing the melting temperature of the iron. The pasty but relatively solid bloom of wrought iron removed by tongs from the finery furnace, or later from puddling furnaces, represents the final stage in refining cast iron. In between the liquid cast iron and the pasty but solid bloom of wrought iron is a stage where a slightly less solid, more mushy bloom of low carbon steel could be manipulated and drawn out of the furnace with a variety of tools and tongs. In almost all situations, the products of the finery shaft furnace were sent to another furnace, called a chafery in America, for further mechanical (hammering) and heat treatment (quenching, tempering, annealing) before being forged into steel or iron bar stock. It was this bar stock iron of varying carbon content that was fashioned into tools by the blacksmith. In the modern era, we look back on this bar stock, little of which survives today, and think of it as wrought iron with a low carbon content. In fact, metallurgical analysis of early iron implements from throughout the Iron Age, whether in Germany, England, or the United States indicates such iron had a varying carbon content according to the intended use of the iron being produced. Even today there is a continuing confusion about the exact definition of steel. Iron containing less than 0.5% carbon cannot be easily quenched and hardened into steel as can iron with a carbon content of 0.5% or more. There is, nonetheless, a significant difference in a shovel or hoe made from iron with a 0.4% carbon content and a less durable one made from pure wrought iron with one tenth as much carbon. Gordon in *American Iron* (1996) clearly defines steel as iron having 0.2% or more carbon content. Not mentioned in his glossary is the quenching threshold of steel, which must contain 0.5% carbon to be quenched and hardened. In the years before bulk process steel, which didn't appear on the market in large quantities until 1870, significant traces of silicon existed in most ironware, providing interesting qualities of ductility and softness that has been lost in the post wrought iron era of blast furnace low carbon steel. Ironically, modern "low carbon steel" has the same carbon content, and in many cases the same uses, as the more convivial "malleable iron" (0.08 – 0.5%), which had the advantage of containing silicon, which made wrought and malleable iron so much more aesthetically interesting than low carbon steel.

The tools that built the pinnace Virginia were probably not made in Germany or France, but rather in England. What strategy did English forge masters utilize to make the steel for edge tools in the 16th and early 17th centuries? At this time, England had two principal iron making centers, the forest of Dean on the north side of the Severn River opposite Bristol and the Weald in Sussex, southeast of London and slightly northwest of Portsmouth. Although toolmaking activities in the forest of Dean are nearly undocumented, blast furnaces producing cast iron were known to be operating in this area as early as the late 14th century. More well documented is England's largest iron and steel producing region of the 15th and 16th centuries, the Weald. This region is full of mine pits, many of which have been dated to the days of the Roman Empire, circa 58 BC.

Henry Cleere and David Crossley in *The Iron Industry of the Weald* (1985) note in 1520, at least two blast furnaces were operating in an area that had easy access to the most important toolmaking and shipbuilding center in England, London, a short distance to the north. By 1548, a total of 53 blast furnaces, fineries, and bloomeries were operating in the Weald in the waning days of Henry VIII. By 1574, the market economy of the Elizabethan era was beginning to blossom; Cleere notes 52 blast furnaces and 54 fineries and bloomeries in operation. It was at this time that England faced its fuel crisis; the deleterious impact of charcoal production resulted in limitations on cutting white oak and other large trees throughout southern England in 1558, 1581, and 1585. Fuel for the blast furnaces was often restricted to coppice grown on the great estates of the landed gentry who had an intimate role in iron and steel production in England at this time.

After 1600, iron and steel production in the Weald quickly declined, perhaps due to both the shortage of fuel and suitable iron ores, instead spreading to the north, throughout the midlands, and then to the river Derwent and to Newcastle in the far northwest. Barraclough (1984) in his classic *Blister steel: The birth of an industry* notes this shift of the British iron and steel industry to the north and the anomalous appearance of Newcastle as England's most important steel producing center between 1700 – 1775. Sheffield, though an ancient center of cutlery production and an important steel producing center during the early 18th century, did not surpass Newcastle in steel production until after 1775 (Barraclough, 1984). It was at this time that Watts' steam engine was utilized to greatly increase blast furnace production. The tools that built the pinnace Virginia were made with blast furnace derived decarburized cast iron; not from the blister steel melted in crucibles that Benjamin Huntsman produced in 1742.

One of the most interesting aspects of 15th and 16th century iron and steel production in the Weald pertains to the iron ores available at that time. The most important product of this industry was weapons and ordnance. Though Henry VIII imported German blacksmiths to make his armor, the steel he used was probably made to the south of London in Sussex. Henry's attempt to make armor of equal quality to the famed German product failed possibly because he was too impatient to allow the German smiths sufficient time to anneal the armor they made. Nonetheless, the Wealdean ores available to German smiths working in England at this time had a similar chemistry to the famous "steel ores" from the Erzberg (steel mountain) in Austria (ancient Noricum). Large quantities of siderite ores were available in both locations. In the case of the iron ores of the Weald, the most important ore was a clay ironstone containing ferrous carbonate $FeCO^3$ (siderite). The particular formations in Sussex, unlike most other ore beds in England, Sweden, or northern Europe, also contained significant quantities of manganese carbonate $MnCO^3$ and magnesium carbonate $MgCO^3$. As with the manganese-rich ores of ancient Noricum, both the manganese and magnesium carbonates served as a flux during the production of natural steel in the bloomery and the decarburization of cast iron in the finery to produce steel. These fluxes served the useful function of melting at a lower temperature and more efficiently draining off unwanted sulfur, promoting more uniform uptake of carbon in an iron bloom than would otherwise occur in the attempt to make steel from ores with a different chemistry. Such attempts were universally of less success and produced steel of inferior quality, hence the fame of the Noric steel produced in Austria, transported south to Italy through alpine passes, and supplied to Caesar attacking the Gauls (c. 58 – 51 BC) with their greater number of armed warriors and their inferior steel swords. The famed Venetian steel of the 17th century mentioned by Moxon (1975) (see Appendix) was probably derived from these ores, though possibly influenced by Wootz steel technology from Muslim societies to the east, also noted by Moxon as one of the important sources of steel in the 17th century.

When the anonymous edge toolmakers forge welded the edge tools used by the shipwrights who built the pinnace Virginia, they almost certainly used the superior quality steel made from fined cast iron in the Weald. The most probable toolmaking strategy would have been to make edge tools in a manner that was unchanged from the early Iron Age at Halstadt to the mid-19th century in America: strips of steel were forge welded onto iron sockets, shafts, and polls to produce the socket chisels, augers, and hewing axes essential for efficient shipbuilding. A second option may have involved casting a trade ax, for example, as one piece of raw steel and then reforging its cutting edge. (______ add photo here ____) Most early modern French and English axes (1450 – 1650) show no sign of a welded steel cutting edge. The extent of this alternative edge toolmaking technique remains undocumented.

The production of steel by the continental method of fining cast iron was well established in Europe before the first appearance of the blast furnace in England in 1496, or earlier in the Forest of Dean. It was shortly after this date that French blacksmiths began immigrating to the Weald; they were almost certainly a principal source of knowledge about the continental method of making steel by decarburizing cast iron, and they may have played a role in the rapid spread of blast furnace technology throughout the Weald and the Midlands after 1520. Barraclough (1984a) describes the later appearance of German smiths working at Shotley Bridge on the river Derwent in 1686. He notes they were still making steel by the "old German" method. Ironically, in 1686, the first converting furnace for producing blister steel was already in operation in this area, and the rapid conversion to a new more efficient technique for producing steel out of iron ores that did not contain manganese, dominated English steel production until the mid-19th century. The use of the converting furnace also quickly spread to Sweden as well as Danzig, the latter of which became an important Baltic Sea steel producing center. Benjamin Huntsman (1742) soon demonstrated that cast steel of the highest quality could be made by re-melting blister steel in Stourbridge clay crucibles. Sheffield edge toolmakers were soon making those fine quality carving tools and drawknives that we find in American tool chests today. Such tools played a key role in the florescence of the art of making case furniture in the late 18th century, in locations such as Newport, RI, Boston, MA, Salem, MA, Portsmouth, NH, and Philadelphia. No such cast steel edge tools were available to the shipwrights at the Popham settlement; nonetheless, the quality of the steel in the edge tools used at Fort Popham was still probably superior to that offered in any 21st century American hardware store.

Steel made from fined cast iron was raw steel, as was the heterogeneous steel made from the bloom of the direct process shaft furnace when the fuel to ore ratio was altered, with less ore and more charcoal fuel to carburize the iron. Under either circumstance production of edge tools, whether socket chisel, scythe, or knife, was contingent upon the skills and talents of the blacksmith who had to reforge the steel for its intended use. In 1865, the Sanderson Brothers, an English steel producer and importer, issued a price list, which notes a wide variety of steel available before the era of bulk steel production (see Appendix). Many of the types of steel in this listing predate the modern era of cast steel and the rise of England's famous iron and steel industry after 1775. "German steel" is a term that appears in this price listing. Its interesting to note that though German steel in the form of decarburized cast iron dominated the European steel market after 1400, German smiths migrating to England played such and important role in steel production that there still exists some confusion as to the meaning of German steel. When the German smiths were working at Shotley Bridge on the river Derwent, or for that matter, 150 years earlier in the Weald to the south of London, they used a technique of steel production that was centuries old. The German smiths, however, quickly adapted to the presence of blister steel, which could be produced in greater quantities than by fining cast iron. They were so adept at piling, bundling, and refining blister steel into spring steel, silver steel, and other types of carefully refined and reforged blister steel, that even today the high quality steels produced by the reforging of blister steel are still incorrectly called German steel and are often so labeled in English, but only on English made tools of the period. Barraclough notes the multiple ambiguous meanings of "German" steel. This term should now, in fact, denote steel produced by fining or decarburizing cast iron. For England, as well as for some locations in northern Europe, the converting furnace for the production of blister steel represented a great advance in the quality of the steel being produced. Many efforts at using the continental method of fining cast iron to make steel failed because the iron ores being smelted did not have a chemical composition compatible with making high quality steel for edge tools and weapons by the use of this process.

At the time of the building of the pinnace Virginia there were two other strategies for making steel that were still in use, and which most smiths would have been aware of. These two techniques were probably not those used to make the edge tools that were used in the construction of the Virginia, but they should be noted because they may have been used by early colonists to make steel in very small quantities. Not everyone lived around the corner from an integrated iron works with its blast furnace and finery, such as those at the Weald and that at Saugus, which operated only for a little more than two decades after it was established in 1646.

The Bloomery Process

Among the most ancient strategies for making steel is that of producing natural steel from a direct process bloomery furnace. Blast furnace production of iron evolved after 1300, in part due to the inherent wastefulness of the direct process bloomery, where 50 – 65% of the iron in the ore being reduced was lost in the smelting process. Only small kilogram quantities of iron or steel could be produced as the loupe derived from a direct process bloomery. Direct process iron production was, however, simple, and could be easily executed in any isolated location with access both to wood fuel or charcoal and iron ore. For centuries, desert tribesmen as well as isolated central European bloomers made iron in simple bowl and shaft furnaces, hammered it into sheets of iron, and slowly carburized it into sheet steel under the layers of charcoal, which would protect it from the deleterious impact of oxidizing gasses. Any blacksmith could increase the fuel to ore ratio of their bloomery furnace, slightly altering the reduction of the iron ore to wrought iron by increasing the amount of carbon available from the burning fuel. The removal of the carbon from iron ore during smelting was a gradual process. As with fined cast iron, knowledgeable smelters could selectively remove enough carbon to make iron, which would qualify as raw steel, or change furnace conditions to encourage the uptake of carbon in malleable iron. Tylecote in his classic *The Early History of Metallurgy in Europe* states:

> Two grades of iron can be produced in the Catalan hearth: soft iron or natural steel. The latter is made, as expected, with a higher fuel/ore ratio and slag tapping is more frequent so that the Fe is not decarburized too much in the slag bath. More time is needed and manganese must be present in the ore. This is in agreement with the ideas on Noric iron, but in neither case does the Mn appear in the iron; it merely alters the equilibrium so that a higher carbon iron is in equilibrium with a lower iron slag which is made fluid with MnO rather than FeO.
>
> …reduction takes place to high-carbon iron (cast iron mixed with slag). This iron is oxidized lower down and finishes in the solid state while the fluid manganiferous slag liquates to the bottom. Frequent slag tapping will avoid over-oxidation of the metal and allow carbon to be retained in the metal, as desired.
>
> The blast from the trompe is saturated and no doubt the water vapour takes part in a water−gas reaction:
>
> $H_2O + C \rightarrow CO + H_2$
>
> The hydrogen formed accentuated the reducing reaction in the higher levels and produced a more steely iron. It has been found that the use of blowing cylinders instead of the trompe results in a more ductile iron. (Tylecote, 1987, pg. 167)

Iron currency bars, iron bar stock used by blacksmiths and traded over long distances, and tools recovered from archaeological sites in central Europe testify to the fact that making raw steel in a direct process bloomery furnace dates from the first appearance of the Iron Age at Halstadt in central Europe. Agricultural tools recovered from central European sites and dating to pre-Roman times as well as the currency bars shipped to many areas of central Europe from the iron smelting centers of Austria often contained surprisingly high levels of carbon, enough to qualify them as natural steel artifacts

(Pleiner, 1980, Wertime, 1980). Though not homogenously distributed, the carbon content of these tools and currency bars means they cannot be defined as wrought iron, i.e. containing less than 0.08% carbon. Making natural steel from a direct process bloomery in the Forest of Dean or the Weald in Sussex, the two major English iron producing centers of the 16th century, would have been one of three well known options for steelmaking at the time of the construction of the pinnace Virginia. Few, if any, written sources have survived to tell us which techniques Bristol and south coast England blacksmiths used to fashion the edge tools used to build the Virginia.

Nonetheless, the robust iron and steelmaking industry played a key role in the burgeoning market economy of late Elizabethan England. Humphrey Gilbert, father of Raleigh Gilbert of the Popham expedition, could not have made his ill-fated attempt to settle North America (1578) without a robust edge toolmaking community to help build the ships he used to visit Canada and Newfoundland. During the 16th century, most of the bloomeries in the Weald were replaced by blast furnaces and their associated fineries. Natural steel production, which required careful and attentive reforging of raw steel into the higher quality steel needed for edge tools, probably became a secondary option for edge tool production, in view of the increasing number of fineries that could decarburize cast iron into raw steel. The blister steel industry arose in part in response to a world with very restricted availability of manganese-laced iron ores. The best alternative source for high quality iron was not the deposits of northern and central England or northern France and Germany, but the low sulfur, low phosphorus ores of western Sweden. It was these ores that were imported into England for use in the converting furnace. But the age of blister steel was still a century in the future when that shipwright from Digby used his adz to dub the planking of the pinnace Virginia on the shores of the Kennebec in 1608.

Brescian Steel

The most ancient tradition of steelmaking in Europe is that of making natural steel from the direct process open hearth shaft or bowl (Catalan furnaces). Small scale production of direct process derived steel continued in isolated areas of southern Europe until the end of the 19th century. The other method was the technique of making steel by submerging wrought iron bar stock in liquid cast iron – the Brescian method, sometimes called fusion, which was apparently fairly widespread during the Italian Renaissance, especially in the Italian city states. Though the appearance of the blast furnace in southern Europe cannot be dated earlier than 1350, the accidental and/or deliberate production of cast iron in shaft furnaces that ran too hot dates from the earliest days of the Iron Age. Not all of that cast iron that dribbled out of the bottom of a Catalan forge was necessarily a waste product. There was no way to document how often in ancient times this waste cast iron, with its higher carbon content and lower melting temperature, was not remelted and mixed with wrought iron bars with their lower carbon content and higher melting temperature. The wrought iron bar stock would naturally absorb carbon and become more steel-like.

The Brescian method was widely used during the Italian Renaissance, especially for making swords for the condottiere, the mercenaries employed by Italian city states such as Florence and Siena, and was contemporaneous with the continental (German) method of producing steel by fining cast iron. An argument could be made, however, that the Brescian method, which can easily be utilized to produce small quantities of steel, may have roots in the early Iron Age. Shaft and bowl furnaces (Catalan) could never be so closely regulated by their forge masters as to only produce low carbon wrought iron. If a shaft furnace ran too hot or the fuel or ratio was deliberately changed, unwanted liquid cast iron would run out of the bottom of the furnace and solidify, illustrating the principal that at the same time the reduction of iron ore to nearly carbon free wrought iron was occurring, higher furnace temperatures encouraged the opposite reaction: absorption of carbon by the heated iron. Early Iron Age smiths may have noted that re-melting the cast iron and submerging wrought iron bar stock into the melted high carbon cast iron would produce steel that was sometimes of a surprisingly high quality. The blacksmiths of Renaissance Italy, making swords and armor for the condottiere of the Italian city states, may not have been the first to produce Brescian steel. One of the unanswered questions pertaining to the history of metallurgy is: did the blacksmiths of Celtic Noricum (Austria) make Brescian as well as natural steel from their manganese rich iron ores? It was this steel that was transported south over the alpine passes to Venice and northern Italy and supplied to Roman gladiators and soldiers fighting with Caesar in the Gaullist wars (58 – 51 BC). Did the accidental availability of cast iron wastes at smelting sites in Noricum play any role in the forging of steel weapons and edge tools during the Roman Republic and Roman Empire?

By the time of the building of the first ship Virginia at Fort Popham, 1608, knowledge of the Brescian method of making steel would have been as universal among European, including English, forge masters and blacksmiths as making natural steel, the most difficult of the three steelmaking strategies of the time. Nonetheless, making steel by the continental method of decarburizing cast iron (German steel) was the dominant steel producing strategy of the 16th century and required finesse of judgment about the texture of the bloom of iron evolving from the decarburized melted cast iron. Soon, the coming age of blister steel would replace bloom texture with iron and steel fracture and color as a rule of thumb guide (Barraclough, 1984) to the production of steel. In the meanwhile, any back street Bristol or countryside Forest of Dean/Weald Sussex blacksmith could make raw steel in his forge with small quantities of waste cast iron and wrought iron bar stock. As with other early age forge masters and blacksmiths, they didn’t leave a written record of their work or about their steelmaking strategies.

Toolmaking Techniques

The primordial form of all edge tools, including those that built the pinnace Virginia, is the knife. Sword making is an ancient and specialized area of knife making. The forge welding of woodworking edge tools is another variation of the art of the knife maker.

The first knives and edge tools were made of iron, not steel. Such tools were no more serviceable and possibly less durable than cold hammered bronze swords and edge tools. Once the Iron Age and its ferrous metallurgy becomes evident in archaeological sites, few knives and edge tools survive from ancient times without evidence of some steel content. Three variations of toolmaking techniques can be sketched from the accidental durable metallurgical remnants of prehistory. The rarest and most difficult to forge was the all-steel edge tool best exemplified by the Wootz steel Damascus sword, not to be confused with the pattern welded damascened swords and guns that survive today. The most well known example of a Wootz steel edge tool was the Viking sword, knowledge of the manufacture of which Viking smiths might have obtained when they ranged throughout Europe, the Black Sea, and westward to the Indian continent. No examples of woodworking tools made from Wootz steel are known to the author.

The most ubiquitous form of edge tools surviving from both prehistory and the late medieval and early modern eras, is the pattern welded sword, the most common edge tool before the era of firearms. Layers of sheet or thin bar steel were interspersed or piled (folded and welded) with thin sheets of wrought iron, reheated and reforged, sometimes many times, to produce strong durable swords. Knowledge of quenching and tempering dates to the earliest Iron Age and has been verified by metallographic analysis of the crystalline structure of the martinized steel, which results from heat treatment. Wertime (1980) notes a carefully quenched Egyptian adz dating to the 9th century BC.

Pattern welding was sometimes also used for knife and cutlery production but not usually for edge toolmaking. Variations in knife making techniques included inserting the steel blade in an iron frame such that continued sharpening of the steel edge will wear away almost the entire knife body. (INSERT Pleiner here ----- diagram) Other techniques included wrapping sheet steel around an iron core, carburizing an iron edge tool in a charcoal fire to steel it, or steeling its edge by welding on a steel cutting edge. In ancient times, that is, before the advent of the modern blast furnace (c. 1350) three principle techniques were utilized to produce edge tools.

1. The careful selection or production of nodules of steel in or from the coalescing loupe or bloom in a direct process bloomery furnace.
2. The slow and tedious carburization of the edge of an otherwise enclosed (e.g. in clay) iron tool.
3. Steeling an iron shaft or poll by welding a piece of steel to the iron.

Only a few edge tools could be produced by reforging nodules of raw steel from the bloomery or could be produced by the tedious process of carburizing the lower edge of a chisel. The oxidizing impact of the forge fire probably destroyed many an edge tool during the carburization process. Even in the 19th century, guides to blacksmithing such as Richardson's (*The Practical Blacksmith*, ____) classic are full of warnings not to overheat the tool being forged. The systematic production of steel from sheet iron or at special purpose fineries using raw steel from the bloom probably came to dominate steelmaking strategies in the centuries before the blast furnace simply because larger quantities of relatively high quality steel could be produced by forge masters whose only task was to make steel out of iron.

As the art of steelmaking became known, bar steel in small quantities could have been and, in fact, was produced not only for the sword makers of the Roman Empire, but also for the edge tools of the shipwright who built the wooden ships that sailed the Mediterranean and then the Atlantic coast of Europe. The key to producing high quality desirable edge tools with their welded steel edges was the extent of mechanical (hammering) and heat treatment (quenching then tempering to soften the hard steel) given to each steel edge tool by the blacksmith who forged it. In maritime communities these early edge toolmakers were also the shipsmiths who forged the ironware needed for ship construction.

In the early Iron Age, before the advent of the blast furnace, and especially in situations where swords for warfare were not being mass produced, the forge master operating the bloomery and producing both wrought iron and low quality natural steel with a wide variation of carbon content, was also the blacksmith who had to forge weld the final product. It was this smith who welded his precious pieces of natural steel onto the iron shaft, socket, or ax poll. In the years after the construction of the Virginia, this ancient tradition of toolmaking survived in American not only in the colonial era but throughout rural areas of North America especially in the Appalachian mountain areas until the end of the 19th century. A complex market economy of specialized trades was already developing in Europe when the Popham settlement was attempted. Bar steel produced by the sophisticated German finers was probably available as a trade commodity and was certainly the dominant strategy for steel production in England before the age of blister steel. By the end of the Elizabethan era, isolated bloomeries making natural raw steel and back alley artisans working up a batch of Brescian steel would have only been able to supply a tiny fraction of the already burgeoning demand for iron and steel for shipsmiths and edge toolmakers who made iron fittings and edge tools for the shipwrights, who made settlement of the New World possible.

The building of the pinnace Virginia, the first ship built in America that returned to Europe (twice) was a landmark event in the adventure of the settlement of North America. The origins and state of contact period ferrous metallurgy and its hidden role in the successful settlement of North America is a nearly forgotten chapter in this history.