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# The Tin Frontier: Mining, Empire, and Environment in Southeast Asia, 1870s–1930s

## Abstract

This article investigates the interactions between culture, technology, and environmental change during the tin mining boom in colonial Southeast Asia, the world's dominant tin-producing region in the late nineteenth and early twentieth centuries. It approaches the explosive growth of the industry—above all in western Malaysia and the "tin isles" of the Netherlands Indies—as a variation on the concept of the commodity frontier: namely, one whose topography comprised not just the surface landscapes over which it expanded but also the various grades and depths of ore beneath them. Like most commodity frontiers, this one presented a series of resource windfalls tapped by successive waves of entrepreneurs producing for a rising international market. But beneath these overarching commonalities, two interrelated factors lent it a distinctive dynamic: first, the central role of new technologies in repeatedly pushing the frontier into new underground strata and types of terrain, and second, the ways in which this three-dimensional expansion was animated by colonial ideologies of nature, race,



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waste, and industry that were deeply embedded in the project of European imperialism.

## INTRODUCTION

Tin is one of the oldest metals known to humankind. Used since ancient times mainly in alloy form (bronze, pewter), by the late nineteenth century it had become a crucial component of industrial civilization. Among its numerous applications, tin played an essential role in several key sectors of industry, from textiles (mordants, dyes) to electrical and mechanical engineering (solder, bearing metal) to military armaments (gun metal). Most, however, was used for tin plating, or coating sheets of steel or iron with molten tin to prevent corrosion. And among the many uses of tinplate, the most significant was the humble tin can. By allowing producers to conserve and transport food surpluses over ever-greater distances, the tin can played a mundane but critical role in processes of urbanization and industrialization in the metropoles of the global economy. As its uses expanded, demand for tin skyrocketed, especially in Europe: world production rose from 36,000 tons in 1874 to 124,000 tons in 1914. But since European (mostly Cornish) reserves had been largely exhausted by this time, the bulk of supplies came from overseas. The scarcity of nearby sources, along with its military significance and lack of easy substitutes, made tin an important strategic resource. It is ultimately the reason why the Netherlands Indies government ruled the island of Bangka directly from Batavia, and why the British intervened to establish the residency of the Federated Malay States (FMS) in 1874.[1]

Tin was, then, quite literally a key element in the expansion of Europe's industrial empire into the tropical world. Few other metals were so integral to the web of industrialization and mass consumption yet so reliant on trade from tropical territories—above all the western foothills of the Malaysian peninsula and the "tin isles" off the southeast coast of Sumatra. These areas witnessed an explosion of tin production after the 1860s, and together accounted for over two-thirds of world supplies by the turn of the century.[2] Here, as in many other parts of the world, the quest for mineral resources was one of the chief incentives behind territorial conquest. It was also one of the dirtiest and most labor-intensive of economic activities, bringing major social and environmental upheaval in its wake. While the immediate mining districts bore the ecological brunt of the industrial world's burgeoning appetite for tin, the complex ripple effects also altered forests, rivers, and patterns of land use throughout their hinterlands. Although mining in Southeast Asia (as elsewhere) has remained a relatively understudied aspect of the region's environmental history compared to its vast forests, plantations, and rice frontiers, the tin boom drove a far-reaching set of social

and environmental transformations that profoundly changed the physical, ethnic, and cultural landscape.[3]

This article outlines the growth of Southeast Asia's tin industry as a dynamic interaction between imperial power and colonized environments. It has two overarching aims: first, to outline the economic and technological development of the industry and its alteration of the natural systems in which it was embedded; and second, to consider more broadly what it tells us about contemporary notions of nature and efficiency, and how they were linked to racialized justifications of colonial domination. As a generation of scholarship on European empire has shown, the aspiration to control and profit from colonized territories opened up vast opportunities not only for traders and investors but also for a host of scientific and technical experts. The twin deployment of financial and intellectual capital powerfully reshaped landscapes, socioeconomic relations, cultural norms, and forms of political rule throughout Europe's colonies. In Southeast Asia as elsewhere, technology represented not just a "tool" of empire but a broader mode of empire—one in which large-scale environmental transformation was not a by-product but an integral part.[4]

Moreover, as this article emphasizes, the development of the tin industry also illustrates how culture and ideas interact with material and economic factors to shape the character and consequences of commodity production. If the study of commodity chains has furnished an invaluable set of tools for examining the socioeconomic and environmental linkages bridging increasingly distant sites of production and consumption, the focus on such longitudinal and largely material relationships can easily lose sight of the many "lateral" interactions with social institutions and the prevailing ideas and values that shaped commodity production.[5] In an ideological context in which a people's level of "civilization" was largely defined by its mastery of the biophysical environment, the ability to harness nature's bounty was as much a measure of a society's fitness to rule as it was a source of material wealth. During the heyday of colonial rule, Europe's industrial prowess simultaneously permitted and served to justify its global preeminence.

In the interest of exploring these broader dimensions of the Southeast Asian tin boom—as well as suggesting comparisons with other instances of resource extraction—this article employs the time-honored concept of the "commodity frontier," an advancing boundary of trade, political control, investment, and (sometimes) settlement that together reshaped environments and the ways in which people perceived and used them.[6] Like commodity frontiers in general, this one had its pioneers and latecomers, its phases of expansion and consolidation, and it tended to reward predation over prudence. Like mining frontiers more specifically, its multidimensional expansion—both outward across the surface landscape and downward into lower depths and grades of ore—gave it an unusually provisional character, closing and

reopening as technological advances made previously unworkable deposits both physically and economically exploitable. Yet for all these commonalities, the development of Southeast Asia's tin mines also demonstrates how local peculiarities shape the ecologies of resource extraction. If many of the basic economic processes were familiar, their meaning and effects were refracted by contemporary ideas about race, waste, and efficiency that fundamentally structured colonial society.

## THE SOUTHEAST ASIAN TIN FRONTIER

The string of alluvial cassiterite (tin oxide) deposits stretching from Larut, the Kinta Valley, and Kuala Lumpur to the islands of Bangka and Belitung marked the world's primary *tin frontier* during the late nineteenth and early twentieth centuries. I use the term guardedly, and in full awareness of its many connotations, above all the unavoidable Turnerian associations with successive waves of American pioneers moving westward to create a new civilization in the former wilderness.[7] But leaving aside Turner's social-evolutionary logic, let alone his arguments about how it shaped the American character, the frontier concept is useful here for suggesting an interlocking set of economic, social, and cultural conditions that are either absent or less pronounced in other circumstances. As Walter Prescott Webb later formulated it, a defining characteristic of a frontier is the availability of resource "windfalls" seemingly there for the taking.[8] These windfalls—land, wood, soil fertility, minerals—generally attract a transient population of pioneers and speculators with an instrumental attitude toward the land and with both the means and motivation to move on once the assets of any particular locality are exhausted, thus repeating the cycle of extraction and driving the frontier onward. In turn, this ability to escape the consequences of one's actions, often underpinned by a weak state presence and an ideology of unending resources, imposes few social restraints against destructive behavior and even fewer obligations to cover the costs of depreciation—a tendency magnified wherever the frontier is sparsely populated or regarded as idle "wilderness." If one way of seeing a frontier is as a transitory boundary of settlement, trade, or technology, another is as a set of conditions that encourages short-term extractive behavior over other forms of land use.

Much of colonial Southeast Asia was a "frontier" in both senses.[9] Outside the main centers of population (above all Java), land was abundant and the state's power precarious. Well after the turn of the century, the bustling towns and mining camps of Malaysia were still viewed as "mere patches" in the vast expanse of forest "that sweeps from one Sultanate to another, and is only limited by the sea."[10] In such a seemingly endless wilderness it was relatively easy for commodity producers to move on once resources were depleted in any given area.

The early growth of the tin industry clearly exhibited these characteristics. On the Malaysian peninsula and Bangka, Malays had long mined tin via several methods. The simplest was panning in streams with a *dulang*, or large wooden dish. More common was the creation of a *lampan*, or ground sluice, which essentially involved clearing the area above the would-be mine, digging a channel from a nearby stream to divert the water through a deposit and then treating the pay dirt (*karang*) in the channel. As the light sediment washed into a tailrace, the heavy tin sand was retained by a series of small dams where it was periodically scooped out and concentrated in a sluice box (*palong*). Both methods were remarkably lucrative on unworked tin fields where the cassiterite particles were heavy enough not to be washed away. Neither, however, could tap the deeper ores just above the bedrock. To reach these deposits, miners dug open pits (*lombongs*) several meters deep, usually upward into a hillside so they could wash the pay dirt in a channel below. All of these techniques worked within tight constraints. Panning and ground sluicing were only feasible on slopes in close proximity to streams, whereas *lombongs* could scarcely go below the groundwater level and were likewise dependent on streams for concentrating the pay dirt. Essentially, the early Malay tin frontier was limited to shallow deposits on the sides of foothills that benefited from good drainage and easy access to water.[11]

In many respects the arrival of Chinese *kongsis* (commercial syndicates fueled by "coolie" labor) represented a second wave of pioneers who tapped another windfall by extending the frontier both outward and downward. First on Bangka (from the late 1810s) and then in Malaysia (from the late 1840s), their key innovation was the Chinese *chin-chia*, a traditional wooden bucket-chain mechanism driven by a water wheel, which could remove up to 3,000 gallons (13,650 liters) of water per hour and allowed miners to reach deposits 10 (and sometimes up to 25) meters deep. Apart from the attainable depth, the technique was broadly similar to Malay open casting. After the clearance of all vegetation, the retention of any hardwood for charcoal, and excavation to the water table, a nearby stream was diverted to drive the water wheel and the waste overburden was piled around the mine head to keep rainfall from running into the pit. As miners burrowed into the hillside, they raised the pay dirt manually, concentrated it in sluice boxes, and generally smelted the dried ore with charcoal fuel on site or at a nearby smelting house. The waste tailings were simply washed downhill and deposited on the worked-out area below. Chinese *kongsis* formed the backbone of the industry during its rapid expansion in the late nineteenth century. On Bangka, they had already made tin the third largest East Indies export. In Malaysia, they quickly dominated the tin fields of Perak and Selangor, unleashing veritable "tin rushes" in Larut from midcentury and in the Kinta Valley from 1880 onward, the latter

quickly mushrooming into the world's single largest tin field once the railways came in the 1890s.[12]

But Chinese mining was also restricted by the need for regular water supplies. The water-wheel *chin-chias* were only deployable near streams, were no use during droughts, and were not powerful enough to keep the mines dry in heavy rains. On Bangka in particular, whose many small fast streams quickly emptied in the dry season, water posed the single greatest constraint on tin production. As one contemporary remarked, "Bangka is rich in rivers but poor in water."[13] Not even the construction of reservoirs—a crucial prerequisite to working many sites on the island—could guarantee adequate supplies. Although this problem was less extreme on the Malaysian peninsula with its larger watersheds, prolonged dry spells also caused mine stoppages there.[14] Chinese opencast techniques overcame only some of the constraints that had bounded the earlier mining frontier.

All of these methods were extensive and correspondingly destructive: they worked the shallowest and most accessible deposits and quickly abandoned them, leaving denuded and severely eroded hillsides in their wake. As the industry expanded in the late nineteenth century, both the aesthetic and material costs were increasingly manifested in pockmarked and scarred landscapes, abandoned wastelands, and silt-laden rivers. "Being full of large holes, and covered with an excavated soil of gravel and sand [. . .] such land is a great eyesore, and gives a bad impression of the country to the casual traveler," noted a visitor to Malaysia in 1904.[15] As production rose, the valuable *Dipterocarp*

Figure 1: Yong Phin Open-Cast Mine near Taiping, 1908. Credit: Arnold Wright and H. A. Cartwright, eds., *Twentieth-Century Impressions of British Malaya: Its History, People, Commerce, Industries, and Resources* (London: Lloyds, 1908).

forests near the mines also paid a heavy tribute to the smelting ovens. "There are certainly few mining operations that run in such cavalier fashion as the tin mines on Bangka," remarked a medical officer in the 1870s. Neither the permanent dereliction of large areas, nor the "ruthless devastation of the forest," nor any attempts to replant them were given serious consideration.[16] Similar concerns emerged in Malaysia, especially Larut, whose mines had severely depleted the forests within a 20- to 30-kilometer radius by the end of the 1870s. Attempts to slow the damage—first by banning inefficient smelting ovens, later through more sweeping forest regulations—were of limited effect. In 1906 the Malaysian mines still paid no duty on the half million tons of wood they consumed annually, and Bangka lost an estimated two-thirds of its forest between the mid-nineteenth century and the 1920s.[17] Ultimately, the most important reprieve for the woodlands came not from early conservation measures but from the coal-fired smelters built on Pulau Brani island near Singapore in 1890, followed by smaller works at Butterworth and Penang.[18]

Waterways were also acutely affected as mine tailings clogged streams and eventually worked their way into the major riverine arteries. By 1885 ore was no longer brought to the coast down the heavily silted Larut River, necessitating a rail link from Port Weld to Taiping. During the Kinta Valley boom of the 1890s, uncontrolled tailings emissions threatened not only the riverine environment but also the industry itself, which still depended on the ever-shallowing waterway for transport. The Kinta Valley Railway, completed in 1896 between Ipoh and Telok Anson, was explicitly built to obviate the need for navigating what was increasingly written off as a doomed river. As the 1896 Perak Annual Report unsentimentally put it, "The competition of the Kinta River is still being felt, but should decrease as the higher part of the river becomes silted up by the operations of the miners."[19]

But given the importance of tin revenues for the FMS and East Indies authorities, it was economic rather than ecological concerns that caused the greatest apprehension. The problem, as many saw it, lay in the growing disparity between the industrial scale of demand and primitive methods of extraction. Bangka, noted one contemporary, "is for Holland like a hen that still lays golden eggs but which sacrifices a bit of itself with every egg, so that one can foresee a time when there is nothing left but a dead skeleton. It is therefore an imperative duty to ensure that this moment is delayed as long as possible through the most systematic, thrifty and gentle method of exploiting the still available ores."[20] Once it was clear that the major tin fields of the region had all been discovered (if not yet worked), the specter of decline could only be banished by expanding the tin frontier in several directions: into deeper strata, into poorly watered areas, and above all into lower grades of ore that could not return a profit via current methods. In

short, the exploration frontier had to be replaced by a frontier of technological innovation.

## THE INDUSTRIAL FRONTIER

Calls for "modernizing" Bangka's tin industry could already be heard in the 1850s (concurrent with the start of operations on nearby Belitung), and mushroomed by the 1870s amid concerns about future production. They soon resonated in Malaysia as well, where they culminated in an 1895 Mining Code that deliberately encouraged European investment by granting secure tenure and distributing mineral concessions in large tracts suitable only for sizable enterprises. The aim was to make profits where older methods could not. Contemporaries estimated that *lampanning* was viable on only 2 to 3 percent of a given plot. Even Chinese open-cast techniques recovered only half the available ore. Through technological innovation, so it was argued, miners could widen and literally deepen the tin frontier by tapping low-grade deposits and even reopening worked-out wastelands.[21]

The problem was that most early attempts to modernize the industry were lessons in what *not* to do. Although the mines on Bangka (owned by the East Indies government) and the famous Billiton Maatschappij on Belitung (forerunner to the multinational BHP-Billiton) proved that European firms could make handsome profits, their actual operations relied almost entirely on Chinese laborers and their traditional methods.[22] By contrast, the first wave of European entrepreneurs who flocked to Malaysia in the 1870s and 1880s generally imported mechanized techniques from elsewhere, and nearly all were failures.[23] Rather naively, most assumed that highly capitalized systems (with teams of surveyors, engineers, steam equipment, etc.) were inherently superior to labor-intensive methods. But as the British Resident of Perak remarked in 1893, "After possibly a series of great hardships to the staff and disasters to the company, it is found that the tin raised is infinitesimal in value when compared with the rate of expenditure. . . . The company is wound up and the State gets a bad name with investors, and the only people who really enjoy themselves are the neighboring Chinese miners who buy the mine and plant for an old song and make several large fortunes out of working on their own ridiculous and primitive methods."[24]

It is an intriguing remark, at once denigrating non-European methods while conceding their commercial effectiveness. Indeed, many colonial officials found it consternating, even disconcerting, that European firms should find it so difficult to prevail over their Chinese competitors. But if the subversion of presumed civilizational hierarchies (on which more later) was one cause for concern, the main worry was that these techniques would inevitably render themselves obsolete by depleting the rich, shallow deposits within their reach. By the turn of the

century, attempts to modernize the industry thus revolved around three main elements: new laws to facilitate concessions for large firms, realienating concessions that were left unworked, and improved control of water resources.[25] The first two measures were effectively a form of commercial discrimination against small Chinese outfits and were followed by ordinances against opium use, gambling, and the so-called truck system.[26] The third measure sought to lure investors by precluding private monopolies of water supply and thereby making the business of resource extraction more predictable. But despite such efforts it remained difficult to attract investment and all but impossible to compete with Chinese *kongsis* on labor costs given their dominance of coolie recruitment networks. This inability of European firms to adopt capital- or labor-intensive methods as a means of breaking into the industry eventually prompted them—much as their counterparts in the American West—to implement resource-intensive methods instead.[27]

The solution was hydraulic mining, which targeted low-grade deposits in which the Chinese and Malay competition was uninterested. The basic method is simple. Water is collected in a reservoir at altitude and piped to the mine face where high-pressure monitors wash entire hillsides down sluices, sometimes with the aid of water- or steam-powered gravel pumps to elevate the wash dirt onto raised chutes. Though ancient in conception, it had been perfected in the gold rushes of California and Victoria during the 1850s and 1860s.[28] Despite being banned in California in 1884 as excessively destructive, hydraulic mining was introduced near Ipoh in 1892 and became more widespread around the turn of the century. Its crucial advantage was minimal labor input per ton of earth moved. At the pioneering Gopeng mine, for example, water was diverted from a nearby river along a 2.5-mile watercourse and 5 miles of pipe to a 2-inch monitor nozzle. Ten to twelve Chinese laborers broke up the mine face and washed the pay dirt into a nearby ditch, where some forty Malay and Tamil women panned for ore while ten more workers washed the accumulated tin sand in sluice boxes.[29] The basic technique was similar on Bangka and Belitung: huge monitors capable of removing 50 cubic meters of earth per hour washed entire hillsides into tailraces where suction dredges (*spuitbaggers*) pumped the slurry onto raised chutes.[30] This combination of hydraulic cutting and gravel pumping made earthmoving far cheaper, costing only thirteen cents per cubic yard (ca. 1.25 tons) compared to at least sixty-one cents by traditional open-cast techniques. By 1916–17 it accounted for around half of all earth moved in Belitung's mines (ca. 1.25 million cubic meters). In Malaysia the proportion of miners in hand-dug pits fell from three-quarters in 1911–15 to only one-third by 1921–25.[31]

Hydraulicking and gravel pumping thus drove a twofold expansion of the tin frontier: first, into areas more distant from watercourses; and

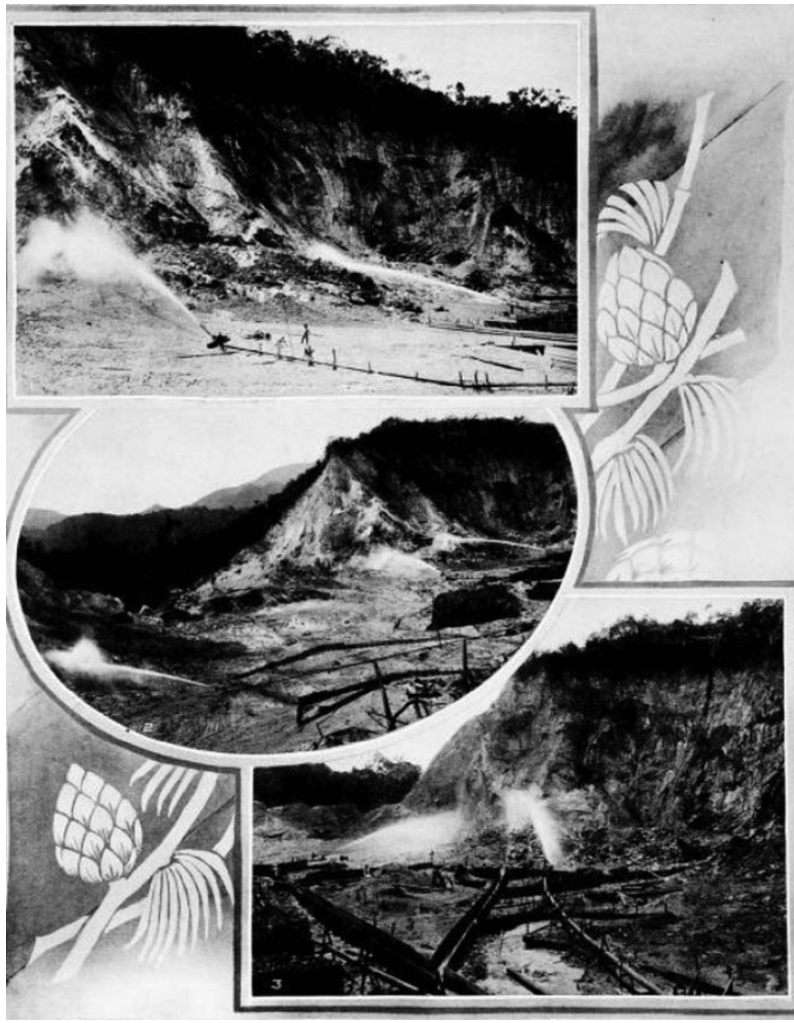

Figure 2: Cutting a 320-foot face at the Bruseh Hydraulic Tin Mining Company, ca. 1908. Arnold Wright and H. A. Cartwright, eds., *Twentieth-Century Impressions of British Malaya: Its History, People, Commerce, Industries, and Resources* (London: Lloyds, 1908).

second, into lower grades of ore. In the process, the very definition of a "deposit" became as much a question of technological application as geological serendipity. Whereas hand-dug open casts in the 1890s required a minimum 3 pounds of ore per cubic yard for profitability, hydraulic mines worked deposits only one-sixth as rich, especially as prices gradually rose after 1900.[32] By 1908 it was generally agreed that "The day when the Federated Malay States might be regarded as the happy hunting-ground for the small miner seems to have passed, and

the future of the tin mining industry in the States will depend upon the economical development on a large scale of low-grade propositions."[33]

If the advent of hydraulic mining thus carried considerable social costs for small operators, its ecological costs were similarly steep. In many ways it represented what Tim LeCain has called a "mass destruction" technique, wherein miners worked ever-lower grades of ore by shifting ever-greater burdens onto the environment.[34] As was also the case with the copper mines LeCain has studied, the key characteristic of this system was not the reduction of labor costs per se (which it also achieved), but rather a dramatic increase in throughput by means of a highly indiscriminate method of resource collection that chewed up and spat out much more than what it targeted. Contemporaries noticed the shift: "the whole mass of the hill, rich and poor, hard and soft, is served alike; all is removed and passed through sluice boxes."[35] As lower grade deposits came into production, the ratio of ore to tailings shifted accordingly. For every kilogram of tin produced, five to six times more waste soil was washed away.

And where did all these tailings go? They ended up in vast "dead zones" and ultimately in the rivers, just as in California.[36] Although local rivers had long suffered from *lampanning* and open-cast effluents, the advent of hydraulic mining greatly exacerbated the problem. As the discharge of tailings rose, especially in Perak, streams that had been "clear as crystal" in the 1870s turned into muddy, meandering watercourses "the colour and consistency of tomato soup."[37] Numerous riverbeds were raised by several feet, some by several meters, increasing the frequency of floods and covering agricultural land downstream with sterile tailings. Among the worst affected was the Sungei Raia, a tributary of the Kinta River. Despite attempts to dredge its channel and stabilize its banks, the continued deposition of sand and silt on the river plain gradually transformed a large rubber estate into a marsh of lagoons and swamp grass.[38] Frequent flooding in the urban centers was a particular concern, especially after the "great flood" of 1926, which inundated much of Ipoh and Kuala Lumpur and triggered major canalization and flood retention works.[39] There were even cases of mine tailings killing off entire settlements. Balun Bidai, a village of two thousand padi farmers near the mouth of the Tumboh river, gradually became a swamp in the 1900s as the river silted up. Even more dramatic was the fate of Kuala Kubu, a market town that was eventually relocated after being buried under 5 meters of tailings washed down the Selangor River from mining operations in the Peretak hills.[40] There is also evidence that tailings damaged shad fisheries along the west coast of Malaysia. Amid declining catches around 1920, one official repeatedly "picked up these fish by hand in a dying condition apparently choked by silt in their attempt to ascend the rivers."[41]

Simply put, the costs of mining were passed on to others downstream. And what made the siltation problem so intractable was the difficulty of


Figure 3: Ipoh during the Great Flood of 1926. Credit: www.ipohworld.org.

repairing the damage once it was done. Many of the worked-out sites—devoid of all topsoil and vegetation, often nothing more than exposed rock and regolith—were virtually impossible to stabilize and continued to erode at a rapid pace. On Bangka, the hundreds of washing sluices left vast flats of sterile sand where vegetation could scarcely take hold even after decades.[42] In Malaysia, it was estimated in 1939 that the mines were still annually depositing 16 million tons of silt (nearly twice as much earth as was removed for all three tunnels of the Channel Tunnel project) into the rivers of Perak and Selangor, much of it from abandoned sites.[43] Even after the watersheds were stabilized, the silt still took decades to clear from the rivers. As a 1928 report on Malaysia's rivers noted, "Today the country is faced with the problem of dealing by curative measures with a disorder, which in the nature of things is peculiarly amenable to preventive measures, and which, had adequate preventive measures been taken in the past, need never have attained very serious proportions."[44] By the time a new Drainage and Irrigation Department was founded in 1932, it could do little more than remedial work, dredging, channeling, and straightening watercourses into classic "organic machines" bearing little resemblance to their previous riverine ecosystems.[45] Indeed, the legacies of wasteland erosion and accumulated silt persisted long after the colonial period. Studies in the 1990s still found that sediment loads on tributaries of the Klang River increased

nearly fivefold as they ran through derelict mining sites, whose sediment yields were over eighteen times higher than even disturbed forest catchments.[46]

These defaced mining landscapes were situated at one end of a long chain linking the kitchens and factories of the industrialized world to the forests of Southeast Asia. For many years their remote location and indispensability for colonial coffers allowed them to operate with scant regard for the damage they caused. On Bangka and Belitung, the quasi-official status of the industry essentially gave it a free hand. In Malaysia, where early attempts to retain effluents led to "serious friction between the Mines Department and the miners," the creation of a Tailings Commission effectively meant self-regulation and lack of enforcement.[47] During the First World War even these lax regulations were loosened to maintain production.

Over time, however, the dire consequences for the region's rivers posed a new set of constraints on the industry. For one thing, the damage increasingly attracted regulatory attention, especially in Malaysia. A 1922 Control of Silt Enactment—by far the oldest such provision in the British Empire—was soon followed by a ban on hillside mining above the 250-foot contour.[48] In 1928, two years after the "great flood," a further enactment required permission to dispose of all overburden and tailings on any given site.[49] As regulations tightened, resource depletion also grew more acute. By the mid-1920s, engineers agreed that the hydraulic frontier had closed. There were few suitable areas for new reservoirs, and miners had already cut down most of the workable hill sites.[50] But as the soils and streams of the foothills were showing signs of exhaustion, world consumption of tin—and the prices it fetched—continued to rise, surpassing prewar levels by 1920 before peaking at 193,000 tons by the end of the decade.[51]

Everything pointed to a new frontier in the lowlands, especially in swampy areas like the lower Kinta Valley or Bangka's estuaries where earlier techniques were inapplicable. The solution was the bucket dredge. Having already chewed up river bottoms from the Antipodes to California, the first dredges arrived in Malaysia just before the First World War and systematically began eating their way across the river valleys of Perak and Bangka during the 1920s. By 1930 the hundred or so dredges operating in Malaysia accounted for 30 percent of its tin output, rising to over half by 1940.[52] They essentially combined three operations in one: a chain of buckets excavated and lifted the pay dirt, a series of jigs separated the ore from the waste, and the tailings were deposited at the rear, often into bunded paddocks on previously worked land. Fueled by vast amounts of inanimate energy, they devoured entire landscapes in search of the tiny (and ever-decreasing) fraction of resource that they valued. Even the early 300 hp dredges could lift and treat up to 100,000 cubic yards per month, equivalent to the output of around two thousand laborers. In the mid-1920s, new

models the size of apartment blocks could process up to 300,000 cubic yards per month to depths of over a hundred feet. Low operating costs—similar to the cheapest hydraulic mines—meant that grades as meager as two-thirds of a pound per cubic yard were profitable. Like hydraulicking and gravel pumping, dredges extended the tin frontier in two senses: they not only opened up whole new landscapes, but also allowed miners to work low-ore grades including even long-abandoned tailings dumps (e.g., at Larut).[53]

By utilizing different resources, dredging opened the "final frontier" on the wet valley floors. In addition, by making a different waste footprint, it took some of the pressure off erosion-prone foothills and damaged rivers. While there were a host of economic and political reasons why colonial governments promoted dredging over other methods, mitigating environmental damage also played a part, especially as the rubber industry expanded in Malaysia. It was, by and large, less detrimental to local hydrology: contemporaries estimated that no more than 5 percent of the excavated ground escaped in the form of fine slimes. Dredging was also centered on swampy terrain unsuited to agricultural production, and it could even ease the drainage problems caused by mining and siltation upstream.[54]

But as is often the case, the solution for one set of problems brought new ones. Although historians have suggested that dredging markedly reduced the ecological costs of mining, it is more accurate to say that it displaced them from the hillsides and rivers to the lowlands and

Figure 4: Tin bucket dredge north of Manggar, East Belitung, 1937. Credit: Tropenmuseum, Amsterdam.

coasts.[55] For one thing, the sites themselves were demolished in the process, which mixed the ground from 25 to 150 feet deep and thereby spoiled the topsoil with vast amounts of infertile subsoil. Moreover, even when the finer slimes (which contained nearly all the organic matter) and coarser material were separated, the latter was often deposited on top of the former, leaving the surface effectively dead. As the dredges worked their way across valley floors, they left behind a landscape of sterile sand hummocks and miniature dunes that contemporaries regarded as "permanently damaged."[56] They also extended mining from terrestrial to marine environments. Bangka and Belitung quickly became the world's largest offshore tin producers as dredges tore up the former alluvial river bottoms that had been inundated by rising ocean levels after the last Ice Age. Along the coasts, too, they slowly excavated whole new waterways that changed river and tidal flows as they chewed their way inland.[57]

Despite repeated calls for the mandatory deposition of slimes on top of sterile sands and the stockpiling of topsoil for subsequent redistribution, the failure to enact such preventive measures meant that the restoration of former mining lands (like damaged rivers) was limited and remedial.[58] In Malaysia, where rapid population growth and the expansion of rubber planting intensified land pressure, the Agricultural Department conducted rice growing trials on dredged sites in the 1930s and later experimented with green dressings—especially woody shrubs of the *Mimosa* and *Crotalaria* genera—as a means of kick-starting plant succession (former open-cast or hydraulic sites were generally deemed irretrievable).[59] But despite some successes, the lack of binding regulation meant that worked-out sites were usually left infertile and derelict.[60]

Dredging was, then, another form of "mass destruction." Like hydraulicking and gravel pumping, it expanded the tin frontier primarily at the expense of the biophysical environment. But as with these earlier innovations, it was crucial for meeting the rising demand for tin. World production peaked in 1929 (193,000 tons) and once again between 1937 and 1941 (211,000 to 242,000 tons), principally thanks to output from Southeast Asia.[61] Although wartime disruption (due to Japanese occupation and the deliberate sabotage that preceded it) made tin one of the scarcest of major war materials, it remained a crucial element of numerous manufacturing processes.[62] Dredging already accounted for around half of tin production in the region, and it became the mainstay of the industry after the war. As real energy costs fell and electrolytic techniques for thinner plating pushed tin prices downward, dredges enabled miners to process ever more minuscule percentages of ore through the ever-greater substitution of inanimate power for human energy.

## TECHNOLOGY, RACE, AND EFFICIENCY

In certain respects, the history of tin offers a particularly vivid illustration of the link between "mass destruction" and mass consumption in the modern world. One of the basic fundaments of modern consumerism is an unprecedented ability to escape local resource constraints by drawing on distant raw materials—in world systems terminology, to create "metabolic rifts" of unequal ecological exchange.[63] For industrial Europe and North America, the growth of the global tin economy helped expand their ecological footprint in two ways. Directly, of course, the metal itself constituted an important material subsidy from half way around the world, underpinning a range of vital industries and ending up in countless consumer goods. But indirectly, too, it critically facilitated other subsidy flows linking the industrial metropoles to their increasingly far-flung areas of supply. As one of the principal means for conserving and transporting the perishable goods that they required, the tin can quite literally fed the rise of modern consumer societies. By the late 1950s, world production of canned food reached 18 million tons. In 1962 the United States alone produced over 48 billion cans, which corresponded to around 257 per person annually.[64] Though few consumers knew it, their well-stocked cupboards were closely tied to the human-made badlands and silted rivers of Southeast Asia.

Tin was therefore a doubly important element in the globalization of consumption and imperial networks of extraction. The complex connections between the households of the industrial world and the subsoils of Southeast Asia in many ways typified the expanding resource frontiers and thickening web of commodity chains that stretched across the globe during this period. This is why the tin frontier showed so many parallels to processes of social and environmental change elsewhere.

But if the common themes are clear enough, it is the variations that enable us to situate particular goods and industries more firmly within their historical contexts. For the case of tin, one such variation relates to industrial-era mining, and in particular the role of technological innovation as a key driver of mineral frontiers. By the early twentieth century, the mining industry at large relied progressively less on the discovery of new reserves and ever more on the ability to tap known but previously inaccessible or unprofitable deposits. In Southeast Asia as elsewhere, the progressive depletion of the richest deposits prompted miners to work declining ore grades through greater mechanization and economies of scale.[65] Admittedly, a mineral "reserve" is always a moving target, ever shifting in accordance with prices and methods of extraction. By this time, however, most mines had ceased to be treasure troves stumbled across by prospectors and instead had become essentially anthropogenic sites, products of a

particular constellation of closely interrelated factors: technological innovations that made mines profitable at current prices, a political system that privileged large enterprises and allowed many of the costs to be passed to the environment, and a culture broadly willing to countenance these costs in the name of "progress." In this sense, mining epitomized what Carl Sauer called "the doctrine of a passing frontier of nature replaced by a permanently and sufficiently expanding frontier of technology."[66]

Other variations were rooted predominantly in sociocultural phenomena, an understanding of which helps reduce the risk of economic tunnel vision that can sometimes plague commodity analyses.[67] The tin frontier was, like any other space, not merely a physical stage for human activity but was itself constituted by ideas and experiences, by "mental geographies."[68] Much as the rhetoric of "idle lands" and profligate aborigines animated the colonization of the American West or Australian interior, perceptions of the "waste" or "inefficient plunder" of resources in Europe's tropical colonies both promoted and served to legitimate European dominance.[69] Viewed in this light, efforts to mechanize the tin industry reflected not only commercial imperatives but also the colonial ideology of the right, even duty, of Europeans to spread their mastery of nature to benighted parts of the world. As British colonial secretary Joseph Chamberlain remarked in 1895, "I regard many of our colonies as being in the condition of undeveloped estates" that must be "developed for the benefit of their population and for the benefit of the greater population which is outside."[70] Wedded to this outlook was a quasi-moral objection against permitting a resource to lie idle if it could serve human purposes. According to the sociologist Benjamin Kidd, it was imperative to avoid "the inexpediency of allowing a great extent of territory in the richest region of the globe—that comprised within the tropics—to remain undeveloped."[71] This same attitude was still manifest in a 1939 Malaysian mining report, which asserted that anyone in control of ore deposits was "under an onus to permit the exploitation of that mineral."[72] As elsewhere in the tropical world, imposing industrial technology in Southeast Asia's tin fields was both a sign of European power and a means of exerting it.

Understanding these relationships between technology, culture, and power has been one of the foremost preoccupations of colonial and postcolonial historiography in recent years. A central leitmotif has been the concept of "technopolitics," which has influenced work on fields ranging from colonial medicine to agricultural development. Among the many merits of this conceptual approach is its emphasis on the inextricable links—often obscured by an ideology of scientific autonomy—between control of the material and social world. As Timothy Mitchell has formulated it, technopolitics is "a particular form of manufacturing, a certain way of organizing the amalgam of the human and nonhuman, things and ideas, so that the human, the

intellectual, the realm of intentions and ideas seems to come first and to control and organize the nonhuman."[73] Since the 1990s a vast literature has shown how the application of supposedly apolitical expertise, usually in the name of "modernization" or "development," carries fundamental political and social implications, even if scholars disagree on the extent of its quiet hegemonic power.[74]

Seen through this lens, the modernization of Southeast Asia's tin industry was one of many examples where the application of technical expertise, and assertions of its necessity and universal validity, served to underpin imperial power. But perhaps more than most cases, it shows how such expertise, far from merely parading in its "apolitical" guise, was also overtly politicized, whether in the incessant complaints about superficial Asian methods or the celebration of Western miners as saviors of the industry. At one level, such evidence confirms the well-established argument that nineteenth- and early twentieth-century imperialism was strongly animated by ideologies that measured human societies by their technical achievements.[75] But to take this argument a step further, the evolution of the tin industry also suggests that it was not just "machines" and technical rationality per se that were regarded as the "measure of men," but more generally the degree to which human communities were able to control the physical environment and extract wealth from it.

What was ultimately being judged in evaluations of different mining processes was not so much their level of mechanization as their level of "efficiency." We can get a broad sense of how this was defined from Kidd's 1898 treatise on *The Control of the Tropics*, which declared that "the last thing our civilisation is likely to permanently tolerate is the wasting of the resources of the richest regions of the earth through the lack of the elementary qualities of social efficiency in the races possessing them."[76] Efficiency, in this scenario, denoted not only a superior organizational and technical aptitude but also a deeper knowledge of the natural world that permitted an appreciation of the full bounty it offered for human design—provided that design be good enough.

Such ideas were deeply engrained in the imperial project, and what made them so compelling was that they linked colonial authority not only with technological prowess but also with contemporary notions of race and environment. In the particular context of Southeast Asia's tin fields, Malays were seen to lack both elements of "efficiency." Regarded by colonial observers as "an indolent, contented, thriftless, unambitious, polite and peaceful race," they supposedly possessed neither the urge nor the know-how to capitalize completely on the assets that lay under their feet.[77] By comparison, Chinese miners were seen to have the former but not the latter: though industrious and commercially astute, their technical capabilities confined them to rich shallow deposits.[78] Only the colonizers purportedly had both the motivation and ability to maximize the extraction of available resources, and

this tendency to associate race and technology was magnified by the close structural correspondence between the ethnic ownership of a mine and the techniques it deployed. By the turn of the century, colonial administrations made no bones about deliberately promoting Western mining enterprise—though it was unclear whether the various mining codes, prohibitions on the "truck system," and increasing size of concessionary plots merely amounted to or were specifically intended as a form of racial discrimination.[79]

Clearly, these ideological hierarchies of efficiency and waste framed general perceptions of Southeast Asia's tin fields. In certain ways they also helped to promote the specific policy of modernization via Western mining techniques, particularly as European entrepreneurs turned to hydraulicking and gravel pumping in order to break into the hitherto Chinese-dominated industry. When European hydraulic miners faced the prospect of tighter environmental regulations, they repeatedly cited the "thoroughness" and "economy" of these methods to counter what they saw as "a persistent prejudice against monitor workings on the assumption that they cause immense damage."[80] The real damage, they contended, resulted from extensive Asian methods that did not exhaust the ground before moving elsewhere. As one hydraulic mine manager boasted in 1905, "The most striking feature of mining affairs at present is the losing of ground by the wasteful Chinese miner, who has practically picked the eyes out of the country, and the advance of the White miner, who is making excellent profits out of ground the Chinese could not touch."[81] That Chinese miners were not slow to adopt the hydraulic monitor and gravel pump did little to undermine these racialized claims to superiority, and if anything was taken as confirmation of Europe's technological trailblazing and the benefits it brought to subject peoples. Indeed, many of the same assumptions framed the subsequent advent of dredging, which was celebrated for performing a racial role reversal in the working of low-grade ores. "It had always been the case in alluvial working, whether in California or Australia, that the patient Chinaman could come after the hasty European and obtain a living from what the European had left," noted one engineer in the mid-1920s. The fact that "dredging now took place in considerable part upon areas already worked and left by the Chinaman" provided "a comfort more grateful than cocoa, and a stimulation greater than that of wine."[82]

These examples illustrate an important point: despite the vast amounts of waste material they produced, hydraulicking and dredging were not considered wasteful. On the contrary, they represented the pinnacle of "efficiency" for coaxing profits from even marginal grades of ore. What counted as profligate in the economic culture of colonialism was not the systematic destruction of entire hills, rivers, and valley floors for low-grade ore, but rather the inability to make meager deposits pay—to allow them to run "largely to waste under the management of

races of low social efficiency."[83] If waste therefore denoted a failure to convert a potential resource into cash, then efficiency represented a maximization of output regardless of the collateral effects. A survey of the Malaysian industry summed up the matter as follows: "Efficiency of mining really means the degree of completeness attained by the miner in recovering the mineral from the ground that has been leased to him."[84] The only thing that truly counted was profitability in relation to current world prices, including transport, fuel, and all other costs. The "mass destruction" technologies that European firms introduced in the region worked because the costs were shifted to the environment, which did not have a column on the balance sheet.

## CONCLUSION

Obvious though it may seem, it is worth emphasizing that these definitions of waste and efficiency were markedly different from—even diametrically opposed to—those that have informed more recent critiques of pioneer profligacy and "frontier economics." The core issue at the time was not whether natural resources were used sparingly but whether they were exploited thoroughly. This meant that, ironically, the "waste" of untouched ore in the ground represented a greater transgression than laying waste to an entire mountain or watershed in the pursuit of low-grade ore. And what permitted the maximal extraction of the targeted resource was of course the active utilization of other natural resources—above all, fossil fuels and hydrological power—that could be harnessed to this endeavor. Tapping nature's energy flows to capitalize fully on the other gifts of nature thus gave this particular brand of efficiency a double environmental dimension, though neither entered its cost calculation.

As some contemporaries noted, this narrow method of accounting was hardly unique to tin mining, or even mining at large, but increasingly characterized economic thinking in general during this period.[85] "We have lived so long in what we have regarded as an expanding world, that we reject in our contemporary theories of economics and of population the realities which contradict such views," remarked the ever-quotable Carl Sauer in 1938. "Economics unfortunately has become restricted increasingly to money economics, instead of embracing the study of *Wirtschaften*, and largely has missed this ominous fact."[86] Keynes likewise criticized the obsession with "the financial results" for turning the entire conduct of life "into a sort of parody of an accountant's nightmare. . . . We destroy the beauty of the countryside because the unappropriated splendors of nature have no economic value. We are capable of shutting off the sun and the stars because they do not pay a dividend."[87]

The expansion of the tin frontier in Southeast Asia clearly exemplified central elements of this broader economic culture. In various respects it

also reflected distinctively imperialist ideas about race, technology, and efficiency that served to justify colonial power. If the main drivers of change were economic and material pressures common across much of the global mining industry—above all declining ore percentages and a corresponding need for economies of scale—the attitudes and values that framed these processes nonetheless provided a significant ideological support. The colonial condescension of bringing Europe's mastery of nature to the "underused" resources of the tropical world not only abetted the entry of mechanized Western firms into the industry, it also condoned, even encouraged, the deployment of techniques more wasteful, by other criteria, than what they replaced.

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## Notes

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