安第斯山脉地区国土规划
与（后）矿山开采生态修复的新范式

NEW PARADIGMS OF TERRITORIAL PLANNING AND (POST-)MINING ECOCLOGICAL RESTORATION IN THE ANDES

1 引言

采矿业为包括城市化在内的全球消费提供了物质原料。20世纪，近30亿人口迁入城市，大大增加了对住房、食物、淡水和基础设施的需求[1]。在可行的替代方案问世之前，建造业仍将依赖金属原料供应[2]，这就会间接地加剧矿山所在地景观的破坏。为了保持持续增长，采矿业不断追求产能的提高。在国际金融机构和新自由主义采矿法案的支持下，全球对金属原料的巨大需求以拉丁美洲安第斯山脉的采矿投资为代表[3]。早在16世纪，采矿企业就已经成为安第斯山脉开采出了“世界级”的矿藏。今天，随着世界各地的城市的持续扩张，更多的矿场开始作业，同时也有一些矿场随着国际市场价格波动和技术进步而不停地在停工或复工间摇摆。
1. **Introduction**

Mining provides the materials for worldwide consumption, including urbanization. In the 20th century, nearly three billion inhabitants have moved into cities, significantly increasing the demand for shelter, food, fresh water, and infrastructures. For the time being, construction will keep relying on the provision of metals and there will be the continued collateral destruction of remote landscapes of extraction. Mining industries incessantly improve productivity in order to stay ahead of growth. Supported by international financial institutions and neoliberal mining codes, mining investments in the Latin American Andes play a crucial role in quenching the worldwide thirst for metals.

2. **Potosí, Huancavelica, Hualgayoc, and Cajamarca: Co-Evolution of Mines and Settlements**

Mining enables the establishment and growth of settlements, while exacerbating large-scale ecological destruction. Mining, explicitly and implicitly, generates urban environments. Initially, mining settlements owed their existence to the perpetuity of the productive cycles of extraction in remote landscapes. They required the primary capital for resource extraction, namely human labor. The physical proximity to mines characterized the settlements. They emerged where resources were found, commonly in areas that did not necessarily have the locational assets to host human agglomerations on.
Traditionally, Andean settlements were dispersed in order to cleverly exploit locational assets that were distributed over different ecological floors (areas with different ecological conditions that correspond to variations in altitude). Spanish colonization — and colonial mining — radically distorted this dispersed settlement pattern.

The first so-called “mining settlements” of the Andes were a colonial product of the 16th to 19th century Spanish regime. They transformed indigenous mining practices, which served local needs, into industrial-scale exploitation. They supplied the world market and fueled imperial treasuries across the ocean. In contrast to other colonial cities of the time, mining settlements emerged immediately following the identification of mineral deposits, often before they were officially established by Spanish authorities as cities. The well-known settlements of Potosí and Huancavelica are emblematic examples of environments which were instantly generated by metal fever and only subsequently officially recognized, let alone rationally planned. They appeared as proof reductio ad absurdum of acting before thinking, satisfying greed before taking responsibility. The mining settlements were, by definition, at odds with ordinary town development rationality where services are created for permanent use and financed through accumulated surplus value. Potosí and Huancavelica were created without a perspective of permanent investment. All generated surplus value was, as a rule, exported as quickly as possible. In short, mining initiated an impossible development condition, which also explains their inherent problematic nature. Nonetheless, although they were based in geographically remote areas, colonial mining settlements converged over time with local, regional, and global processes of translocation. Their role and importance are self-evident, given the never-ending silver and gold hunger of the ever-warring Spanish empire.

The city of Potosí (in Bolivia) emerged at the foothills of the Cerro Rico Mountain with the tin-silver belt of the Andean Altiplano. Scarce yearly precipitation, great evaporation, and an annual temperature ranging from -16 °C to 7 °C made Potosí a challenging environment for both human occupation and mining. Potosí and Cerro Rico (at 4,000 and 4,700 meters above sea level, respectively) belong to a larger hydrological system of lakes and tributaries of the Pilcomayo Basin headwaters. The first settlers of Potosí relied on seasonal springs. However, mining intensity (ore-grinding energy) and accompanying urban development (human consumption) required the use of headwater sources in the upstream part of Pilcomayo. The construction of 32 artificial lakes — which complemented natural ones — allowed 132 mills to be powered and supply local populations. Potosí’s network of human-made
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3. 680m处，这里的首个采矿定居点万卡维利卡于1563年建成。相较当时的安第斯山脉城市（卡哈马卡，海拔2 750m；阿雷基帕，海拔2 350m；阿亚库乔，海拔2 700m），万卡维利卡和波托西都高于人类定居点常见的海拔高度[7]。

分散建立在万卡维利卡地区的临时性村庄表明当时存在季节性农耕及朱砂（化妆品原料）开采活动。在西班牙殖民时期，万卡维利卡还未有人烟[12]。然而，圣塔芭芭拉的矿山开采使得当地的定居点呈爆炸式增长，这些聚落依赖其他资源来满足居民生活及开采需求。食品和物品的采集来自于方圆450公里内的多个生态层，包括来自利马（海拔120m）的布匹和工具、来自纳斯卡（海拔560m）的酒、来自万塔（海拔2 640m）的古柯叶和蔬果、来自阿亚库乔（海拔2 750m）的面包和来自安达韦拉斯（海拔2 890m）的糖。因此，开采业与当地山脉生态环境的严重破坏密切相关。例如，由于万卡维利卡就地熔炼水银需要大量木柴，导致生长在海拔3 500m以上的安第斯山脉典型的秘鲁茅草（Stipa ichu）草原，以及龙鳞木林的显著退化[7]—这不仅是对矿石的开采，也是对区域资源的无情掠夺。

在安第斯山脉北部的热带地区，位于卡哈马卡地区的瓦尔加约克矿区则是秘鲁殖民时期环境破坏的罪魁祸首。瓦尔加约克海拔3 500m，位于马拉尼翁河流域。在18世纪70年代初，瓦尔加约克已显现出典型的分散殖民开采模式[13]。瓦尔加约克的矿脉“比赛罗里科的矿脉更丰富，且更易开采”[14]，因此造就了吸引众多西班牙投资者的区域经济。即便是位于瓦尔加约克银矿附近的海拔高达4 000m、阴冷多风、“不宜人居”的山谷中，仍然出现了采矿定居点[14]（图2）。瓦尔加约克与该地区的主要居民聚集区——包括查塔（银加工）、卡哈马卡（食品湖泊，完成于1621年，被设置于7到15公里的东南方向，以保护和采矿山。合起来，湖泊、水道、坝、运河、隧道、道路和桥梁改变了远超采矿区域的土地。

The mines of Santa Bárbara (in Peru and now a UNESCO World Heritage), one thousand kilometers northeast of Potosí and 4,400 meters above sea level, provided the necessary mercury (quicksilver) for Potosí’s silver processing. Huancavelica’s first mining settlements rose in 1563, 2.5 kilometers south of the mines at 3,680 meters above sea level. Compared to other Andean cities of the time (Cajamarca at 2,750, Arequipa at 2,350, and Ayacucho at 2,700 meters above sea level), Huancavelica — as Potosí — was located above the usual altitudinal range for a human settlement[7].

Evidence of scattered villages for temporary occupation in Huancavelica indicated the seasonal practice of agriculture and cinnabar-mining activities for cosmetics production. Huancavelica was uninhabited at the moment of the Spanish occupation[12]. However, exploitation of Santa Bárbara’s mines turned the region into nuclear-like settlements, which relied on other resource niches to cover its urban and mining demands. Food and goods were sourced from a wide range of ecological floors up to a distance of 450 kilometers away. Cloth and tools came from Lima (120 meters altitude), liquor from Nazca (560 meters altitude), coca leaves, fruits, and vegetables from Huanta (2,640 meters altitude), bread from Ayacucho (2,750 meters altitude), and sugar from Andahuaylas (2,890 meters altitude).

Mining endeavors went hand in hand with the rampant destruction of local Andean ecologies. For example, in-situ smelting of mercury in Huancavelica required massive amounts of firewood, which led to the significant retreat of local Stipa ichu pastures (a typical vegetation of the Andes which grows above the 3,500 meters altitude) and Quinual trees[7]. Mining was not limited to ore extraction; it implied a ruthless seizure of regional resources.

In the northern tropical Andes, Hualgayoc (in the Cajamarca region) has the most significant environmental liabilities caused by colonial mining in Peru. Hualgayoc — located at 3,500 meters above sea level — belongs to the Marañon watershed. By 1771, Hualgayoc represented a dispersed model of colonial extraction[13]. Hualgayoc’s mineral veins were “richer than those of Cerro Rico and simpler to extract”[14] and generated a regional economy that attracted many Spanish investors. The mining settlements of Hualgayoc emerged near the Hualgayoc silver hill — up to 4,000 meters above sea level — and in the Hualgayoc Valley, despite the “inhospitable” cold, humid, and windy climate[14] (Fig. 2). Hualgayoc formed part of a larger
The Hualgayoc mining works consisted of four thousand mine-openings along eighteen known underground silver veins. As so often in colonial Latin America, assembling and subsequently catering to a major labor force was a primary issue. Mining technology was neither capital intensive, nor that advanced to require centralization of working sites. Hence the multitude of “investors” and mine-openings. Micuyampa, El Purgoratorio, and La Punta, were established in order to accommodate laborers. Micuyampa emerged at the foot of Huagayoc Hill on both sides of the valley and served as the main gate to the working sites. By the end of the 18th century, Micuyampa accommodated three to four thousand miners and around 400 “hovels” made from surrounding ichu.

Already at this early stage of mass extraction, mining was heavily contested due to its disastrous ecological and social consequences. Extraction greed appears to be simultaneously at the roots of capitalist development and of an unjust society and damaged environment. At the same time, it should be noted that the Los Dos Carlos project, envisioned by Bishop Baltazar Jaime Martinez Companon, was exemplary for its reformist (Enlightenment) agenda in Hualgayoc. It imagined the increase of labor efficiency by radically improving the appalling local living-working conditions that the Spanish colonial regime — always looking for greater and quicker revenue — had tolerated. In his vision (then qualified as utopian), the Los Dos Carlos settlement was to replace Hualgayoc and include miner’s land-tenures (land tenure for indigenous workers), working hour shifts, and housing facilities in the nearby region located at lower ecological floors.

Political economy that involved the main urban agglomerations of the region, including Chota (for silver processing), Cajamarca (for providing food and goods), Trujillo (for the fabrication and shipping of silver bars), and Huancavelica (for providing mercury), and other regions located at lower ecological floors.

Mining即一度备受争议 — 贪婪榨取是资本主义发展的本质，也是造成社会不公及环境破坏的根源。因此“投资者”纷涌而至，大量矿口不断出现。米库伊班帕、埃尔普拉托里奥和拉庞塔定居点正是为了容纳劳动力而建。其中，米库伊班帕定居点分布于瓦尔加约克山脚下的山谷两侧，犹如矿区的一道大门。截至18世纪末，米库伊班帕的矿工已达三四千人，并就地取材利用茅草建成了约400间“茅屋”。

因对生态和社会造成的灾难性后果，在大规模开采的早期阶段，采矿即一度备受争议 — 贪婪榨取是资本主义发展的本质，也是造成社会不公及环境破坏的根源。因此，作为瓦尔加约克地区的“启蒙运动”改革典范，由西班牙巴尔塔萨尔·杰米·马丁内斯·科姆潘主教所提出的“洛斯多斯卡洛斯计划”(尽管这一计划在当时被认为是空想)应运而生。该计划试图通过彻底改善当地恶劣的生活和工作条件，从而实现从功利主义的人-地过度开发转向基于环境整体性的开发，包括详细说明可以种植哪些植物、饲养哪些动物、利用哪些建筑材料等。通过战略性地利用现有人力和自然资源，他规划了如何从功利主义的社会不公及环境破坏的根源。因此，“投资者”纷涌而至，大量矿口不断出现。米库伊班帕、埃尔普拉托里奥和拉庞塔定居点正是为了容纳劳动力而建。其中，米库伊班帕定居点分布于瓦尔加约克山脚下的山谷两侧，犹如矿区的一道大门。截至18世纪末，米库伊班帕的矿工已达三四千人，并就地取材利用茅草建成了约400间“茅屋”。

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2. 矿工不再仅限于单身男子，而是以家庭为单位，可以同时从事开采和农业等经济活动。马丁内斯主教详尽地描绘了该计划所涉及的动植物、地质、人文等方面的内容，并配以插图(千余幅水彩画)，可以与亚历山大·冯·洪堡的当代安第斯山脉调查相媲美。对所涉及的动植物、地质、人文等方面的内容，他进行了科学文献研究加强了计划的可行性，并配以插图(千余幅水彩画)，可以与亚历山大·冯·洪堡的当代安第斯山脉调查相媲美。他们所使用的分类方法与洪堡的方法相同，但对所涉及的动植物、地质、人文等方面的内容，他进行了科学文献研究加强了计划的可行性，并配以插图(千余幅水彩画)，可以与亚历山大·冯·洪堡的当代安第斯山脉调查相媲美。他们所使用的分类方法与洪堡的方法相同，但对所涉及的动植物、地质、人文等方面的内容，他进行了科学文献研究。
Not surprisingly, the project was sabotaged by Hualgayoc’s main mining investors. Nonetheless, after a peak of mineral production in 1792, Hualgayoc entered a phase of mining retreat. It was abandoned by 1804. Until today, feasibility and market logic arguments resonate through reforms of the ruthless exploitation of both nature and humans. The transformation of land and humans into culture (the production of a human environment rather than the reproduction of a natural one) was part and parcel of the bishop’s aborted reform project.

Cajamarca’s large-scale surface mining (Yanacocha) was established two centuries later. Gold mining operations started in 1993, at 3,500 ~ 4,150 meters above sea level, in the headwaters of the Cajamarca Basin (Fig. 3). As in Hualgayoc’s working sites, Yanacocha’s leaching mines invaded the region’s unique Jalca ecosystems, a denomination for the tropical Andean ecoregions located above 3,500 meters altitude and below the limits of permanent snow (Fig. 4). Jalca vegetation and thick topsoil absorb and store water, thereby nourishing the basin’s aquifers and tributaries[19], as well as the rivers of the quechua ecological floor (2,500 ~ 3,500 meters altitude). Since pre-Hispanic times, a vast amount of caseríos (multi-ethnical assemblies of extended-family houses) were dispersed in “vertical archipelagos”[20] across quechua altitudes. The self-subsistence economies of the caseríos rely on reciprocal mechanisms of housing, farming, and water management. The city itself, Cajamarca, lies at the foothills of the Cajamarca Valley — the floodplain of which is believed to have once been an ancient lake[14] (Fig. 5). The Ronquillo,
流。回溯至前殖民时代，大量的农舍（多民族聚居的宗族民居）垂直散布于克丘亚生态层中[20]。自给自足的农舍经济有赖于住房、农业和水管理的相互促进机制。卡哈马卡市坐落在卡哈马卡山谷的丘陵地带，这一带的泛滥平原曾为一个远古湖泊[14]（图5）。隆基略河、波肯河和格兰德河促进了该流域农业和畜牧业等主要经济活动的发展。

在矿石开采和加工方面，尽管亚纳科查高度依赖现有的自动化技术，而非从采矿定居点引入劳动力，但这里仍然拥有一支庞大的劳动力大军（8,000多名工人[21]）。这些矿场在卡哈马卡市以北40km处，且海拔高度又提升了1,250m，显然不适合人类长期居住，更不用说永久居住了。但是卡哈马卡市的地理位置相对优越，配备了引进物资和专业劳动力所需的最基本的基础设施，以确保能将矿石运送至特鲁希略的沿海港口。因此，卡哈马卡就像是“矿区与大都市之间的一个中转站”[22]

在亚纳科查矿区，很少有供短期作业人员居住的临时住房设施[23]，亚纳科查开采企业在城市与矿区之间建立了一个庞大的公交运输系统，以组织成千上万名矿工的日常通勤。卡哈马卡的存在使得亚纳科查实际上变相控制了格兰德河和波肯河的水源地，造成该市两家饮用水厂必须依赖于矿业公司才能获得充足水量。为了缓解这一问题，2004年，亚纳科查修建格兰德大堤，以便调节泥沙排放，从而增加城市供水，使该市饮用水的日产量翻番。因此，即便是卡哈马卡，其尚未形式完整的开采产业体系，因为开采活动的固有属性已经决定了这里应当创建一个全面而包容的环境，从而实现人与生态的和谐共荣。

而且，由于亚纳科查矿区的出现，该地区的城市人口从1993年的311,135人增长至2017年的537,000人，其中大部分集中于卡哈马卡市[25]。在过去30年间，卡哈马卡的城市建设大肆向山区扩张，这反过来又增加了城市汲取地下淡水的需求。与此同时，亚纳科查的采矿活动也显著改变了当地流域的水管理。邻近地表水水源地的地理优势一方面有利于亚纳科查的金矿开采，另一方面法律上也要求矿业公司保护上游水质，并为保障下游居民（包括城市居民和大量居住在分散农舍中的居民）而征用的水坝。因此，亚纳科查实际上变相控制了格兰德河和波肯河的水源地，造成该市两家饮用水厂必须依赖于矿业公司才能获得充足水量。为了缓解这一问题，2004年，亚纳科查修建格兰德大堤，以便调节泥沙排放，从而增加城市供水，使该市饮用水的日产量翻番[26]。除了城市供水的集中化和高度工程化，农舍居民还开发了复杂的灌溉系统、精细如迷宫般的运河系统以及能够自给自足的梯田。目前，卡哈马卡及其周围的农舍，以及亚纳科查都在争夺安全使用淡水的特权。这引发了关于小型和大型水系统的争议，这些供水系统也关系到当地、区域和全球的开采战略[27]（图6）。

毋庸置疑，目前的用水商品化政策在资源争夺方面的收效甚微。不过，在过去30年的实践中，围绕水和土地的社会—环境冲突对常规的开采作业构成了威胁，也正是由于这些原因，卡哈马卡北部原始草

Porcón, and Grande Rivers articulate the primary agricultural and cattle-raising economical activities of the basin.

For the purposes of excavation and ore processing, Yanacocha relies heavily on currently available automated technologies rather than on imported human labor from mining settlements, although the labor force of Yanacocha (of more than eight thousand workers[21]) is still impressive. The mines operate forty kilometers north of Cajamarca City and 1,250 meter higher, hence in areas not proper for long, let alone permanent, human settlement. The city, however, is better located and sufficiently equipped with the minimum infrastructure necessary to import supplies and specialized labor force, and to ensure the transportation of ores to the coastal harbor of Trujillo. Cajamarca serves as a “stepping-stone between extraction sites and bigger metropoles”[22]. Within the Yanacocha compound, very few temporary housing facilities host a “fly-in fly-out,” specialized labor force for short periods of time[23]. The majority of miners are bussed daily from Cajamarca. The Yanacocha mining company developed an impressive city-mine bus transportation that organizes the daily commute of thousands of miners. Cajamarca’s existence allowed Yanacocha to evade structural investment in settlement. Yanacocha rather makes use of Cajamarca, than contributes to its sustainable development. Yanacocha’s investments in Cajamarca are restricted to minimal payoffs for the financing of exclusive schools, medical facilities, etc., most of which only benefit the mining workers and their relatives[24]. One is still far away from a mining industry as an integral and inherent part of its activity produces a full, inclusive environment in which humans and ecology can thrive.

Yanacocha triggered notable demographic growth. The region’s urban population increased from 311,135 in 1993 to 537,000 in 2017, with a large part of that growth concentrated in Cajamarca City[25]. In the last thirty years, the imprint of Cajamarca has abruptly expanded uphill. This, in turn, has increased the demand for pumped, freshwater provisions. At the same time, Yanacocha’s mining has significantly transformed the basin’s water management. Its adjacency to ground and surface headwater sources not only serves the purposes of mining, but also legally requires the mining company to safeguard upstream water quality and develop basin-scale mechanisms of water provision for downstream livelihoods — including both the city and dispersed, but extensive, rural settlement pattern of caserios. The fact that Yanacocha controls the headwaters of the Grande and Porcón Rivers, has created dependency on the mining company for sufficient water flow to the city’s two potable water plants. In 2004, the Grande Dike was constructed to regulate sediment discharge and thereby increase urban water supply, doubling the regular production of the city’s potable water plants[26]. Besides the centralization and heavy engineering of
urban water provision, communities of the caserios developed sophisticated irrigation systems with elaborated, fine-mazed canal systems and agricultural terraces (Andenes) that sustained self-subsistence. Presently, Cajamarca, its surrounding caserios, and Yanacocha compete for the privileged and secure access to fresh water. This results in disputes over small-scale and larger water systems that are connected to local, regional, and global strategies of extraction[27] (Fig. 6).

It goes without saying that the current policies, which allow using water as a commodity, are far from helpful in this respect. However, in an increasing number of cases over the past three decades, socio-environmental conflicts around water and land have challenged business-as-usual mining operations. For this reason, new mining projects in the northern jalcas of Cajamarca have notably failed to materialize. At the same time, although the systematic mechanization of mining and two centuries of labor legislation have brought work conditions and related social issues to the fore, they have not resolved the general social crisis generated by mining. Today, this is evident in issues of land tenure (expropriation by mines) and environmental destruction affects the livelihoods of local farming communities. Water quality (namely pollution), quantity, and distribution underscore the conflicts between mines and society, global and local actors, ecology and economy. There is convergence of social and environmental injustice. In 2010, Yanacocha attempted to expand its operations to Cajamarca’s eastern jalcas area. Massive protests against the potential environmental impact forced the Peruvian Government to declare a state of emergency in the city[28]. Until socio-environmental issues are overcome, the project remains on hold.

In Hualgayoc and Cajamarca, headwater landscapes remain at the mercy of market logics. In order to remain competitive, the mines have resorted to the exploitation of lower-grade minerals with new mining techniques, and to the re-mining of openings and waste-piles in search for ores previously not extracted. Since 2008, more than two centuries after its abandonment, Hualgayoc has been undergoing a new cycle of intensive mining investment, this time in the hills of Cerro Corona (2.5 kilometers west of the settlement). The gold and copper surface mines of Cerro Corona are expected to be profitable for 15 years[29]. Their large-scale exploitation runs parallel to prevailing artisanal mining of old and new underground sites in the Hualgayoc Hill. Likewise, since 2007, the Potosí region has also experienced a new cycle of intensive mining for the extraction of low-grade silver, zinc and lead in the surface mines of San Cristóbal[30]. The San Cristóbal mines are located 300 kilometers southeast of Potosí City. As in Hualgayoc, Potosí's large-scale operations co-exist with artisanal exploitation of Cerro Rico’s remaining minerals. In the same way, since 1993,
3 (后)矿山开采景观的生态遗迹特征

1804年,由于（为处理天然含水岩石的渗水而建造的）排水隧道维护的终止，瓦尔加约克的矿场也随之废弃，然而河谷中废弃矿泥所产生的污染却不断增加。根据秘鲁政府的统计，瓦尔加约克长期的开采作业造成了千余项环境负债，且大部分是露天的酸性开采废水。瓦尔加约克的酸性开采废水严重污染了廷戈-梅加斯班巴河，这些河流都是该地区的主要生态水源。自2016年，这三个流域的水源地被宣布进入为期90天的环境紧急状态。在这段短的时间内明显不足以开展深思熟虑的补救行动。接着，2018~2019年划拨了1550万美元的财政预算，用于继续开展废弃采矿隧道和废石堆的关停和关停后的相关工作。

在瓦尔加约克，尚未完成的生态修复工作包括淹没成千上万的地下隧道、封闭通风烟囱及设置排水渠。除此之外，还需要在整个排水管道中布置工织物和石灰石，并常年维护，才能有效中和外流的酸性开采废水。瓦尔加约克长期的开采作业造成了千余项环境负债，且大部分是露天的酸性开采废水。瓦尔加约克的酸性开采废水严重污染了廷戈-梅加斯班巴河，这些河流都是该地区的主要生态水源。自2016年，这三个流域的水源地被宣布进入为期90天的环境紧急状态。在这段短的时间内明显不足以开展深思熟虑的补救行动。接着，2018~2019年划拨了1550万美元的财政预算，用于继续开展废弃采矿隧道和废石堆的关停和关停后的相关工作。

3 Ecological Legacy of (Post-)Mining Landscapes

The abandonment of Hualgayoc’s mines in 1804 went hand in hand with the end of maintenance of drainage tunnels (constructed to deal with the natural watery rocks), while pollution generated by the disposal of mining sludge in the river valleys accumulated. According to Peruvian Government inventories, historic mining operations in Hualgayoc left behind more than one thousand environmental liabilities, mostly open sources of acid mine drainage (AMD). Hualgayoc’s AMD seriously pollutes the Tingo-Maygasbamba, Hualgayoc-Arascorgue, and Perlamayo Rivers, all of which are main water sources for the region’s ecologies. In 2016, a state of environmental emergency was declared concerning the headwaters of the three catchments for a period of ninety days. This limited time was evidently insufficient for a thoughtful remediation venture. A budget of 15.5 million dollars was allocated for 2018 and 2019 to continue closure and post-closure procedures of the abandoned mining tunnels and waste piles.

Pending ecological restoration in Hualgayoc include the flooding and tampering of thousands of underground tunnels, the closure of their ventilation chimneys, and the installation of outlet drainage canals. Even with such measures, neutralizing the outflows of AMD requires the implementation — and perennial maintenance — of geo-textiles and limestone throughout all the drainage canals.
tackling of pollution from abandoned tailings involves different physical, chemical, hydrological and biological stabilization measures. Some of these include the construction of gabions in the slopes of tailings[34] and the isolation of sulphide-containing surfaces with plastic over liners and consecutive layers of clay, gravel, and top-soil[35]. Thoughtful revegetation requires top-soil fertilization with nitrogen, potassium and phosphorus, and the subsequent plantation of native species[36]. Networks of limestone-canals are necessary to divert the runoff from the covered tailings in order to continuously neutralize effluents as they move downstream.

Similar to Hualgayoc, Potosí’s oscillating mining cycles have also generated continuous pollution of water sources. Mine abandonment, flooding, dewatering, and multiple re-opening have stimulated a ceaseless production of AMD. Interconnected tunnel works and collapse threats complicate the inspection and accurate location of pollution sources[37]. Toxic emissions over from the last five centuries have severely contaminated surface and subsurface waters, stream sediments and soils. Hualgayoc and Potosí are examples of a typical larger mining context in the twenty-first century, where AMD is a primary legacy of mining activities. In a global perspective, new mining operations co-exist with the socio-environmental legacies of “old mining.” The challenges of mining in the twenty-first century intersect with the liabilities of orphan mining sites — sites that will continue to be orphaned until the moment that they are once again exploited or left to return to a second nature.

In Cajamarca, ecological restoration has been carried out simultaneously with ongoing mineral exploitation — when mineral resources are partially exhausted, or the mining heaps have reached their maximum storage capacity. The measures focus on the outflow of AMD. To this end, standard environmental engineering protocols are followed. The measures entail the isolation of AMD sources, re-contouring of slopes and the application of reserved topsoil (stripped and stored prior to mining excavations). The ultimate aim is to trigger a process of a re-vegetation to induce and accelerate natural succession and the re-colonization by native species[38]. It goes without saying that such re-vegetation cannot reconstruct anything close to the original jalca that was the ecological outcome of thousands of years of evolution.

In 2000, a partial backfilling and neutralization of environmental hazards was implemented in Yanacocha’s Maqui Maqui Pit. Within this context, a Mining Closure Experimental Centre has been on operation since 2006 in the pit’s re-contoured surface, in parallel to the continuous treatment of AMD effluents and the monitoring and maintenance of the
上游运河（这些运河曾经直接从水源地引水）提供了水源。2015年，从拉奎努阿矿坑开采出的物料重塑了其北部废石堆，而作业范围则向南扩展，一直延伸到格兰德河的源头\textsuperscript{41}。

酸性开采废水的持续处理与亚纳科查的开采作业同步进行\textsuperscript{42}。一系列的运河和管道将酸性水输送到酸性开采废水处理厂——即格兰德水库或圣何塞水库——随后排放到格兰德河或上游运河中，促使经过处理的水重新进入已严重失衡的卡哈马卡水循环系统。今天，下游水质极其依赖这一人工（重新）设计的水源系统，该系统还可以补偿由从矿坑底部含水层抽水造成的下游水流损失。

总体而言，亚纳科查的逐步关停并不妨碍那些仍在进行的采矿活动（图7）。金矿挖掘、浸出、提炼和熔煅等过程产生了成堆的氰化金，并造成了土地贫瘠、大地满目疮痍。露天矿、堆浸垫层和废石堆成为金矿开采过程中及开采后出现并遗留下来的主要开采特征和地貌。与此同时，整个黄金加工的日开挖量可达50万吨，并需要消耗与之成正比的水资源，因此，随着冶金过程中氰化物和水在堆浸垫层、水库和选矿厂之间的不断循环，水源地的景观与生态正发生着不可逆转的改变\textsuperscript{43}。

亚纳科查采矿景观规划和建设的总体目标是在开采地下矿藏的同时，经济而高效地运输或储存开采出的物料。在采矿工程所决定的地形形态和空间分布基础上，生态修复企业负责进行细化设计。在堆浸垫层和废石堆的建造过程中，大型挖掘机将爆破后的物料逐层堆填，并以自然休止角度形成台地\textsuperscript{44}。台地的大小由运输设备所决定，而建造位置则以节省运行为原则。灾区规划首先要保证地下矿藏开采的便利性，堆浸垫层和废石堆的置放应与周围地形相协调。据此，上游河谷非常适合以经济的方式堆填物料，因此用河谷填充方式建造堆浸垫层的做法非常普通\textsuperscript{45}。虽然从表面上看起来这种做法没有破坏自然天际线，但却使山谷丧失了天然的水利功能——卡哈马卡的水源生态系统成为了追求利益最大化的金矿开采作业的牺牲品。这种新的采矿地貌遍布整个草原地区，同时也使当地典型的空间和生态结构严重退化。迄今为止，后矿山修复仍无法逆转空间和生态破碎化的情况（图8）。通过挖掘矿石和处理废石上覆地层，亚纳科查的采矿活动从根本上改变了当地的地质结构和生态环境，相比之下，渐进的修复工作显得杯水车薪\textsuperscript{46}。

在瓦尔多约克和卡哈马卡，对水源地景观的不断改造已经对当地及更大的生态系统产生了长期影响。后矿山水源地景观需要常年人工干预才能保证下游的基本水质。为了重建后矿山生境并保证水源地的可持续性，需要处理大量土壤并改变开采过程。瓦尔多约克的经验表明，当开采作业缩减时，对石堆进行彻底重新安置（即二次改变地貌和集水区）的做法成本高昂却收效甚微，地方政府不愿也无力负担\textsuperscript{47}。

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Cajamarca’s headwater ecosystems remain a mere leftover from the ground operations to most profitably extract gold. While distributing new landforms across the jalca, mining atrophies its typical spatial and, thus, ecological configuration. To date, post-mining restoration is unable to overturn spatial and ecological fragmentation (Fig. 8). By unearthing ores and disposing waste rock overburden, Yanacocha’s mining activities overwhelmingly yield more tectonic landforms and ecologies — than the (progressive) rehabilitation procedures.

In Hualgayoc and Cajamarca, the sequential manipulation of headwater landscapes has had long-term consequences for local and larger ecosystems. Post-mining headwater landscapes require of perennial, artificial mechanisms to guarantee minimal quality of downstream water. In order to re-orient post-mining ecologies and to guarantee the sustainability of headwaters, it is necessary to manipulate massive volumes of soil and reverse the process of mineral exploitation. The case of Hualgayoc demonstrates that, at the decline of mining operations, a thorough relocation of heaps, i.e., handling earth for a second time to rectify landforms and watersheds, is both a costly and inefficient endeavor which local governments are unwilling to undertake, and unable to finance.

Contemporary socio-environmental liabilities of mining have their origins in closed and abandoned operations from decades or centuries ago, long before the establishment of environmental laws. The hazards prevail alongside mining accommodations and abrupt processes of “unsettlement” due to resource exhaustion, fluctuations of mineral market prices, and the shifting of economic activities to other areas. The cultural, economic, and environmental deterioration of previous mining settlements continues long after mining closure. In most cases, such “ghost settlements” become part of a region’s cultural heritage. In other cases, nature reclaims them. Through social abandonment, they become re-naturalized and evolve into a particular kind of “wilderness.”

4 (Post-)Mining Design: Towards a New Paradigm

Mining in the Andes is (as in so many places and for so long) highly problematic and heavily contested. Contestation starts before extraction, as emblematically demonstrated in the halting of new mining site openings in Cajamarca. After mining closure, environmental remediation programs are unfolded to comply to legal obligations that aim for a theoretical ecological restoration but, in reality, are mere smokescreens of greening. AMD remains a near-permanent issue — on old mining sites, in the headwaters and all the way downstream. At the same time, contemporary mining becomes more and more complex: it assembles a layered
As mentioned, mining has acquired its own cyclic characteristics, that unavoidably interfere with the lifecycles of the wider rural and urban environments onto which it imposes itself. The impact of mining on and competition for scarce water resources, intertwines the cycles of ecology, city, countryside, and mining. This is why it is crucial, when developing policies, programs, and projects in mining, to no longer conceptually understand mining as a short-lived linear process — an interruption of the normal that is quickly repaired — but rather de facto recognize it as an enduring and cyclic process.

Cyclic processes in the urban realm are key for accumulation. In other words, they contribute to the layered production of the urban. This is precisely what mining until today omits: to structurally and explicitly contribute to the production of the environment.

Until now, mining has yet to bring nature into culture, consciously developing a post-mining environment. Since mining processes are extremely enduring and layered, it is key to envision the (post-mining)
9. The (post-)mining vision entails a progressive transformation of haul roads into large-scale water infrastructures. The new spine aims to articulate water treatment processes while re-directing flows of cleansed water and clean runoff towards the sub-catchments of the Pacific and Amazonas watersheds.

10. On the up streams of the Grande River, the design strategy redirects water towards constructed "techno soils" with a high capacity of water retention. In these artificial wetlands, mining effluents go through a slow cleansing process before infiltrating to aquifers or joining the Grande’s tributaries, which recovers the Jalca “sponginess.”

说，这些过程有助于城市地区的海拔高度上的分层式生产。至今，开采业仍在忽视对环境生产结构进行清晰而明确界定的必要性。因此，目前，开采业仍未将自然视作一种文化，也未曾有意识地对开采后的环境进行规划。所以，鉴于采矿过程旷日持久、涉及因素众多，在矿山开采期间即制定（采后）规划也变得非常关键——矿山开采与（采后）规划互为因果，相互促进。

这也意味着在周期性规划的采矿过程中，开采和开发是交织在一起的，开采前后并没有截然区别。显然，在这种情况下，后开采景观不可能仅通过将采矿和环境工程简单结合就能实现——这种结合只是对法律义务和规章进行的收敛甚至技术转化——这，就需要发挥设计的作用了。

但是，采矿工程、环境工程和设计之间存在着结构上的脱节。在以单一专业视角处理矿山景观和对其进行技术修复的过程中，设计被低估为矿山开采后的土地复垦再利用、绿化或美化工程。在金属开采过程中，人们既不承认也不利用设计能力来整合各个层面的需求，大量景观构造都未曾经过设计——这阻碍了设计本应在综合生态修复设计的作用中。

这研究项目拟将用于运输的道路逐步改造成大型水利基础设施。新的干道道路在连接各个水处理流程，同时重新将净化过的水经径流汇入太平洋和亚马逊流域的次级集水区。

在格兰德河上游，通过设计将水引入具有高保水力的“改良土壤”是人工湿地中，使得开采废水在渗入含水层或汇入格兰德河支流之前，能够经过一个缓慢的净化过程，以发挥原始草原的“海绵性”功能。

取，项目旨在补给水源地含水层，恢复地域整体“海绵性”，以使这片原始草原最终去除毒害，恢复至其可自我维持状态。

9. On the up streams

10. On the up streams of the Grande River, the design strategy redirects water towards constructed "techno soils" with a high capacity of water retention. In these artificial wetlands, mining effluents go through a slow cleansing process before infiltrating to aquifers or joining the Grande’s tributaries, which recovers the Jalca “sponginess.”

In cyclically conceived mining processes, there is not a categorical distinction of before and after, but an intertwined process of extraction and development. It is evident that in such condition, there is no question of a postmining landscape that solely results from mining and environmental engineering logics (which is nothing more than an always unsatisfactory technical translation of legal obligations and regulations). This is, in other words the moment that design comes in.

However, there is a structural disassociation between the endeavors of mining engineering, environmental engineering, and design. The monotechnic fabrication and technical remediation of mining landscapes relegates design practices to the application of land-use recycling, greening, and mere beautification projects of post-mining reclamation. The capacity of design to integrate requirements of various natures is neither acknowledged nor being made use of in processes of metal-mining. Design is absent from the scenes of substantial landscape formation. This prevents the constructive influence of design in comprehensive ecological restoration projects. Spatial configuration — a primary output of design — is, nevertheless, key to ecological performance [49]-[51].

A series of design research was completed at KU Leuven for a possible future of Cajamarca. The ongoing land-forming processes of large-scale, surface goldmining was subverted to also serve as a new water management and settlement system. Clearly, a thoughtful (re)construction of headwater landscapes requires imbuing Yanacocha’s earthworks with a multi-scalar design in respect of the jalcas, linked to its ecological performance [47]. It also implies to design the (post-)mining landscapes already in the early mining stages, and to construct them simultaneously with, and through, exploitation. It surely requires intertwining the development of clean water harvesting, retention, and redistribution infrastructure during the mining operations. Thereby, Cajamarca’s lower ecological floors can be provided with water to sustain its ecology and human occupation.

A design scenario tests a possibility for restoring Cajamarca’s landscape. It develops a new water management system coupled with a novel manner of organizing agricultural land on (post-) mining areas. The haul-road infrastructure of the Yanacocha mining compound is progressively transformed into water infrastructure that guides clean rainwater to a new irrigation system (Fig. 9), while polluted pits are covered with geomembrane and AMD is treated with a series of constructed wetlands (Fig. 10). The project aims to recharge headwater aquifers and restore an overall “sponginess” to the territory in order that the jalca can eventually return to a non-hazardous, self-sustainable state [48].

An ecological water system that guides clean rainwater to a new irrigation system (Fig. 9), while polluted pits are covered with geomembrane and AMD is treated with a series of constructed wetlands (Fig. 10). The project aims to recharge headwater aquifers and restore an overall “sponginess” to the territory in order that the jalca can eventually return to a non-hazardous, self-sustainable state [48].
The construction of the (post-)mining landscape is conceived simultaneously with the progressive closure of mining (Fig. 11, 12). The allocation of operative resources of mining (funds, logistics, machinery, and mining engineering expertise) must anticipate the design, territorial planning, and progressive construction of post-mining landscapes. The evolving resilience and self-sustainability of Cajamarca’s headwaters might be better ensured while mining activities on sites that are already in exploitation are allowed to continue. Design is a medium that not only allows the integration of different expertise, but also mediates negotiation between different actors. In this case, the contradictory interests of ecology, city, countryside, and mines are evident. Surely, most of these actors also operate on different scales, from the local over the national to the global. By generating design, a projective perspective is added to the often-conflicting discussions on principles between these stakeholders. A projective perspective can make the difference in such discussions. There is no reason that the principles of economy, ecology, fairness, and justice cannot be simultaneously achieved. LAF

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