The Earliest Shipboard Gunpowder Ordnance: An Analysis of Its Technical Parameters and Tactical Capabilities

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Abstract

Few technological developments in the history of warfare have been as portentous as the appearance around the turn of the sixteenth century of effective heavy gunpowder ordnance on shipboard, which began a new era in sea warfare. Employed on Mediterranean war galleys and Portuguese caravels, the weapons marked the solution of a series of daunting technological problems discussed in this article, beginning with the appearance of gunpowder in Europe about 1300. Unlike developments on land, change was at first gradual, but shortly after 1400 the pace of development sharply accelerated to culminate in what may legitimately be termed a revolution in firepower at sea.

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AROUND the turn of the sixteenth century, gunpowder ordnance of unprecedented effectiveness began to appear aboard European warships. Employed on Portuguese caravels and Mediterranean war galleys, these weapons swiftly and dramatically reshaped the face of warfare at sea. Tactically, they bestowed the ability to achieve quick decision in ship-to-ship encounters. Hitherto, sea fights had been attritional battles, siege warfare afloat with wooden bulwarks replacing stone battlements. Ships could now be swiftly disabled from a distance or even sunk. It did not always happen that way, even with appropriately armed vessels—sea combats are inherently uncertain encounters—but the potential was there. Operationally, gunpowder had restored the possibility of decisive battle, absent since the age of the ram-armed galley save for Byzantine successes with Greek fire and the remarkable victories of Roger of Lauria in the War of the Sicilian Vespers, 1282–87.[1] Strategically, heavy naval guns mounted aboard purpose-built warships gave the Portuguese effective control over as much of the Indian Ocean as they chose to dominate and provided the operational means for the Habsburg-Ottoman struggle for control of the Mediterranean that culminated at Lepanto in 1571.[2] Tactically, they challenged the high-sided carrack, until then the premier European sailing warship, and within a few decades would render it obsolescent save as an armed transport in distant and lightly contested waters. They also paved the way for the development of the galleon, the first genuinely transoceanic warship able to bring heavy guns offensively to bear, and—although the process took over a century and a half—the galleon evolved into the ship-of-the-line, the definitive instrument of European world hegemony.[3] These developments are matters of no small historical importance, yet their beginnings have received surprisingly little scholarly attention.

By 1500 gunpowder artillery had been used aboard European warships for over a century, but the new ordnance and the way in which it was used represented a new departure. Considered individually, few of

sity for their support, and to my fellow conferees for their comments and suggestions. I am further indebted to the anonymous referees for the *Journal of Military History* for their input and suggestions.

1. Lawrence V. Mott, *Sea Power in the Medieval Mediterranean: The Catalan-Aragonese Fleet in the War of the Sicilian Vespers* (Gainesville: University Press of Florida, 2003); John H. Pryor, "The Naval Battles of Roger of Lauria," *Journal of Medieval History* 9 (1993): 189–216. Roger of Lauria's victories were anomalies, products of the peculiarly maritime character of the war and of his tactical genius.

2. John F. Guilmartin, Jr., *Galleons and Galleys* (London: Cassell & Co., 2002), 77–97 and 126–55, for a summation.

3. John F. Guilmartin, Jr., "Military Technology and the Struggle for Stability," in *Early Modern Europe: From Crisis to Stability*, ed. Philip Benedict and Myron Guttman (Newark: University of Delaware Press, 2005), 259–77, especially 270–73.

the developments responsible for that departure were without precedent, but the way in which they came together with synergistic effect was, and we may legitimately refer to a revolution in naval gunnery.[4] We can only sketch the outlines, for the evidence is sparse, but it is apparent that the new ordnance was heavier and more efficient than that commonly in use hitherto. The best of it was cast bronze, previously reserved almost exclusively for use ashore, particularly in fortifications and siege trains. Most important, it was used differently.

The developments in gun design did not take place in a vacuum. The new ordnance was mounted aboard purpose-built warships that were employed in squadrons using novel tactics, a combination that introduced a new era in warfare at sea. The dawn of that era was demonstrated most spectacularly off the Malabar Coast in early 1503 in Vasco da Gama's defeat of an Indian-Arab fleet that vastly outnumbered his force in vessels and men. Da Gama formed his fleet into two squadrons, one of caravels and one of carracks. The caravels, though substantially smaller than the carracks, carried the heavier guns, taking advantage of the caravels' low freeboard to mount them near the waterline in order to inflict maximum damage on enemy hulls.[5] Da Gama's caravel squadron led the way in what would later be called line ahead, using superior sailing characteristics to work to windward of the Muslims. There, the caravels' broadside firepower kept the smaller and more numerous Muslim vessels at bay, destroying or disabling them by gunfire before they could close and board, leaving the carracks with their more numerous, lighter guns to mop up.[6] The result was the beginning of more than a century of Portuguese hegemony in the Indian Ocean and the emergence of tiny Portugal as a world power.

4. The earliest mention of such a revolution of which I am aware is Frank Howard's reference to a "revolution in naval armament that took place between about 1480 and 1520" in his posthumous article "Early Ship Guns. Part I: Built-up Breech-loaders," *Mariner's Mirror* 72 (November 1986): 439.

5. John F. Guilmartin, Jr., "The Military Revolution: Origins and First Tests Abroad," in *The Military Revolution Debate: Readings on the Military Transformation of Early Modern Europe*, ed. Clifford J. Rogers (Boulder, Colo.: Westview Press, 1995), 313–14. Fernando Gomes Pedrosa, "A Artilharia Naval Portuguesa no Século XVI" (paper presented at the XXIV Congress of the International Commission of Military History, Lisbon, 26 August 1998), 4, quoting the chronicler Garcia de Resende, affirms that by the reign of Dom João II (1455–95), Portuguese caravels were armed with very heavy bombards (*muito grandes bombardas*) and that the proximity of the guns to the waterline was considered an important element in their effectiveness.

6. Gaspar Correia, *Lendas da India*, 4 vols. (Porto: Lello & Irmão, 1975), 1:328–39; Geoffrey Parker, "The *Dreadnought* Revolution of Tudor England," *Mariner's Mirror* 82 (August 1996): 276. See also Guilmartin, "Military Revolution"; Richard A. Barker, "A Gun List from Portuguese India, 1525," *Journal of the Ordnance Society* 8 (1996): 52–71.

The results in the Mediterranean were more subtle operationally, but no less pervasive. At the turn of the sixteenth century, the *sine qua non* of commercial dominance and armed might afloat was the carrack, whose towering sides and ordnance-studded castles dominated sea fights.[7] To such vessels, well manned and armed, war galleys were more a nuisance than a serious threat, until galleys began sporting main centerline bow guns capable of puncturing their hulls with heavy balls of stone or iron fired from distances beyond the effective range of the carracks' light topside ordnance. To be sure, some carracks carried heavy ordnance as well—in fact, they were the first ships to do so—but for reasons of structure and stability the guns in question were mounted low in the stern, firing rearward through ports on either side of the rudder, a profoundly defensive arrangement.

Although there were precursors, about which more below, effective heavy gunpowder ordnance began to appear with some frequency on the bows of ordinary galleys (as distinct from *galées grosses* or great galleys, merchant galleys armed for war) in the 1510s. The weapons in question were main centerline bow guns in sliding carriages capable of absorbing the recoil of pieces with barrel weights ranging from 2,000 pounds to their logical upper limit of some 6,000 pounds and firing balls weighing from 20 pounds, to, exceptionally, 100.[8] Galleys so armed and employed in squadrons fighting in line abreast quickly changed the character of warfare at sea.[9] Tactically, galleys with heavy centerline ordnance coming upon a carrack in light air or a calm could stand off at a safe distance, immune to the carrack's lighter ordnance, pick their time and place of attack, and bombard their larger opponent into submission. The earliest combat between heavily armed galleys and sailing warships of which I am aware took place in the spring of 1513 and, as we shall see, resulted in a significant victory for the galley.[10] The heavily armed war galley took

7. Ian Friel, "The Carrack: The Advent of the Full Rigged Ship," in *Cogs, Caravels, and Galleons: The Sailing Ship, 1000–1650*, ed. Richard Unger (London: Conway Maritime Press, 1994), 86–90.

8. John F. Guilmartin, Jr., "The Early Provision of Artillery Armament on Mediterranean War Galleys," *Mariner's Mirror* 59 (August 1973): 257–80, especially 263–65; 1510 is my best estimate for a not later than date for recoil-absorbing carriages for main centerline bow guns. I have used pounds avoirdupois throughout.

9. N. A. M. Rodger, "The Development of Broadside Gunnery, 1450–1650," *Mariner's Mirror* 82 (August 1996): 301–24, especially 302; Jan Glete, *Navies and Nations: Warships, Navies and State Building in Europe and America, 1500–1860*, 2 vols. (Stockholm: Almqvist and Wicksell, 1993), 1:140.

10. Ottoman and Venetian galleys engaged sailing warships at Zonchio in 1499, but do not seem to have had main centerline bow guns. For the 1513 combat, see Nicholas A. M. Rodger, *The Safeguard of the Sea: A Naval History of Britain, 660–1949* (New York and London: W. W. Norton, 1997), 170. At the battle of Prevesa, 29 September 1538, a Venetian "great galleon" successfully fended off the attacks of

time to assert its dominance, however, for such vessels were expensive to build, arm, and operate, and had little commercial utility, while the carrack was a capacious cargo carrier. That notwithstanding, by the 1520s cannon-armed war galleys fighting in squadrons were firmly established as the *sine qua non* of offensive strategic operations in Mediterranean waters. Tactical dominance was not far behind: as maritime historian Jan Glete's exhaustive data show, in the Mediterranean, sailing warships declined precipitously in numbers beginning in the 1540s and had all but disappeared by the 1570s.[11] The strategic consequences were not trivial. Tactically and operationally, the sixteenth-century struggle for dominance of the Mediterranean was largely waged by war galleys. Strategically, the outcome of that struggle was in no small measure determined by the success of the contending parties in mobilizing the resources needed to build, operate, and maintain galley fleets. In addition, main centerline bow gun-armed galleys also proved well suited to operations in the English Channel and in the Baltic, where they continued in use into the eighteenth century.

The importance of the sixteenth-century revolution in naval ordnance is clear. Conversely, the manner in which it came about is anything but, and we are left with a question: How was it that gunpowder technology, seemingly mature by the turn of the sixteenth century, had so little impact on armed conflict at sea previously and so much subsequently? Clearly, the technological and tactical maturity of heavy ordnance at sea lagged significantly behind that on land. The chronology of gunpowder's earliest strategic triumphs makes the point: against the establishment of Portuguese hegemony in the Indian Ocean, we may reasonably set French victory in the final stages of the Hundred Years' War, 1437–53, and the fall of Constantinople to Ottoman guns in 1453. How, then, do we explain the delay of half a century?

One possibility is that sailors and shipwrights were less open to innovation than their equivalents ashore, and there is a kernel of truth in this hypothesis. Both sailors and shipwrights were generally reluctant to

cannon-armed Turkish galleys; the episode was much noted at the time, no doubt because it was exceptional (two "tall ships" carrying Spanish infantry were overwhelmed by Muslim galleys in the same fight); Richard Knolles and Sir Paul Rycaut, *The Turkish History* (London, 1687), 464.

11. Glete, *Navies and Nations*; Glete has tabulated every known warship in every European and American navy from 1500 through 1860 in five appendixes, 2:499–714. Glete, 1:140, notes the disappearance of sailing warships from the Mediterranean between the 1540s and 1570s in the following terms: "It is hard to avoid the conclusion that the disappearance of the sailing warships during a period of *expanding* naval forces and intensive warfare indicates that the early 16th century sailing warship had many shortcomings and that the galley proved superior in the Mediterranean environment."

undertake radical departures from established practices of proven worth, and the extreme vulnerability of ships to fire no doubt made sailors wary of gunpowder. But conservative design practice is not inimical to rapid progress, for the cumulative effect of incremental changes can be enormous. It is worth noting in this regard that the period between the appearance of gunpowder weapons in Europe and the technical maturation of land ordnance, roughly 1325 to 1450, coincides almost exactly with the development of the full-rigged ship, a remarkable example of accelerated technological innovation.

At the broad level of resource allocation, the locus of political power was ashore, serving to channel money and ingenuity toward the solution of problems of obvious value to land-bound monarchs and ruling councils to whom the importance of fortifications and siege trains was more evident than that of naval armaments. Moreover, when gunpowder weapons made their debut in Europe, capital was scarce and maritime armaments had to prove their strategic worth to attract investment. Only where maritime commerce was considered vitally important and where the state possessed significant sources of tax revenue and effective fiscal machinery were these constraints likely to be overcome, considerations which help to explain the leading roles of Venice and Portugal in the development of effective naval ordnance.

In the final analysis, however, the evidence suggests that while the factors noted above played a role in retarding the development of naval ordnance, technical problems peculiar to service afloat were the key factor. This is all the more evident when we consider the enormous advantages of ships over land transport in carrying heavy and bulky loads, including weaponry.

The main purpose of this essay, then, is to identify and analyze the key technological and conceptual developments that led to the appearance of effective naval ordnance. This is not a simple matter, for written records are scarce. Moreover, the process of technical development was anything but straightforward and varied considerably from place to place.

The essential first step was the discovery of gunpowder, black powder in modern terminology, a mechanical mixture of saltpeter, charcoal, and sulfur. Black powder was known in China by the eleventh century, was used in cannon by the first quarter of the twelfth, and probably reached Europe through the Mongol invasions of the 1220s and 1240s.[12]

12. Jixing Pin, "The Origin of Rockets in China," in *Gunpowder: The History of an International Technology*, ed. Brenda J. Buchanan (Bath, U.K.: Bath University Press, 1996), 25–32, for early Chinese use of gunpowder. See Lu Gwei-Djen, Joseph Needham, and Phan Chi-Hsing, "The Oldest Representation of a Bombard," *Technology and Culture* 29, no. 3 (July 1988): 594–695, for evidence of Chinese guns firing spherical projectiles prior to 1128. Iqtidar Alam Khan, "The Role of the Mongols in

The modern and presumably optimum recipe is 75 percent saltpeter, 15 percent charcoal, and 10 percent sulfur by weight, but the exact proportions are not critical, for the chemical and thermodynamic decomposition reactions are remarkably robust, and seemingly major variations in the proportions make little difference.[13] More important than the proportions was the quality of the ingredients, particularly saltpeter. The saltpeter in modern black powder is potassium nitrate. By contrast, as Gerhard Kramer has shown, that in the earliest European powder was made according to the original Chinese methods and was thus mainly calcium nitrate, with some potassium and manganese nitrates.[14] That is significant, for in contrast to potassium nitrate, calcium nitrate is highly deliquescent, that is, it readily absorbs atmospheric moisture with obvious implications for use afloat. In naval service, atmospheric moisture absorption was a problem with potassium nitrate gunpowder;[15] it must have been unmanageable with calcium nitrate powder. The solution came when European saltpeterers learned to treat aqueous saltpeter with wood ash to precipitate out calcium and manganese salts, enabling them to produce relatively pure potassium nitrate. When this took place is unclear, but Bert Hall, who has investigated the matter in depth, concludes that it was about 1400.[16] Knowledge of the process seems to have spread slowly—saltpeterers and powder makers kept their secrets well—

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the Introduction of Gunpowder and Firearms in South Asia," in Buchanan, *Gunpowder*, 33–44, offers a convincing presentation of evidence for an analogous Mongol transmission of gunpowder technology to India.

13. John F. Guilmartin, Jr., "Ballistics in the Black Powder Era," in *British Naval Armaments,* Royal Armouries Conference Proceedings 1, ed. Robert D. Smith (London: Trustees of the Royal Armouries, 1989), 73–98, especially 74–76. See Niccolò Tartaglia, *Three Bookes of Colloquies Concerning the Arte of Shooting in Great and Small Peeces of Artillerie . . .* , trans. Cyprian Lucar (London: John Harrison, 1588), 71–72, for mid-sixteenth-century recipes in which the proportion of saltpeter varies from 61 percent to 78 percent and that of charcoal from 24 percent to 11 percent. Note that the propellant characteristics of black powder differ radically from those of modern, nitrocellulose-based propellants and that attempts to analyze the design and performance of black powder ordnance based on data gained from experiments with modern propellants are of limited value at best.

14. Gerhard W. Kramer, "*Das Feuerwerkbuch*: Its Importance in the Early History of Black Powder," in Buchanan, *Gunpowder*, 51–52.

15. That was because charcoal is modestly deliquescent, though the presence of magnesium and sodium salts as impurities in the saltpeter contributed to the problem. See Howard Douglas, *A Treatise on Naval Gunnery, 1855* (facsimile ed., London: Conway Maritime Press, 1982), 486–92.

16. Bert S. Hall, "The Corning of Gunpowder and the Development of Firearms in the Renaissance," in Buchanan, *Gunpowder*, 93–94, cites an unclear reference in a German document dating from 1411 and believes that the process was known somewhat earlier; in this he disagrees with Kramer, "*Das Feuerwerkbuch*," 51–52, who concludes that the process was not discovered until 1529–40.

but it is suggestive that records of shipboard ordnance, rare before the turn of the fifteenth century, become increasingly common thereafter, a point to which I shall return.

Solid evidence for European guns does not appear until the mid-1320s, and when it does, the weapons in question were vase-shaped affairs firing quarrels or bolts. Contemporary depictions show them firing from flimsy-looking trestle tables without stocks or restraining tackle, suggesting modest power and recoil.[17] At first, guns seem to have been used mainly to defend fortifications, reflecting their considerable weight and bulk relative to their modest destructive powers.[18] It should also be noted that for the first half century or so, most, though not all, gunpowder weapons were quite small.[19] Then, about the middle of the fourteenth century, European smiths perceived that guns with tubular barrels of welded hoop and stave construction firing spherical projectiles were superior to the alternatives. This perception may have stemmed from improvements in smelting methods and foundry practice, specifically hammer welding. It may have stemmed from the realization that very short barrels and barrels with inverse taper wasted most of the powder's propulsive force. More likely, it was a combination of the two.[20] Whatever

17. Based on two English manuscript illuminations circa 1326, in Walter de Milimete, *De Notabilibus, Sapientiis et Prudentiis Regem*, fol. 70v, MS 92, Bodleian Library, Oxford, United Kingdom; and *De Secretis Secretorum Aristotelis,* fol. 44v, Add. MS. 47680, British Museum, London. The depictions, probably by the same artist, are realistic and technically credible; see Kelly R. DeVries, *Medieval Military Technology* (Peterborough, Ontario: Broadview Press, 1992), 144–45. I am indebted to Kelly DeVries for sharing his insights concerning the identity and dating of these depictions.

18. The earliest recorded use of cannon in a siege was by the English defenders of Breteuil in Normandy in 1356, recorded in *Chroniques de Jean Froissart* (Paris, 1869–1975), book 1, chaps. 369–70, cited in "The Manufacture and Use of Cannons at the Siege of St-Sauveur-le-Vicomte, 1375," by Peter J. Burkholder (M.A. thesis, University of Toronto, 1992), 10.

19. Clifford J. Rogers, "Military Revolutions of the Hundred Years War," in Rogers, *The Military Revolution Debate*, 55–94, especially 64–65. Note, however, that the gun depicted in *De Secretis Secretorum Aristotelis*, Fig. 8, in Gwei-Djen, Needham, and Chi-Hsing, cited above, n. 12, was some eight feet long and three feet in diameter if it was drawn to the same scale as the knights firing it.

20. The introduction of the Catalan forge circa 1300 is generally credited with giving European smiths the ability to smelt high-quality wrought iron in substantially greater quantities than previously. The delay of a half century suggests that the breakthrough involved fabrication rather than smelting. The most likely candidates are larger, hotter forges and improved welding techniques. Economic factors no doubt played a role as well since ordnance was expensive and became disproportionately more so as size increased. What is clear is that the fabrication of large wrought-iron ordnance was an immensely difficult enterprise requiring extremely high levels of skill and organization. See Robert D. Smith and Ruth Rhynas Brown, *Bombards: Mons Meg and Her Sisters*, Royal Armouries Monograph 1 (London: Trustees of the

the causes, it was a major breakthrough, for the new guns not only were more efficient, but also could be made larger. Wrought-iron hoop and stave construction quickly became the norm for large ordnance, and by the 1360s and 1370s, French, Flemish, and German founders were building pieces capable of throwing stone balls weighing as much as 220 pounds.[21] Called bombards, these pieces had relatively short barrels of five to six calibers (that is, the length of the bore was five or six times the internal diameter) and powder chambers with internal diameters between a half and third that of the bore.[22] An offshoot of these developments was the first effective use of guns in the Mediterranean, by German gunners in Venetian service who employed two wrought-iron guns at the siege of the Genoese fortress of Choza in 1366.[23]

Large bombards were the first guns capable of doing serious damage to fortress walls or the hull of a ship, but considerable time was to pass before their powers were systematically exploited. The reasons for this are unclear, but the intellectual heritage of the trebuchet, the premier siege engine of medieval times, was surely a factor. Like trebuchets, large guns were viewed first and foremost as siege weapons, and like trebuchets they threw spherical stones.[24] We should not be surprised, then,

Royal Armouries, 1989), viii–ix; the welding process required the smith to coordinate the sledgehammer blows of from three to as many as "twenty or thirty" strikers, judging the heat, positioning, and condition of the forging by eye.

21. Burkholder, "Cannons," 10–11, 26, cites a late fourteenth-century Pisan chronicle referring to the use of a bombard weighing 1,000 kilograms (2,200 pounds) in 1362; and *Froissart*, book 1, chap. 786, noting that the Duke of Burgundy used guns throwing balls of 100 kilograms (220 pounds) and more at the Siege of Oldkruik in 1377.

22. Smith and Brown, *Bombards*, vii; the ratio of bore to powder chamber diameters is mine based on Smith and Brown's figures and my own observations. I am considering the length of the chamber separate from that of the barrel.

23. Luís Collado, *Plática Manual de Artillería* (Milan, 1592), *Capitulo XI*, fol. 6, 8. Writing in the 1580s, Collado drew on oral traditions as well as documentary evidence; he also refers to Choza as Claudio Fossa.

24. The trebuchet threw its projectiles from a sling attached to the long end of a pole mounted on an axle set atop an elevated frame. Shooting was accomplished by pulling the short end of the pole downward. In the earliest trebuchets, motive power was provided by people pulling on ropes attached to the short end of the pole. Called traction trebuchets, these reached the Mediterranean from China in the late sixth century AD; though of comparatively modest power (projectiles of five to twenty pounds were probably typical), they were useful siege weapons. The counterpoise trebuchet appeared in Europe in the mid to late twelfth century and used a fixed or pivoted weight for motive power. Unlike the traction trebuchet, these could be made very large. See Paul E. Chevedden, Les Eigenbrod, Vernard Foley, and Werner Soedel, "The Trebuchet," *Scientific American* 273 (July 1995): 66–67; and W. T. S. Tarver, "The Traction Trebuchet: A Reconstruction of an Early Medieval Siege Engine," *Technology and Culture* 36 (January 1995): 145, 161.

that gunners at first imitated the trebuchet's high, looping trajectory, for they had no other conceptual framework on which to draw.[25] Nor should we be surprised that founders sought to make more powerful guns by increasing projectile size in apparent imitation of trebuchets, the largest of which could throw projectiles weighing a ton or more.[26] In the meantime, small guns predominated: at the siege of St-Sauveur-le-Vicomte in Normandy in 1375, the French siege train included a gun that fired a 100-pound stone ball, but 31 pounds of gunpowder sufficed to charge "three large iron cannons, 24 bronze cannons, and five smaller iron guns," an average charge of less than a pound.[27] This heterogeneity is noteworthy and suggests that cannon design remained in flux.[28]

The first clear evidence of effective shipboard gunnery comes from this period with the use of galley-mounted bombards by Venice in the 1379–80 siege of Chioggia, a singular and intriguing case. Pressed hard by a close Genoese blockade based in the port of Chioggia at the southern end of the lagoons, Venice responded by besieging the besiegers, rooting them out in a bastion-by-bastion, watercourse-by-watercourse campaign.[29] It was a desperate moment for Venice, and the island republic mobilized every resource at her disposal, including two heavy siege bombards, firing stone balls of 205 pounds and 174 pounds respectively,[30] and galley-mounted bombards, evidently small though we know nothing about them in detail. Significantly, bombard-armed galleys were used only in the siege, probably because the Venetian powder was made with calcium nitrate saltpeter and spoiled quickly.

The turn of the fifteenth century saw significant advances in the gunfounder's art, manifested most spectacularly in the appearance of mon-

25. John F. Guilmartin, Jr., "Changing Technology and Mediterranean Warfare at Sea in the Sixteenth Century," 2 vols. (Ph.D. diss., Princeton University, 1971), 2:326–27; and Tarver, "Traction Trebuchet," 163–64, for a description of the trebuchet's "eerily Aristotelian" trajectory.

26. Chevedden et al., "The Trebuchet," 66–71.

27. Burkholder, "Cannons," 40.

28. This impression was reinforced by an unscientific survey of fourteenth- and fifteenth-century depictions of gunpowder ordnance in modern works, e.g., Richard Humble, *War in the Middle Ages* (Wigston, Leicester: Magna Books, 1989); and H. W. Koch, *Medieval Warfare* (Greenwich, Conn.: Bison Books, 1978). The same point applies to museum specimens. My survey suggested that wrought-iron guns with tubular barrels gradually became more or less standard during the fifteenth century.

29. The best available account of the siege of Chioggia in English is Francis C. Hodgson, *Venice in the Fourteenth and Fifteenth Centuries* (London: George Allen and Sons, 1910), 243–56. The basic primary source is Daniele di Chinazzo, *Cronica de la Guerra da Veniciani a Zenovesi* (Treviso, 1439), in *Monumenti Storici*, *Nuova Serie*, ed. Vittorio Lazzarini, vol. 11 (Venice: Deputazione di Storia Patria per le Venezie, 1958); Chinazzo was in Venice during the war.

30. Chinazzo, *Cronica*, 86–103.

ster siege bombards, now of cast bronze as well as wrought iron. A bronze bombard in the collection of the Musée de l'Armée, Paris, cast in Innsbruck in 1404, weighs 10,100 pounds (4,581 kilograms) and threw a 480-pound (219-kilogram) stone ball,[31] and by mid-century muzzle-loading wrought-iron bombards of gargantuan proportions were being made in northern France and Flanders. The biggest of these weighed upwards of 15,000 pounds (6,800 kilograms), firing 300-pound (136-kilogram) projectiles,[32] and the Turks cast bronze bombards that were even larger.[33] Guns of this type were used on shipboard on occasion: a Turkish carrack mounting a pair of huge bombards fought at the battle of Zonchio in 1499.[34] But such cases were exceptional, and it is clear that the vast majority of bombards in fifteenth-century warship inventories were wrought-iron breech-loaders of modest dimensions.[35]

Concurrent with the appearance of the monster bombards, a class of wrought-iron breech-loaders was evolving with substantially longer barrels, ranging from twenty calibers' length to, exceptionally, forty or more, and having powder chambers of the same internal diameter as the bore. They emerged from two perceptions: the first was the realization that it was not only the mass of a projectile, lobbed trebuchet-like, that inflicted damage, but that impact velocity was important as well; the second was that there was an essential connection between barrel length and effective range and destructive power.[36] These pieces were variously

31. Merrill Lindsay, *One Hundred Great Guns: An Illustrated History of Firearms* (New York: Walker, 1967).

32. The values cited are for Edinburgh's celebrated Mons Meg in Smith and Brown, *Bombards*, viii–ix.

33. For example, the so-called Dardenelles gun in the collection of HM Royal Armouries, Tower of London. Cast in 1464 in two pieces with a screw-on powder chamber, probably for ease of transport, it is 17 feet (518 centimeters) long assembled, has a 25-inch (63.5 centimeters) bore, and weighs some 19,714 pounds (8,941 kilograms); Howard L. Blackmore, *The Armouries of the Tower of London*, vol. 1, *Ordnance* (London: HMSO, 1976), 172.

34. Kâtib Çelebi (Haji Khalifa), *The History of the Maritime Wars of the Turks*, trans. James Mitchell (London: Oriental Translation Fund, A. J. Valpy, 1831), 20–21. Çelebi does not use the term *bombard*, but refers to the pieces as "immense guns." Perhaps significantly, he states that the builder of the vessel had worked in Venice as a shipbuilder.

35. The *bombardas* and *lombardas* listed aboard Spanish vessels in the sixteenth century were probably no larger than six to twelve pounders. See, for example, *"Ordenanzas Reales para la cassa* [sic] *de la contratación de Sevilla . . . ,"* a compilation of ordnance required on vessels trading with the Indies, 1543–1556, *Colección Navarrete*, Vol. II, dto. 4, fol. 55–132; and *"Relación de las cinquenta chalupas y dos pataches . . . ,"* a survey of ordnance aboard fifty private vessels berthed near Seville in 1564, Vol. XII, dto. 77, fol. 281–87, Museo Naval, Madrid. Rodger, "Broadside Gunnery," 302, agrees that the term *bombard* denoted a relatively small piece in mid-fifteenth century naval usage.

36. Guilmartin, "Changing Technology," 2:325–28.

called *veuglaires* (French); *cerbatanas*, *pasavolantes*, or *bombardetas* (Spanish); *schlangen* (German); or slings (English). So far as we can judge, the largest threw balls of some twenty to thirty pounds. Whereas bombard design was driven by the desire to maximize projectile size, the design of these pieces was driven by the desire to maximize velocity. Some were strong enough to take a cast-iron ball, and as foundry techniques improved, the advantages of cast-iron projectiles—lower cost and greater penetration—became evident. At the same time, bronze-casting technique caught up with wrought-iron foundry practice. By the final decades of the fifteenth century, some few founders were casting bronze muzzle-loaders of similar proportions designed to fire an iron ball, ancestors of the later culverins, sakers, and falconettes.[37]

At the same time, black powder began to assume its definitive form with the appearance of corning, the process of compounding the ingredients wet and forming the powder into grains. With full hindsight, the ballistic advantages of corned powder are clear. Since the decomposition reaction spreads more rapidly from grain to grain than within the grain by a factor of about 150, corned powder develops its propulsive force far more quickly than a tightly packed charge of dry-mixed, or serpentine, powder. Gunners were slow to exploit this advantage, not least of all because fast-burning corned powder could cause guns designed for serpentine to explode. Perhaps more to the point, the inspiration that led to corning had nothing to do with ballistic performance. In its earliest form the process involved pressing moistened powder into small cakes or lumps to reduce the surface area exposed to atmospheric moisture in order to extend shelf life. Before use, the lumps were broken up into crumbs which, serendipitously, allowed the decomposition reaction to proceed more rapidly.[38] Recognition that crumb powder was "stronger" then led to the development of corned powder. How rapidly corning was perfected and how quickly the process assumed its final form, in which the grains are tumbled in drums to give them spherical form and sieved for uniformity of size, is unclear. The earliest record of a precursor process dates from 1411, and a fuller description is given in an edition of the gunner's manual *Das Feuerwerkbuch* dating from about 1420.[39]

All of these developments came together with synergistic effect around 1420–40 in northern France, with founders and gunners in Bur-

37. The argument that the culverin class of bronze muzzle-loaders evolved from the earlier *cerbatanas*, *pasavolantes*, etc., is supported by the similarity of proportions and by the fact that all fired iron balls. In addition, the raised reinforcing rings on the wrought-iron pieces are faithfully reproduced in bronze despite the fact that they have no functional value in a cast bronze gun. The term *schlangen* applied to both wrought-iron and bronze pieces in German.

38. Hall, "Corning," 88–89.

39. Ibid., 89.

gundy, Germany, Spain, and the Ottoman Empire following suit. The effects were most apparent in siege warfare where guns were used increasingly to breach walls by direct battery, rather than to fire into towns in the manner of trebuchets.[40] These developments found their apotheosis in the reform of the French royal artillery by the brothers Jean and Gaspard Bureau in the final stages of the Hundred Years' War. In standardizing on bronze muzzle-loaders using corned powder to drive a cast-iron ball, the Bureaus anticipated the developments of the next century.[41] Though pushed hardest in France, such reforms were indicative of an accelerated pace of technical development that would encompass Europe and the Mediterranean world from Morocco through Iberia, France, Italy, and Germany, into the Balkans. The final touch was the adoption on large ordnance of integral trunnions, cylindrical lugs projecting from the barrel at right angles just ahead of the center of gravity. Suspended from its trunnions in an appropriately designed carriage, such a barrel could be freely adjusted for elevation by sliding a wedge beneath the breech. This feature gave land artillery its essential shape for the next three and a half centuries and soon found its way into naval service. The results, unleashed on the Mediterranean world in 1494 with Charles VIII's invasion of Italy, were shattering. Imitation is the sincerest form of flattery, and in 1500 the best pieces in the Spanish artillery train destined for Italy were described as *cannoni a la francese*—French-style cannons—by an informed Venetian reporter.[42]

References to guns at sea before 1400 are few and equivocal and, the siege of Chioggia aside, where they can be trusted at all seem mostly to involve guns carried as cargo.[43] Then from around 1410 references to shipboard ordnance become common, indeed almost commonplace. The chronicler Christine de Pizan, writing at about that date, advocates

40. When guns began to be used systematically for battery is controversial. I agree in substance with Clifford Rogers, "Military Revolutions," 64–73, who dates a revolution in battery to 1420–40. Rogers's principal critic, Kelly DeVries, has correctly noted earlier examples of battery used, for example, by Charles of Burgundy against Oldkruik in 1377, cited above, but I agree with Rogers's argument that these were isolated examples.

41. H. Dubled, "L'Artillerie Royale Française à l'Époque de Charles VII et au début du règne de Louis XI (1437–1469): Les Frères Bureau," *Sciences et Techniques de l'Armament: Mémorial de l'Artillerie Française* 50, pt. 4 (1976): 571–72; the reforms can reasonably be dated to Jean Bureau's appointment as Royal Counselor to King Charles VII in 1437, ibid., 557–58.

42. Gomes Pedrosa, "Artilharia," 1, citing *I Diarii Marino Sanuto*, ed. Rinaldo Fulin et al., 56 vols. (Venice: 1879–1903), 1:391.

43. Kelly R. DeVries, "A 1445 Reference to Shipboard Artillery," *Technology and Culture* 31 (October 1990): 819–29, for a comprehensive discussion.

"greeting" enemy ships "ryght well with gode bombardes,"[44] and English warship inventories from the reign of Henry IV include ordnance clearly intended for shipboard use. The earliest of these, dating from 1410–12, are for the *Christopher,* listing three iron guns with stocks and five chambers, and for the *Marie of the Tower,* listing an iron gun with two chambers and a "brass" gun with one.[45] The royal galley (*galera real*) of Alfonso V of Aragon mounted two bombards in 1418,[46] and references proliferate thereafter. The change was abrupt and, in the absence of other causal factors, is probably attributable to the adoption of potassium nitrate saltpeter: correlation is not causation, but the timing is suggestive.

Most shipborne ordnance remained small for several decades (the bombards on Alfonso's royal galley were probably small pieces mounted on either side of the galley's "spur," or beak). Note, for example, a French arms contract from the beginning of the fifteenth century involving forty "large" vessels in La Rochelle, each of which was to be armed with four culverins and two *veuglaires*. The culverins fired lead projectiles, clear evidence of small size, and each *veuglaire* was to be furnished with 120 stones and 60 pounds of powder, also indicative of modest size.[47] This impression is reinforced by the 1445 arms inventory of a Burgundian war galley listing five *veuglaires*, each with three chambers; two mounted culverins, each with three chambers; and twelve culverins *à main*, that is, hand culverins. The *veuglaires* were four feet long and had four- inch bores, making them three pounders, and the culverins were smaller still.[48] This inventory, the earliest of a war galley of which I am aware, is particularly valuable in that it gives us some sense of how early shipborne gunpowder ordnance was used. Twelve large crossbows of steel and their winding tackle and twelve smaller steel crossbows are listed ahead of the *veuglaires*, suggesting that the latter were looked

44. Cited by DeVries, "1445 Reference," 821, 821 n. 14; his source is Christine de Pizan, *The Book of Fayttes of Armes and of Chyvalrye*, trans. William Caxton, ed. A. T. P. Byles, 2nd ed. (London: Oxford University Press, 1937), 182.

45. Frank Howard, *Sailing Ships of War, 1400–1860* (New York: Mayflower Books, 1979), 38.

46. Jorge Vigón, *Historia de la Artillería Española*, 3 vols. (Madrid: Instituto Jeronimo Zurita, 1947), 1:84–85, citing Antonio Capmany y Montpalau, *Ordenanzas de las Armadas Navales de la Corona de Aragón* (Madrid, 1787). Francisco-Felipe Olesa Muñido, *La Organización Naval de los Estados Mediterráneos, y en Especiál de España durante los Siglos XVI y XVII*, 2 vols. (Madrid: Editorial Naval, 1968), 1:312, gives the date as 1481, a typo (Alfonso V reigned 1416–58), repeated in my "Early Provision," 260.

47. Philippe Contamine, *War in the Middle Ages*, trans. Michael Jones (New York: Basil Blackwell, 1984), 206.

48. DeVries, "1445 Reference," 822–23. I computed projectile weight assuming marble balls and windage (the difference between bore and ball diameter) of .12 inch.

upon as crossbow equivalents with the advantage of mechanical simplicity and the disadvantage (or so I presume) of greater cost.[49] At least in this case, mechanical and gunpowder artillery plainly occupied the same tactical niche and were used within the same conceptual framework.

With few exceptions, gunpowder ordnance on sailing vessels remained small through the end of the fifteenth century and consisted of wrought-iron bombards on sledge or trestle mounts and swivel guns, mostly wrought-iron breech-loaders. Evidence includes five wrought-iron breech-loaders in the collection of the Tøjhusmuseet (Royal Arsenal Museum) in Copenhagen recovered from a late fifteenth- or early sixteenth-century wreck off Anholt island in the Baltic[50]; ordnance recovered from a wreck on Molasses Reef in the Turks and Caicos Crown Colony in the Caribbean, dated to circa 1495–1525[51]; English ships' inventories; and pictorial evidence, notably the Flemish artist WA's depiction of a carrack, probably drawn in 1467, and illustrations in the so-called Warwick Roll dating from about 1480.[52] WA's carrack and the Warwick Roll are of particular value for their superior draftsmanship and detail. Considered in light of other contemporary depictions and archaeological evidence, they give a reasonably firm idea of the armament of contemporary northern European carracks. WA's carrack was armed with eight wrought-iron guns firing above the rail beneath the stern castle and a small, stocked, wrought-iron muzzle-loader in the mizzen top.[53] André Sleeswyk argues convincingly that the engraving was drawn as the basis for a votive model used to celebrate the wedding feast of Charles the Bold of Burgundy and Margaret of York.[54] If he is right, the light armament is noteworthy, for this was hardly the occasion for a royal bridegroom to understate his power, nor was Charles one likely to do so! The absence of gunpowder ordnance at the foretop and on the forecastle, the heart of the vessel's offensive power, is striking, a point underlined by a boarding grapple hanging beneath the bowsprit. The large carracks on the Warwick Roll were armed with six to eight wrought-iron guns

49. DeVries, "1445 Reference," 828–29 (a transcription of the inventory).

50. Howard, "Early Ship Guns, Part I: Built-up Breech-loaders,"440–48.

51. Joe J. Simmons, III, "Wrought Iron Ordnance; Revealing Discoveries from the New World," *International Journal of Nautical Archaeology and Underwater Exploration* (henceforth *IJNA*) 17 (January 1988): 25–34.

52. André Wegener Sleeswyk, "The Engraver Willem A. Cruce and the Development of the Chain-Wale," *Mariner's Mirror* 76 (November 1990): 345–61, for WA's identity and the dating of the depiction. The Warwick Roll illustrations are reproduced in part in Howard, *Sailing Ships of War*, 12, Fig. 2, and 19–27.

53. Sleeswyk, "Engraver Willem A. Cruce," 347, Fig. 2; only the port side is shown and I have assumed lateral symmetry.

54. Sleeswyk's argument for Cruce's identity, "Engraver Willem A. Cruce," 350–52, is compelling; see also Friel, "The Carrack," 79.

mounted to fire in broadside above the midship bulwarks; if they were drawn to the same scale as the humans beside them, the largest of these would have fired a stone ball of only three pounds of so. The impression that guns were not the heart of the carrack's fighting power as late as the 1480s is reinforced by a Warwick Roll drawing of an encounter between the Earl of Warwick's ship and two French or Genoese carracks: although guns are shown, the brunt of the fight is borne by longbows on the one side and by crossbows, lances, and gads (iron javelins) and stones thrown from the masthead tops on the other.[55]

Guns protruding through circular ports in the hull begin to appear on depictions of sailing warships in the last two decades of the fifteenth century, suggesting larger guns.[56] That having been said, however, carracks did not commonly mount ordnance capable of doing serious damage to ships' hulls until a decade or so after the turn of the sixteenth century when, or so we surmise, the invention of the watertight gunport made it possible to mount them low in the hull on what would become the gun deck. In the meantime, the tendency was toward larger numbers of small guns firing above the bulwarks and rails.[57] It was against this background that the Portuguese began arming caravels with heavy ordnance.

On balance, it does not appear that early Portuguese success with heavy naval ordnance was attributable to any one technological breakthrough, for which there are four candidates: the watertight gunport, corned powder, improved gun carriages, and guns of new and superior design. Acting in combination, these would eventually increase the effectiveness of sailing warships dramatically, but the effects are barely visible prior to the Invincible Armada of 1588, and it would be a mistake to read the developments of the late sixteenth century backward in time. The earliest evidence of watertight gunports is in the depiction of a three-masted Flemish vessel on the seal of Maximilian, Prefect of Burgundy, dated 1493,[58] but the first gunports about which we know anything were mounted on ships' sterns,[59] and it is clear that the heaviest Portuguese ordnance in 1503 fired laterally. While the Portuguese were

55. Howard, *Sailing Ships of War*, 12, Fig. 2.

56. For example, on a cog on the seal of Louis de Bruges, Lord of Gruythuse, dated 1482. See Timothy Runyan, "The Cog as Warship," in Unger, *Cogs, Caravels and Galleons*, 57. For a 1490 German depiction of a carrack, see Howard, *Sailing Ships of War*, 41, Fig. 49.

57. As, for example, the carrack on Jacobo de Barbari's 1500 engraving of Venice, in Friel, "The Carrack," 79, Fig. B; and see Björn Landström, *The Ship: An Illustrated History* (Garden City, N.Y.: Doubleday, 1961), 109, Fig. 280, for a convincing reconstruction of the same carrack.

58. Detlev Ellmers, "The Cog as Cargo Carrier," in Unger, *Cogs, Caravels and Galleons*, 46. The development of the lidded, watertight gunport has been traditionally attributed to a French shipwright named Descharges at Brest in 1501; Friel, "The Carrack," 89.

59. Rodger, "Broadside Gunnery," 302. Rodger raises the interesting possibility

quick to embrace the watertight gunport and may even have invented it, the concentration of heavy ordnance aboard caravels rather than on the larger carracks argues against its widespread adoption prior to the 1520s.[60]

The Portuguese surely had corned powder by 1500, though whether or not they used it in their largest ordnance is unclear.[61] In any case, there is no need to invoke corned powder, for serpentine continued to be used at sea for many decades and would have served. There is no evidence one way or the other that the Portuguese used novel gun carriages aboard their sailing warships and, as with serpentine powder, sledge carriages, perhaps with a pair of wheels forward to facilitate aiming, would have sufficed.

Finally, it is possible—indeed, probable in my view—that at the turn of the sixteenth century, Portuguese ordnance was the equal of any in the world, though that does not necessarily imply radically new design. It *is* clear that the design of heavy Portuguese ordnance was distinctive. The term *camelo*, applied to the standard Portuguese battery piece for shipboard use, has no equivalent in other European languages,[62] and the design of the *camelo* and smaller *camelete* is unlike that of other European naval guns with which I am familiar.[63] *Camelos* were relatively long muzzle-loading stone throwers with powder chambers of reduced diameter; they could be of bronze or wrought iron.[64] Their proportions suggest that they were exceptionally efficient in terms of destructive power as a function of barrel weight, but while the *camelo's* performance was no doubt superior, the distinction was one of degree rather than kind.

The Portuguese breakthrough in gunnery afloat must have begun with the dual appreciation that a large gun firing a stone ball could do

that the development of the watertight gunport and the appearance of the flat transom in northern waters were related.

60. Gomes Pedrosa, "Artilharia," 6–7, citing Fernão Lopes de Castanheda, *Historia do Descobrimento e Conquista da India pelos Portugueses*, ed. Pedro de Azevedo (Coimbra: University de Coimbra, 1924–29), 5:108, for early Portuguese use of the watertight gunport.

61. Barker, "Gun List," 54, argues that the Portuguese were not using corned powder circa 1500, but notes that the Portuguese distinguished between small arms powder and artillery powder. The distinction might have involved corning, grain size, the proportion of saltpeter, or a combination thereof.

62. The names of the main types of heavy gunpowder ordnance were common to most of the major European languages. See Henry Kahane and Andreas Tietze, *The Lingua Franca in the Levant* (Urbana: University of Illinois Press, 1958), especially 100.

63. Barker, "Gun List," 59, Fig. 3. Barker's drawings of a *camelo* and *camelete* are of guns recovered from a 1554 wreck off Natal. Barker documents the use of the term *camelo* as early as 1513, and it seems unlikely that the name would have been retained had there been any fundamental change in design.

64. Barker, "Gun List," 59–60.

significant damage to the hull of a ship and that heavy shipboard ordnance had to be mounted near the waterline to avoid compromising stability. In practical terms, that meant firing through or over the bulwarks of a low-lying caravel. Since caravels were small, that meant a limited number of large guns, perhaps only one or two. The caravel's speed and maneuverability maximized its effectiveness as a gun platform and, at the same time, reduced the danger of boarding. The caravel's small size and efficiency also meant a small crew, an important demographic and economic advantage for Portugal. Numbers of swivel guns were provided to deal with boarders and to wreak havoc on the open decks of low-lying enemy ships, but the Portuguese seem to have understood at an early stage that it was the heavy ordnance, firing low, that counted. As a conceptual breakthrough, this appreciation ranks with the perception that using guns to knock down walls was more decisive than lobbing projectiles over them. As with the earlier breakthrough, the new tactics cannot be separated from the improved matériel that made them feasible. There is a clear parallel between the Bureau Brothers' celebrated achievements in the Hundred Years' War and those of the anonymous Portuguese officials who oversaw the design of the *camelo*, the manufacture of its powder, and its mounting aboard caravels.

The roots of equivalent developments in the Mediterranean can be traced back farther in time, but stem from similar impulses. Like Portugal, Venice was perpetually short of manpower and considered maritime commerce vital to the health of the state. But where Portugal sought opportunity in its adventures in Africa and Asia, Venice fought for survival. It should not, therefore, be surprising that it was Venice, long on cash and short of manpower, that first imported cannon into the Mediterranean from their European birthplace north of the Alps.

Gunpowder technology diffused across the Mediterranean in the following decades, but it seems clear that it was advanced soonest and furthest by the Venetians, hard pressed by the Turks and perpetually seeking to magnify the effectiveness of their limited manpower. There can be little doubt, too, that the Arsenal with its highly skilled work force gave Venice a well-capitalized institutional base for technological development. Venetian artisans and naval commanders were surely the first to appreciate the value of mounting a sizeable gun on the bow of a galley, in effect turning the vessel into a mobile gun carriage, and were probably doing so by the 1470s.[65] The earliest hard evidence of a galley mounting a main centerline bow gun comes from a woodcut of the Venetian lagoon by the German artist Erhardus Reeuwich in a book published

65. Guilmartin, "Early Provision," 260–62; Rodger, "Broadside Gunnery," 302.

in 1486.[66] Reeuwich's woodcut shows a wrought-iron piece of some size, apparently a muzzle-loader, set in a rigid mount well forward on the bow. Such an arrangement would have been workable, though reloading would have been difficult at best once combat was joined. More important, the shock of repeated discharges would have damaged the light structure of a galley's hull. The solution, as we have seen, was to mount the main centerline gun on a sliding mount that recoiled backward beneath the *corsia*, the raised platform running the length of the galley between the rowing benches.

We cannot say with certainty when and where this arrangement was perfected, but the evidence points to the Venetian Arsenal in response to defeat at the hands of the Turks in the disastrous war of 1499–1503. The first unequivocal evidence of a really powerful gun mounted on a galley's bow involves a *basilisk*—a generic term for a long gun of exceptional power firing a ball of fifty pounds or more—on a Venetian great galley in 1501.[67] It must have been mounted on the centerline, for so large and powerful a piece could not have been mounted on a galley in any other way. It must also have had a recoiling mount, for otherwise it would have done serious structural damage to the hull. The experiment was a tactical failure, for reasons that the shipwrights and arsenal workers readily appreciated: heavy galleys were too sluggish under oars to serve as effective gun platforms in a maneuvering fight. It was, however, a technical success, demonstrating that a powerful gun could be mounted on an oared fighting craft.

The next step was to redesign the hull of an ordinary galley, filling out the underwater lines forward to support the considerable weight of artillery at the bow. That took time.[68] How much we cannot say, but

66. Bernhard von Breydenbach, *Opusculum Santarum Peregrinationium* (1486), reproduced in Guilmartin, "Early Provision," 262, as Plate 12; Louis Th. Lehmann, *Galleys in the Netherlands* (Amsterdam: Mulenhoff, 1984), 31, affirms that the Reeuwich woodcut is the earliest hard evidence of a main centerline bow gun.

67. *I Diarii di Marino Sanuto*, 56 vols. (Venice, 1879–1903), 3:510, 968, 1221, cited by Cmdr. Fernando Gomes Pedrosa, Portuguese navy, "A Artilharia Naval Portuguesa no Século XVI," *Actas,* XXIV International Congress of Military history (Lisbon: Comissão Portuguesa de Historia Militar, May 1999), 329–34, especially 329. See John F. Guilmartin, Jr., *Gunpowder and Galleys: Changing Technology and Mediterranean Warfare at Sea in the 16th Century* (1974; 2nd rev. ed., Annapolis, Md.: Naval Institute Press, 2003); 11, 11 nn 3 and 5, for the technical characteristics and tactical use of *basilisks*. *Basilisk* was common to Spanish, Portuguese, Catalan, French, Greek, and Ottoman Turkish.

68. This is my supposition based on the inescapable logic of structural and hydrodynamic considerations, supported by Rodger, "Broadside Gunnery," 302–3. We know that an increasing weight of ordnance combined with the disappearance of free oarsmen to force major changes in galley design from circa 1550; Guilmartin, *Gunpowder and Galleys*, 266–68. The initial addition of several thousand pounds of

more than was available to have any discernible impact on hostilities before peace was concluded with the Turks in 1503. The result was the definitive main centerline gun-armed Mediterranean war galley, an elegant technical solution to a hitherto intractable tactical problem. It quickly spread beyond its place of origin. We know that in 1506 Ferdinand of Aragon's royal galley carried "a large bombard of iron" weighing some 4,360 pounds,[69] heavy enough to have required full underwater lines forward.

We now turn to 1510, when Louis XII of France, envisioning renewed hostilities with England, commissioned the construction of twelve ordinary galleys in Genoa and Savona and two *bastardas* (exceptionally large ordinary galleys) in Venice.[70] The French king's money was good, and these were surely the best warships that money could buy. They proved it by shooting their way through the entire English fleet in Brest Roads in April 1513, sinking one ship outright in the process. The English were shocked by the power of the French *basilisks*. It was, as Nicholas Rodger has said, an entirely new way of waging war at sea.[71] This event marks the completion of our revolution in naval ordnance in the Mediterranean, though the new technology was expensive and spread slowly.

Our revolution had yet to run its course in northern waters; that would have to await the general spread of the watertight gunport, for the Portuguese solution to the problem of mounting heavy ordnance on a sailing warship was incomplete. Caravels mounting heavy guns on their low-lying decks might rule the Indian Ocean and could defend themselves elsewhere, but they mounted no offensive challenge to European carracks or war galleys in home waters. What some have seen as the birth of broadside gunnery was therefore stillborn; indeed, the war galley's main centerline bow gun was so effective as to establish the conceptual framework within which heavy ordnance would be mounted and used aboard all European warships for the remainder of the century. The point is that of Nicholas Rodger, who argues convincingly that northern mariners sought to arm and fight sailing warships as galleys, with the heavy ordnance that counted most firing forward. Broadside tactics as we understand them today established their superiority only in the Anglo-Dutch wars of the mid to late seventeenth century.[72]

metal on a galley's narrow prow must have had an effect of at least comparable magnitude.

69. Olesa Muñido, *La Organización Naval*, 1:313.

70. Ibid., 2:1171–72.

71. Rodger, *Safeguard of the Sea*, 170–72.

72. That is Rodger's central argument and conclusion in "Broadside Gunnery."

In conclusion, it is clear that European gunfounding and gunpowder manufacturing technology underwent important changes during the fifteenth century that came together synergistically around the turn of the sixteenth to manifest themselves with revolutionary effect on warfare at sea. These developments raised the level of technological and tactical sophistication of naval gunnery at its best to levels prevailing ashore. But the key qualifier is "at its best," for the developments in question took effect within narrowly constrained boundaries. Those boundaries were geographic in the case of the Portuguese caravels' laterally-firing heavy ordnance. They were quantitative and economic in the case of the Mediterranean war galley's main centerline bow gun, for the very rarity of well-armed galleys that magnified their tactical superiority limited their strategic utility. Good heavy ordnance, particularly of bronze, was expensive and therefore rare; several decades would pass before galley fleets truly dominated warfare at sea in the Mediterranean, and by then the qualitative Venetian advantage had narrowed.

The reasons for the timing and geographic locus of the revolution in naval ordnance are complex and interrelated, more a matter of gradual improvements in related areas combining in effect to reach critical mass rather than the result of any single breakthrough. Certain discrete technological developments were essential to the development of effective gunnery afloat: potassium nitrate saltpeter production; the sliding, recoil-absorbing carriage for the war galley's main centerline bow gun; and the lidded, watertight gunport. But these developments, however essential, could only be exploited within a broader intellectual, strategic, and technological context. That context was at first understood only by a limited number of mariners, gunfounders, and gunners in Portugal and the Mediterranean world, notably in Venice, who were able to command the resources to make their visions reality.