

Chapter 2

The Mother of All Collapses: The Fall of Rome

Instead of inquiring why the Roman empire was destroyed, we should rather be surprised that it had subsisted so long. The victorious legions, who, in distant wars, acquired the vices of strangers and mercenaries, first oppressed the freedom of the republic, and afterwards violated the majesty of the purple. The emperors, anxious for their personal safety and the public peace, were reduced to the base expedient of corrupting the discipline which rendered them alike formidable to their sovereign and to the enemy; the vigour of the military government was relaxed, and finally dissolved, by the partial institutions of Constantine; and the Roman world was overwhelmed by a deluge of Barbarians.

— Edward Gibbon. *The Decline and Fall of the Roman Empire*,
“General Observations on the Fall of the Roman Empire
in the West”, Chapter 38

Considering that this book takes its title from a statement by the ancient Roman philosopher Seneca, it seems proper that it should start with a discussion of the fall of the Roman Empire, something that we could define as “the mother of all collapses.” Here, I am not pretending to say anything definitive about such a complex issue, but just to see how it can be approached in systemic terms, that is taking into account the internal feedbacks that control the operation of the system.

2.1 Seneca and His Times

Lucius Annaeus Seneca was, by any standard, a successful man (Fig. 2.1). Rich and influential, he even was the tutor, and later the adviser, of Emperor Nero. It was a slow growth of fortune that made Seneca one of the richest men of his time. But all this success rapidly came to nothing. First, Seneca fell out of favor with Nero and

Fig. 2.1 Lucius Annaeus Seneca, 4 BCE–65 AD. Contemporary bust, presently at the Antikensammlung Berlin (Berlin antiquities collection)



was forced to leave politics and retire to private life. Not much later, Seneca was accused of being part of a conspiracy aiming at killing Nero and installing Seneca himself as emperor. We cannot say if Seneca had ever planned something like that, but the suspicion was enough for Emperor Nero to order him to commit suicide. Seneca complied by slicing his wrists' veins open, as was the custom of that time. It was a rapid end after a long life of successes and we may see this story as one of the best illustrations of something that Seneca had written to his friend Lucilius, that "ruin is rapid." This is what I call the "Seneca Effect" in this book.

Seneca's rapid ruin mirrored the ruin of Rome. At the time of Seneca, the first century of our era, the Roman Empire was still a powerful and majestic structure. But it had started developing the first cracks prefiguring the future collapse. The first ominous hint of the bad times to come may have been the battle of Teutoburg, in 9 CE, when three Roman legions were ambushed and cut to pieces by a coalition of Germanic tribes. It was a terrible shock for the Romans, comparable to the shock that modern Westerners felt with the attack against the World Trade Center in New York on September 11, 2001. For the ancient Romans, being defeated by a band of hairy and bad-smelling barbarians was against all the rules of the universe; it just wasn't possible. But it was what had happened and Emperor Augustus, a consummate politician, exploited the defeat with a masterpiece of propaganda. He spread the rumor that he was so shocked by the defeat that he would wander at night in his palace, mumbling to himself "*Varus, Varus, bring back my legions.*" That sealed the role of Emperors as defenders of the Romans for the rest of the lifetime of the Roman Empire; that was to span almost half a millennium.

The decline of Rome was slow enough that some modern historians say that it shouldn't be described as a collapse but as a cultural transformation. But, still, the decline was real, far more than just a change in the political structure of the Empire

or in the cultural habits of the Romans. You can read in a massive book such as *The Cambridge Economic History of the Greek-Roman World* [8] about the many economic parameters that showed a downward trend. For instance, maritime trading declined, as evidenced by the declining number of shipwrecks. All commerce declined, too. Then, the changing diet of the Romans left traces in the smaller number of animal bones in landfills, indicating that the protein content of the diet had declined. There is also evidence for a lower level of lead and copper pollution [9], meaning that the metallurgical industry had declined, too.

The Romans themselves provided us with poignant descriptions of the decline. Not that they ever really understood it; perhaps the only ancient author to have had a hint in this sense was the Christian writer Tertullian (ca. 150–230 CE) to whom we may perhaps attribute the first description of the phenomenon of “overpopulation” in his *De Anima*. The authors of the late Roman Empire generally lamented the bad situation of their times but they always attributed it to contingent factors, never hinting that there may have been something badly wrong with the way the Empire was run. Around 410–420 CE, the Roman patrician Rutilius Claudius Namatianus wrote the poem titled *De Reditu Suo* (“Of His Return”); a chilling report of his travel along the Italian coast as he was running away from Rome to seek refuge in his possessions in Gallia. In it, we read of abandoned cities, ruined roads, derelict fortifications, and general decay of everything. The text that survived breaks before the end and we don’t know what Namatianus found when he arrived in Gallia. But we may perhaps imagine it from the work of a contemporary, or slightly later, author, Paulinus of Pella, a wealthy Roman landowner. In his *Eucharisticos* (“Thanksgiving”), written probably around 420 CE, Paulinus tells us of his desperate attempt to keep together his vast land possessions in Europe and how the collapse of the Roman law and order caused him to lose almost everything to Barbarian looting.

Despite the economic decline, and probably the decline of the population as well, the Roman empire managed to keep alive its political structure up to the mid-5th century CE, but only with increasing difficulty. In the early years of the 5th century, or perhaps earlier, the fortified walls at the borders of the empire (sometimes called the “limes” although the Romans didn’t employ this term) were mostly abandoned. In 410 CE, Rome was sacked by the Goths, an event that shocked the world and that led Augustine, bishop of the city of Hippo in Northern Africa, to write his *The City of God*, a book that we still read today, where he tried to grapple with an event that had deeply hocked him as most of his contemporaries. Afterward, Rome recovered, in part, but it was sacked again in 455 CE, this time by the Vandals who gained from the enterprise a large amount of gold and silver and bad reputation that accompanies them to this day. From there on, the Western Empire turned into a ghost of itself and disappeared as a political structure in a few decades. The Eastern Empire lasted much longer and even managed to reconquer Italy for a short period, but it was never able to resurrect the Western Roman Empire.

Rome was said to have been founded in 753 BCE; then, considering that the Empire may have peaked at some moment during the 2nd century CE, we can say that Rome grew for about one thousand years but collapsed in no more than

two- three centuries. Its ruin was much faster than its growth: a good example of the “Seneca Effect.” But, in order to understand what makes empires collapse, we need to understand what makes them exist.

2.2 Whence Empires?

There was a time, long ago, when no empire had ever existed. With the start of the Holocene period, some 12,000 years ago, our ancestors started developing agriculture, building cities, working metals, learning how to write, creating artwork, and more. But it took millennia to see the appearance of the kind of structures that we call empires. Perhaps the first political structure that was close to the modern concept is the one created around 2300 BCE in Mesopotamia by a warlord called Sargon who conquered and ruled most of the independent city-states of the region. We don’t know very much about this very ancient empire except that, like most later empires, it involved a glorious series of victories and conquests followed by a decline that led it to collapse and disappear, replaced by other empires that ebbed and flowed in the region. Empires, however, leave a cultural heredity that can last much longer than their lifespan as political entities. So, to this first empire in human history we owe the heritage left by Sargon’s daughter, Enheduanna, princess, priestess, and poet, the first named author in history, whose poems written on clay tablets have resurfaced in modern archaeological excavations and that we can miraculously read to this day [10].

So, what made empires possible and, eventually, common? Something transformed the human society from a set of independent city-states fighting each other to states with large armies and centralized administrations. To begin, empires are expensive social structures that can’t exist without a steady flow of resources. In ancient times, all complex human societies were based on agriculture; not just a way to feed people but also a way to store and conserve food. We all know the Bible story of the 7 years of fat cows and the 7 years of lean cows that the Egyptian pharaoh dreamed of and how Moses advised him to store grain for the bad times to come. That was the beginning of capitalism and, if there exists accumulated capital, somewhere, it is likely that, somewhere else, someone would be planning to steal it. That was the beginning of the idea of “war,” probably endemic in ancient times. But war doesn’t create empires unless someone manages to create a fighting force not linked to a single city-state. In modern parlance, we say that war is a question of *command and control*. And the basis of command and control is *communication*. These are the fundamental elements that made Empires possible.

The simplest ancient technology of communication was to use messengers. That, of course, worked best if messengers could ride horses and that’s a technology that was developed around the 3rd millennium BCE in Mesopotamia. But, horse mounted messengers also needed to be able to carry information with them, not just what they could remember in their heads. That was probably one of the

reasons for the development of writing: a technology that appeared independently in several parts of the world, again around the 3rd millennium BCE. A written message from the King or the Emperor could be transported by a messenger and reach a remote region of the empire. Then, it could be read aloud and it was as if the emperor were there.

Of course, nobody ever seemed to be happy to submit to a foreign empire without putting up a good fight first, no matter what resonant words they heard as read by a horse-mounted messenger. So, empires needed more effective methods of communicating what they wanted. In a way, you can say that war is a form of communication; brutal, surely, but it carries a clear message: submit to us, otherwise we'll kill you. If this message was carried by a powerful army, it was heard. Assembling a powerful army and sending it to conquer remote lands required resources: weapons and food, but the main point was controlling it: how could an emperor convince soldiers to fight the designated enemy and, perhaps even more difficult, not to fight among each other for the spoils? The problem of command and control was well known already at the times of the early empires. Command is very much a question of authority and ancient kings and emperors would surely take the role of commanders by wearing expensive robes, crowns, and jewels, carrying scepters and all the appropriate paraphernalia that made them impressive figures. But, no matter how majestic a local ruler was, it is unlikely that his aspect, alone, would have been sufficient to convince people to leave their towns to fight in some remote place where they risked being hacked to pieces by unfriendly natives. Control is not just a question of authority, it requires the creation of motivation. And, already in very ancient times, an efficient way to motivate fighters was found: paying them. Payment requires the technology called "money"; the crucial element that made empires possible.

With the third millennium BCE, we see money appearing in the Middle-East and in China in the form of precious metals being traded not anymore for their intrinsic value as decorative materials, but as an exchange medium. At the beginning, precious metals were exchanged by weighing them and that was enough for creating a network of long-range commercial lanes. At the same time, metals became an excellent target for military raids and their redistribution created and maintained the large armies assembled by warlords with imperial ambitions. With the 7th century BCE, we see the appearance of coinage. It was a considerable progress in military technology as it made possible to pay individual fighters. But that changed little to the behavior of empires: beasts of prey that devour their enemies' resources in the form of precious metals.

From the mid-3rd millennium BCE onward, all the needed technologies were in place and the stage was ready for Empires to appear and play their role. Empires appeared everywhere in the world: the Mediterranean, China, India, South America, and Mexico. In this age, we see armies larger than anything ever seen before, armed with weapons never seen before, using tactics and strategies never seen before. These armies conquer cities, burn buildings, kill people, loot goods, and capture slaves. More than all, armies create empires: large, centralized social structures normally ruled by someone who sits on a throne, wears jewels, carries ornate weapons

and, often, claims to be the son of some supernatural being and, hence, a supernatural being himself. These larger than life individuals keep many wives, pretend instant obedience if not straight worship, and are, often, cruel, vindictive, and in many cases also sexual perverts. But that has not changed very much from ancient times to modern ones.

Empires come and go in cycles, with each new empire proclaiming to be the biggest, the best, the God-favored one that will last forever; only to hit the dust after a while, the glorious armies defeated, the invincible rulers dethroned, the eternal cities burned and sacked. Then, another empire comes along, to repeat the cycle. In the modern world, empires are still with us, even though we seem to be curiously shy in using that name for the stupendous military and commercial empire we call “Globalization.” Perhaps it is because the global emperor who resides in Washington D.C. doesn’t wear purple, doesn’t claim a semi-divine origin, and doesn’t require sacrifices in his honor (so far). In the long series of kingdoms and empires ebbing and flowing in the area that includes the Mediterranean coast and the Near East, some were longer lasting than others but none managed to do more than control a fraction of these regions. That changed with the rise of Rome.

At the beginning, around mid-1st millennium BCE, Rome was a small town in a remote region, known mainly for its rugged and uncouth fighters who would be content to fight for chunks of copper (called “*aes rude*”—rude bronze) rather than for the silver coins that the more sophisticated fighters of the East required. But, soon, Rome started gobbling up its neighbors, one by one. It became bigger, more powerful, richer, and more aggressive; conquering most of the world around the Mediterranean Sea. Rome became the first global empire, having reached the maximum size that the transportation technologies of the time permitted for a centralized administration to function.

Several features made the Romans so powerful, but perhaps the most important one was their ability to control the supply of their resources by means of a logistic system unrivaled in the world up to modern times. Ancient cities relied mostly on locally produced food to feed their population and that was the main factor that limited their size [11, 12]. Cities had also to cope with the unavoidable vagaries of agricultural production caused by droughts, infestations, and the like. So, the size of an ancient city depended on its capability to import food from areas farther away than the fields around it. For that purpose, sea lanes were the best solution. Using ships, the cost of carrying bulk merchandise could be enormously reduced in comparison to using pack animals or carts. It has been estimated that, in ancient times, the cost of wheat would increase by 40 percent for every 100 miles it was moved by road, against 1.3 percent per 100 miles when transported by sea [13]. Tainter reports in his *The Collapse of Complex Societies* [14] that, according to the edict on Prices issued by Diocletian in 301 CE, transport by road was from 28 to 56 times more expensive than by sea.

Using sea transportation for their food supply, many ancient cities reached population levels of over 100,000 inhabitants, but Rome did more than that with an estimated population close to a million inhabitants, or perhaps even more [15]. The Romans developed a maritime freight system that could supply Rome and other

coastal cities with grain cultivated in North Africa or in the Middle East. It was not different than the versions developed by previous empires, but it was larger, better organized, and better managed than anything that had existed before. It was so vital for the Romans that it was even seen as a divine creature, "*Annona*," a sort of fertility Goddess that provided food for the Roman citizens, year after year, as the name derives from the Roman term for "year," "*annum*." This explains a lot of the Roman military power. The Romans were surely brave and efficient fighters, but they were also more numerous than their adversaries. They could maintain a large population because they could rely on the *Annona* system.

But that was not the whole story: the power of Rome involved another winning technology: money as a tool for command and control. Again, it was a technology that the Romans had not invented but that they used on a scale that had never been seen before. The Roman military system was based on two types of units: the legions and the auxiliary troops called "*auxilia*." The legions were the backbone of the imperial troops, formed by Roman citizens only. Within some limits, the legionnaires would fight out of patriotism, but they still had to be paid. Then, the *auxilia* were formed of non-Roman citizens who would simply fight for money. So, the Roman army was not limited to the size of the Roman population: by fielding the *auxilia*, it could be enlarged as much as the financial resources of the state allowed.

Of course, paying fighters required money and that, in turn, required metals. Soon, the old "*Aes Rude*" became insufficient for the size and the ambitions of the Roman army. By the 3rd century BCE, the Romans had gained the control of the gold mines of the Alps, in what is today Switzerland, and that gave them monetary resources sufficient to build up their power to levels that allowed them to become the dominant power in the Western Mediterranean region. By defeating the only power that could oppose them, the North-African city of Carthage, they gained a free hand to expand in Spain and exploit its rich gold mines. Using that gold, they built up their power even more in a classic phenomenon of enhancing feedback. In a couple of centuries, the Roman armies swept Europe, North Africa, and the Middle East in a military tsunami that engulfed kingdoms and republics, transforming them into Roman provinces. By the 1st century CE, Rome was officially an "empire," in the sense that it was ruled by an all-powerful military dictator, even though it maintained some of the exterior features of the democracy it had been, once. By then, Rome had become the largest, the richest, the most powerful empire ever seen up to then in the Western part of Eurasia.

We see here what kind of creature the Roman Empire was. It was a typical complex system: structured and hierarchical, an exquisite tangle of interactions formed by a communication network generated by roads, harbors and sea lanes, over which people, goods, and armies moved. It had a control system whose brain was the imperial court in Rome and whose nerves were formed by the financial system that controlled the movement of goods, services, and armies by means of laws, bureaucracy, and of money. The Roman Empire, as all empires, had some of the characteristics of a living being: not a monolithic entity, but something that could rearrange its networks of nodes and links in such a way to respond to external perturbations (forcings) in a variety of ways that included fighting back, retreating, adapting, expanding, and more.

Modern Society inherited a lot from the Romans: laws, philosophy, art and a general understanding of what we think civilization should be. It also inherited a language—Latin—that we still consider nobler than our everyday utterances in whatever local language we happen to speak. Up until about one century ago, the Roman Empire was popular enough that the rulers of Russia still used the title of “Czars” derived from the name of the first Roman Emperor and they called Moscow “The Third Rome,” with the first two being Rome and Constantinople. In parallel, in the 1930s, in Italy, it had become fashionable to wear Roman togas and carry the curious Roman axes that were called “fasces.” The idea was that the tiny Italian Empire of that time was going to recreate the glory and the power of the ancient Roman Empire. History makes short work of silly dreams and the Italian empire only had the distinction of being, possibly, the shortest-lived empire in history.

Nowadays, these ideas have mostly faded as Globalization brought together many cultures that don’t claim a Roman ancestry. Yet, the idea that the Roman Empire was something great and important remains with us. But, if that’s the case, why did such a stupendous structure collapse and fade away? And that brings us to another unsettling question: could a similar collapse happen to our modern civilization?

2.2.1 The Great Fall

In his monumental “Decline and Fall of the Roman Empire” (1776), Edward Gibbon describes the fall of Rome as mainly due to military decline. In turn, he thought the military weakness of the empire was caused by the diffusion of the decadent Oriental religion called “Christianity” that had weakened the moral fiber of the Romans and caused them to lose their willingness to fight their enemies. Nowadays, the idea that the fall of the Roman Empire had a military origin remains perhaps the most diffuse interpretation but it is by no means the only one. Many people seem to have had a good time in devising all sorts of different explanations and Alexander Demandt, in his book “Der Falls Rom” (1984) lists a total of 210 theories, including lead poisoning, Bolshevism, celibacy, culinary excess, Jewish influence, hyperthermia, oriental-ization, socialism, terrorism, and many more. The book doesn’t seem to be available in English, but excerpts are easy to find on the Web [16].

The abundance of theories that claim to explain the reasons for the fall of Rome shows how difficult it is to understand how the gigantic structures that we call “empires” work. Not only do we not know the answer to the question of why these structures tend to collapse, but we aren’t even sure about what the question is. Are we looking for a single cause? Or for many causes acting together? Reviewing even a minor fraction of all that has been said on this subject would be a monumental task that I will not even try, here. But at least some considerations can be made starting from the concept that the Roman Empire was a complex system and, as such, it could adapt, within limits, to external perturbations (or “forcings” as they are called in system science). Evidently, to explain the fall of Rome we are looking for a forc-

ing that was strong enough to overwhelm the system's capability of adaptation. This forcing doesn't have to be very strong in itself: do you remember the story of the straw that broke the camel's back? It is a description of a typical behavior of complex systems that tend to amplify minor perturbations. When you have this effect it becomes difficult to identify a simple cause-and-effect chain of events. Would you say that the straw was the cause of the camel's broken back? No, because the straw, alone, would not have been sufficient. But, on the other hand, hadn't there been the straw, the camel would still be standing. In a complex system, it is normally difficult to identify specific causes and effects, it is better to think in terms of forcings and feedbacks, with the understanding that feedbacks are often self-reinforcing and tend to obscure the forcing that triggered their appearance.

So, what was the straw that broke the back of the Roman Empire? There are several ideas that we can rule out. First, the Empire was not overwhelmed by the sudden impact of a superior military technology, as it happened to the Aztec Empire of Moctezuma II. Throughout its history, the Roman Empire remained a fighting force to be reckoned with, at least when it didn't fight against itself. Even when the Empire had become little more than a shadow of its former self, it still managed to defeat the Huns led by Attila in a major battle at the Catalaunian plains in 451 CE. This Roman victory signaled the end of the Hunnic Empire, but that didn't prevent the Western Roman Empire from disappearing as a political entity a few decades later. We can also rule out that climate change played a role in the fall of the Roman Empire. It is true that there have been cases in which droughts may have destroyed entire civilizations, such as for the Maya [17] and perhaps in other cases [18, 19]. But the European climate remained rather stable up to the last years of the Roman Empire as a recognizable political system [20]. Several other explanations for the fall of Rome can be ruled out. For instance, a popular hypothesis attributes it to lead poisoning, [21, 9], but that seems to be unlikely considering that the mean lead content in Roman bones during the imperial period was less than half of that of modern Europeans [22]. In the same way, we can rule out many fanciful explanations that cannot be supported by real data, such as Bolshevism, gluttony, the loss of moral fiber, and many more.

So, what are we left with? One possibility could be that the Roman Empire ran out of the resources that allowed it to function. Like all complex systems, the Roman Empire was a giant machine that needed energy to function, mainly in the form of food for its citizens. In principle, agricultural food production is a renewable technology, but it can run out of a critical element it needs: fertile soil. The soil layer of cultivated fields is delicate and it can be destroyed by erosion. So, could soil depletion have been the cause of the collapse of the Roman Empire, just as fossil fuel depletion could lead the modern Global Empire to its doom? This would be an explanation perfectly consistent with what we know of complex systems. But things may not be so simple.

In the scientific literature, we can find many studies on soil degradation in ancient times and on its effects [23, 24] but this phenomenon is rarely—if ever—described as a major factor in the collapse of the Roman Empire. Only one recent study, the book "The Upside of Down" by Thomas Homer-Dixon [25], proposes that the

Roman Empire fell because of the diminishing returns of agriculture. Homer-Dixon uses the modern metrics of biophysics in terms of the concept of “Energy Return on Energy Invested” (EROI) [26]. The idea is that the Romans gradually depleted the fertile soil of their lands and that depletion increased the need for labor (energy) to obtain the same amount of output of food (energy). Consequently, the EROI of the Imperial machine diminished. The Roman Empire became gradually weaker and was no longer able to maintain its former level of complexity. Eventually, it had to fall. This is an explanation that goes straight to the core of the functioning of complex systems: no energy—no complexity. But is it what happened to the Roman Empire?

The problem with the hypothesis based on diminishing agricultural yields is that it is difficult to find quantitative data to support it. Homer-Dixon collects and reports impressive data on the high-energy costs incurred by the Romans in building the stupendous structures created during the heydays of the Empire, from the Coliseum to Hadrian’s wall. These structures weren’t built any longer in the decline phase of the Empire, but was that because the agriculture had declined, too? That’s very difficult to assess. We don’t have good data on the agricultural production during Imperial times; the most that we can say is that there are no records of major famines, except for the last decades of the Empire. We also know that the Roman agricultural system continued to produce food and ship it over the sea lanes almost to the end, with the food supply to Rome being stopped only when the Vandals sacked the city in 455 CE. In terms of population, we have some evidence of decline, but the data are not good enough to show how important it was before the fall of the Empire [27]. And even if population declined a little during imperial times, there is no evidence that it collapsed until almost the end. Note also that the population density during the Roman times was much smaller than it is today in the same regions. For instance, Italy may have had only 5–6 million inhabitants in Augustan times [27] against the 60 million of today. With just one-tenth of the present population, it is perfectly possible that erosion could be kept under control and it is known that ancient communities could manage to do that, unless prevented by wars or turmoil [24]. So, in Roman times, it seems that it was political collapse that caused the agricultural collapse, rather than the reverse. We need a different explanation.

At this point, we can turn to the historian who first examined the decline of Rome in terms of complexity: Joseph Tainter with his 1988 book, “The Collapse of Complex Societies” [14]. Tainter notes that complexity is a necessary factor for a large social structure to maintain itself. Clearly, he refers to all the structures that are dedicated to command and control of the system: the police, the army, the judiciary system, the bureaucracy, the imperial court, and more. Tainter notes that complexity has a cost that increases as the system becomes larger and needs larger and more complex control structure. The crucial point of Tainter’s idea is that complexity shows diminishing returns to scale, a well-known characteristic of economic systems [28]. That is, when the control system becomes very large, its returns don’t increase in proportion. On the contrary, they diminish. In the figure, you see how Tainter describes his view in a graphical form (Fig. 2.2).

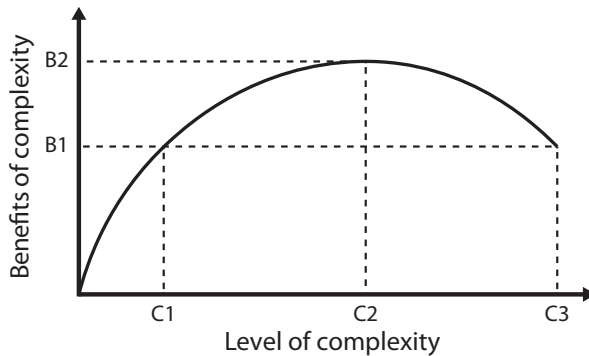


Fig. 2.2 A schematic representation of the diminishing returns of complexity. Adapted from Joseph Tainter's book "The Collapse of Complex Societies" [14]

But how would the phenomenon of diminishing returns to complexity be related to the decline and the collapse of civilizations and empires? According to Tainter, it is because society tends to solve the problems it faces by always increasing the size of its control structures. For instance, facing a military threat, it will normally increase the size of the army, and this is what the Roman Empire did. That, in turn, implied that they needed to provide food and lodging for the soldiers, to increase the size of the command structure, to enlarge the imperial bureaucracy, and so on. All that had enormous costs and, at some moment, the burden started to be excessive for the capabilities of the empire to sustain it. The problem was, in Tainter's view, that all societies have difficulties in going back; that is, in de-complexifying. As a result, they carry an increasing burden of overly complex and expensive structures that are costly and harmful rather than useful. In other words, the society becomes rigid and can de-complexify only by collapsing. Here, Tainter seems to echo the concept of "tipping point," [5] a feature of complex systems that makes them unable to adapt to an external perturbation.

There is a lot that makes sense in this interpretation, and we all know that large organizations tend to become more and more bureaucratized and unable to change—just think of any modern government agency. In the case of the Roman Empire, we have data that show how the size of the Roman army kept increasing in Imperial times (Fig. 2.3).

So, Tainter's idea fits well with the tendency that complex systems have of collapsing when they reach the limits of their capability to maintain their networked structure. But there is more to the collapse of the Roman Empire that we need to examine and to understand. The crucial point, here, is that the first symptoms of trouble appeared well before that Diocletian increased the size of the Roman army to clearly unsustainable levels, during the late 3rd century CE. Already with the first century CE, the Empire had ceased to be the wondrous military machine it had been earlier on. It had started having troubles in containing invaders, suffering crushing defeats such as the one at Teutoburg in 9 AD, and it had stopped all attempts at the kind of "blitzkrieg" military expansion that had been the rule in earlier times. But,

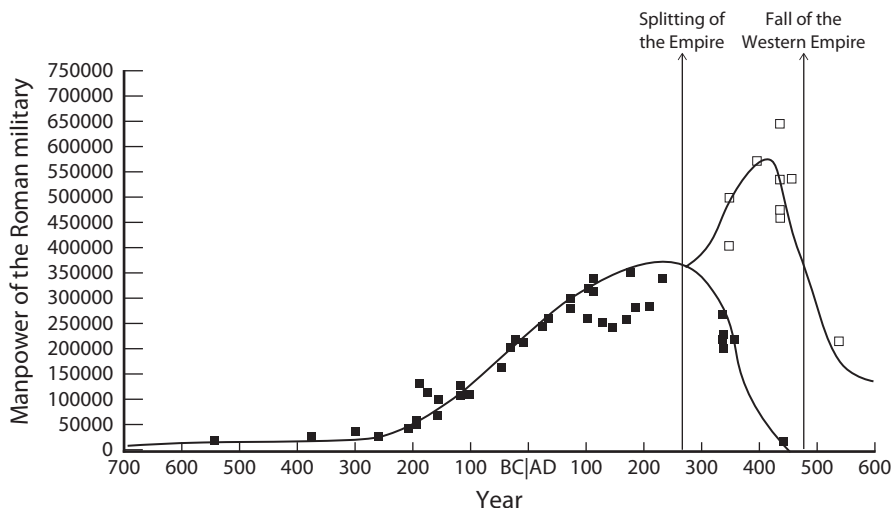


Fig. 2.3 The size of the Roman Army. These data are to be taken with great caution and the continuous curve is to be seen just as a visual aid to follow the behavior of the system. But note the “Seneca Shape” of the collapse of the army. Adapted from the data reported in <https://commons.wikimedia.org/wiki/File:Roman-military-size-plot.png>

during the first and the second century CE, the size of the army had not been significantly increased, as you can see in the figure. So, there was no evident increase in the cost of complexity that could be interpreted in terms of Tainter’s ideas. Still, something was gnawing at the Empire from inside; what was it?

Tainter himself provides us with an answer when he describes the plea of most emperors during the first two centuries CE, desperately looking for the money needed to make ends meet. Few records have survived about the cash flow of the Imperial coffers, but the problem is clearly visible in the archaeological record that shows the debasement of the Roman currency, the “denarius” (Fig. 2.4).

A possible explanation for the debasement of the denarius is that the expenses for the Empire were growing and that forced Emperors to mint more coins. But, during this period, the Empire’s borders were stable, the size of the army was nearly stable, and most emperors refrained from engaging in dangerous military adventures. A better and simpler explanation could be that the mines in Northern Spain could no longer provide silver in the abundance of the earlier times. We have no direct data about the production of these mines, but we know that no mine can last forever and depletion would seem to be the logical explanation for the decline of the Roman production of precious metals and the consequent debasement of the Roman coins. This is not a common interpretation among historians and, for instance, neither Tainter nor Homer-Dixon discuss depletion, even though they both mention the debasing of the Roman currency. The problem seems to be that depletion is commonly equated with the idea of “running out” of a mineral and that was not the case for the Roman mines. In modern times, the Spanish mines were found to contain

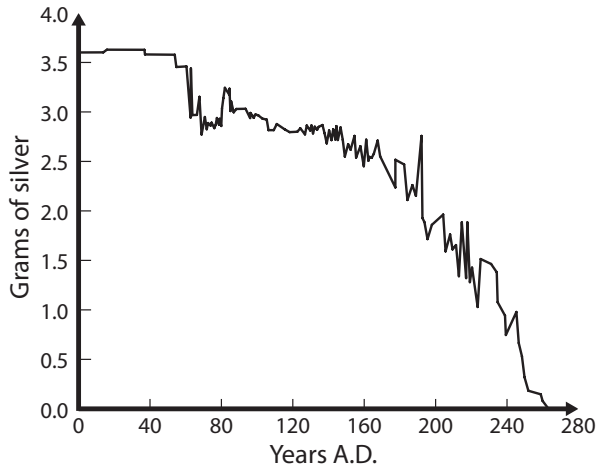


Fig. 2.4 The amount of silver in the Roman denarius. By the third century CE, the denarius had become nearly pure copper. Adapted from J. Tainter: “The Collapse of Complex Societies” [14]

significant amounts of gold and silver, so much that they were re-opened and exploited for a few decades around the beginning of the 20th century [30]. So, if the mines still contained precious metals, it would seem that there were reasons other than depletion for their decline during Roman times.

But depletion is a tricky concept and it has little or nothing to do with running out of something. It is, rather, a question of costs and benefits. Mining has a cost that tends to go up with time since miners tend to exploit first the easiest and most concentrated ores. At the beginning of their expansion, the Romans had been getting their gold from “placer” deposits in the rivers of the Alpine region, using the same technology used by the American 49ers in California, in the 19th century. With only the need of a flat pan as mining equipment, extracting gold nuggets from river sands is a very profitable activity. But that source was quickly exhausted for the Romans (just as it was for the 49ers) and they had to start working with the much more difficult and expensive task of extracting gold and silver from the rugged mountains of Northern Spain. The ores of the region were rich in gold, but expensive to process and the Romans had to develop sophisticated mining techniques for their time. They could produce plenty of gold at the beginning but, with the gradual depletion of the richest ores, the cost of mining could only increase. An additional problem may have been the deforestation of the areas near the mines that deprived the miners of the wood needed for the various mining and smelting operations [29]. There must have arrived a moment in which the cost of producing gold and silver was more than their market value and, at that point, mining had to be stopped.

That’s what depletion is: mines are not closed because the ore they contain has completely disappeared, but because they are not profitable anymore. So, it is not surprising that the gold mines of Northern Spain were exploited again in modern

times: with steam trains and mechanical drills, modern miners had capabilities that the ancient Roman miners couldn't even dream of. They could obtain a profit from ores that had been too expensive for the Romans to exploit. So, it seems that the depletion of the gold mines had been an ongoing process during Imperial times and that it created a dearth of precious metals that is reflected in the progressively lower silver content of the Roman coins. There is a problem, though: metals don't disappear into thin air. Granted that the Spanish mines had stopped, or nearly stopped, producing gold and silver, where did the already mined metals go?

At this point, the story of the Roman Empire becomes entangled with that of the Chinese Han Empire, on the other side of Eurasia. The distance between the two empires was so large that, for a long time, there were no contacts between them. That changed, however, as the result of a technological revolution that in modern times we often do not appreciate: pack animals for transportation. Today, we tend to see transportation by donkeys and camels as a primitive technology in comparison to wheeled vehicles, but we forget that carts and wagons need roads and that roads are expensive to build and to maintain. Pack animals, instead, can just keep going, negotiating mountain passes, rivers, deserts, and all kinds of terrains. Some pack animals are especially sturdy and can walk for long distances without needing much food or care. One of them, the camel, was a true revolution in transportation when it was domesticated, around the early centuries of our era [31]. Not that a single camel could go all the way from Europe to China but, as early as the first century BCE, a series of roads and pathways in central Asia had coalesced together to form a single commercial road that allowed goods to move from one extreme of Eurasia to the other. It was not just a path for camels, but also a route for ships that traveled from the Red Sea to India, and from there to China and back. The Chinese and the Roman empires were now in contact with each other, although only indirectly. And that, in the long run, had disastrous consequences for the Roman Empire.

The long path that connected the Mediterranean to China came to be called "the silk road" for a good reason. The Chinese had developed the technology of silk production from the silk moth possibly as early as the second millennium BCE (or even the third) and, with this, they had created a kind of textile that had no rivals in a world that had only linen and wool available for clothing. For a long time, the Chinese kept this technology as a closely guarded secret and, when silk started traveling Westward along the silk road, the Romans went crazy about it. Lucius Annaeus Seneca himself felt the duty of stigmatizing the habits of the Roman women, writing something that gives us some idea about how important silk was in his times.

I can see clothes of silk, if materials that do not hide the body, nor even one's decency, can be called clothes... Wretched flocks of maids labor so that the adulteress may be visible through her thin dress, so that her husband has no more acquaintance than any outsider or foreigner with his wife's body. (Declamations, vol. 1)

Of course, it was not only silk that was traded along the silk road; there were spices, ivory, pearls, precious stones, and more. In any case, the problem was that, if there is to be trade, goods must travel both ways and the Romans had to give something in exchange for the goods they received. But, of the goods that the Roman Empire produced, neither grain nor legions could be exported along the silk

road. That left only gold and silver as payment. Not that ancient China lacked gold mines; on the contrary, it had plenty of them [32]. But China's appetite for precious metals seemed to be truly insatiable and they were happy to exchange their silk with Roman gold and silver. So, when the Roman mines started declining, the trade with China gradually emptied the Empire of the precious metals it had accumulated over time. Eventually, that may have triggered a destructive feedback phenomenon: deflation. People started noting that precious metals were becoming rare and more expensive, so they tended to hoard them, hoping that they would increase their value even more. In many cases, precious metals were buried underground where they are found sometimes by modern treasure hunters. This underground disappearance of precious metals may be the reason that led to the common medieval legends, still popular nowadays, of dragons and other fabulous creatures hoarding gold in their dens [33]. In modern times, we tend to be worried about inflation, but deflation is much worse as it can destroy the very fabric of society by making commerce impossible for the lack of currency. This was, possibly, the final straw which wrecked the Roman Empire.

The Romans clearly understood what the problem was and some of their military adventures in Imperial times can be seen as desperate attempts to find gold somewhere, somehow, no matter at what costs. Already in 26 BCE, Consul Aelius Gallus brought the legions into Arabia with the idea of recovering some of the gold that had ended up there because of the commerce along the silk road. His expedition was a complete failure when heat and diseases decimated his troops. Then, by the year 101 CE, emperor Trajan attacked and annexed the region of central Europe called Dacia, approximately corresponding to modern Romania, probably with the specific view of gaining control of the gold mines in the Carpathian Mountains. From a military viewpoint, it was a success, perhaps the last campaign where the Roman military system showed its full might. But it may have brought back little to Rome in terms of precious metals, perhaps not even enough to repay for the cost of the campaign. If we look at the curve of the silver contained in the denarius coin, we see that the silver coming from Dacia appears, at best, as a short-lived plateau.

The need of gold seems to have been so desperate that the Empire was sometimes forced to plunder itself. It happened during the 1st century CE, when the Jewish revolt led the Roman legions to Palestine, at that time a province of the Empire. In 70 CE, The Romans quelled the revolt, conquered Jerusalem, sacked it and plundered the city's Temple that they also burned and destroyed (an event that still reverberates in our times). It was perhaps the gold stolen from Jerusalem that provided Trajan with the money needed to pay for his adventure in Dacia. In later times, plundering temples seems to have become a pastime for Roman Emperors. Constantine "The Great" (ruling from 306 to 337 CE) is reported to have sacked pagan temples to replenish the imperial coffers with gold and silver, possibly one of the reasons why he decided to convert to Christianity [34]. Later on, Emperor Theodosius, also known as "The Great," (ruling from 379 CE to 395 CE) is reported to have extinguished the eternal fire in the Temple of Vesta and of having disbanded the Vestal Virgins. And, of course, to have sacked that temple as well as many others of their gold and silver. The hobby of plundering Pagan temples continued for some

time and one century after Theodosius we read that the Bishop of Edessa, Rabbula, built a hospice for women with the funds he obtained from plundering Pagan temples. But, after Theodosius, no emperor ever took again the title of “the Great.” Apparently, the gold stored in Pagan temples had run out or, at least, what remained was no longer sufficient to run an empire.

During the last period of the existence of the Western Roman Empire, the emperors tried to pay their troops with pottery, with land parcels, or even just with food. The last breed of Roman fighters were known as the “*bucellarii*” (“biscuit eaters”), a term that may give us some idea of what they were paid with. But none of these makeshift solutions could work; the Western part of the Empire was doomed by the financial crisis derived from the lack of precious metals. The Eastern part, instead, never completely ran out of precious metals until its demise, during the 15th century CE. How the Eastern Romans managed this feat is not well known. In part, it may have been because their merchants had managed to steal the secret of silk-making from the Chinese and so they could produce their own silk and stop the bleeding of gold toward China. In part, it was also because the rulers of the Eastern Empire kept their remaining gold with great care and the standard gold coin of the late Eastern Empire, the “*nomisma*” (a term that means “money” in Greek) generated the term “numismatics” that we still use today. It is also possible that the Eastern Empire controlled some gold mines that helped them replenish their reserves, but it is not known where these mines could have been.

We see that the Roman Empire fell as you would expect a complex system to fall: in a complex manner. That is, it collapsed in a cascade of feedbacks that was triggered by the forcing generated by a single cause: the depletion of the precious metal mines. Then, multiple feedbacks reinforced each other: political unrest, internecine warfare, military weakness, decline of commerce, and, probably, a decline in population as well. This is typical of complex systems where the feedbacks are normally much more visible and spectacular than the forcing that caused them. As a result, people tend to assume that the feedbacks are the cause of the collapse rather than the consequences of the forcing. So, it is often maintained that the collapse of a civilization is the result of a combination of factors independent from each other that just happen to strike all at the same time. This is a hypothesis that was recently put forward for the collapse of the Bronze Age Mediterranean Civilization [19]. But, in a complex system, nothing is independent of the rest, and there holds the well-known law of biology that says “you can’t do just one thing.”

The history of the Roman Empire gives us a taste of how rich and fascinating is the study of complex systems, especially in the form of social systems. All complex systems are different, but all follow some rules. The cascade of feedbacks that can bring down a gigantic system is one of these rules, the one that I am calling here the “Seneca Collapse.” The collapse of the Roman Empire can probably teach us a lot about the troubles that the current empire, Globalization, is facing. But history never exactly repeats itself, so we can’t say much about how exactly the impending collapse will unfold. The only thing that we can say for sure is that no past empire, not even the mighty Roman Empire ever escaped ruin. Our own Empire has grown so fast that its collapse could be spectacularly fast. Maybe Seneca was more prophetic than he himself would have imagined when he said: “fortune is slow, but ruin is rapid.”

The Seneca Effect

Why Growth is Slow but Collapse is Rapid

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