frontiers | Frontiers in Earth Science

ORIGINAL RESEARCH
published: 22 July 2022
doi: 10.3389/feart.2022.909967

An Inside Sun: Lickanantay Volcanology in the Salar de Atacama

Sonia Ramos Chocobar[1,2] *and Manuel Tironi*[3,4,5,6]*

[1]Fundación Ayllus Sin Fronteras, San Pedro de Atacama, Chile, [2]Indigenous Community of San Pedro de Atacama, San Pedro de Atacama, Chile, [3]Instituto de Sociología, Pontificia Universidad Católica de Chile, Santiago, Chile, [4]Instituto para el Desarrollo Sustentable, Pontificia Universidad Católica de Chile, Villarrica, Chile, [5]Centro para la Gestión Integrada de Riesgo de Desastres — CIGIDEN, Santiago, Chile, [6]Centro de Desarrollo Local, Pontificia Universidad Católica de Chile, Villarrica, Chile

The need of establishing more substantive dialogs between the mainstream and Indigenous knowledge on volcanoes has been increasingly recognized. To contribute to this endeavor, in this article we present the basic volcanological understandings of the Lickanantay people in the Salar de Atacama Basin. The Salar de Atacama Basin is an active volcanic territory within the Central Volcanic Zone of the Andes (CVZA). From the El Tatio geothermal field to Socompa volcano, more than 19 active volcanoes surround the territory that the Lickanantay (Atacameño) people have inhabited for more than 11,000 years. Living around and with the geological dynamism of the CVZA for millennia, the Lickanantay communities have accumulated rich observational and ceremonial data on volcanoes and volcanism. Paradoxically, however, while the Atacameño people have thoroughly characterized the CVZA, the volcanology community has not been properly introduced to the ancestral knowledge articulated in the territory. In order to make traditional Atacameño perspectives on volcanoes, volcanic risk, and geo-cosmic interdependence more amply available to the volcanology community, in this article, we present a basic description of what we call Atacameño volcanology. By Atacameño volcanology, we understand the ancestral principles by which volcanoes are known and understood as partaking in larger processes of a cosmo-ecological formation. Specifically, we describe the basic volcanological notions arising from the Lickanantay ancestral knowledge—volcanic formation, functions, and behavior. Second, we focus on the El Tatio geothermal field to offer a situated example. Finally, we delineate some relevant elements of human–volcano interactions and volcanic risk management from an Atacameño perspective. In our conclusions we suggest that volcanology, particularly in the context of the Andes, needs to engage more substantially with the Atacameño or other ancestral systems of knowledge production to expand volcanological insights and respond to the call for decolonizing science.

Keywords: Lickanantay, volcanology, indigenous knowledge, Salar de Atacama, risk management

OPEN ACCESS

Edited by:
Felipe Aguilera,
Catholic University of the North, Chile

Reviewed by:
Marie-Noelle Guilbaud,
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Jon J Major,
(USGS), United States

***Correspondence:**
Manuel Tironi
metironi@uc.cl

Specialty section:
This article was submitted to Volcanology, a section of the journal Frontiers in Earth Science

Received: *31 March 2022*
Accepted: *17 June 2022*
Published: *22 July 2022*

Citation:
Ramos Chocobar S and Tironi M (2022) An Inside Sun: Lickanantay Volcanology in the Salar de Atacama. Front. Earth Sci. 10:909967. doi: 10.3389/feart.2022.909967

1 INTRODUCTION

In the last few decades, important shifts have been made regarding the validation of Indigenous volcanological knowledge around the world. Earth scientists themselves have begun to recognize that the foundations of geology in general (Scarlett, 2022) and volcanology in particular (Pease, 2021; Scarlett et al., 2022) are inseparable from imperial colonialism, that is, that they have been shaped by

the social and political issues and agendas of colonial expansion (Cartier, 2021). Acknowledging this legacy, there are growing calls for establishing more symmetrical, intercultural dialogues on volcanoes and volcanic processes.

The Salar de Atacama Basin (hereafter the Salar), home of the Lickanantay (Atacameño) people,[1] offers a powerful example. The Salar (23°30S 68°15′O/2,407 m.a.s.l.) is an active volcanic territory within the Central Volcanic Zone of the Andes (CVZA), in northern Chile. From the El Tatio geothermal field to Socompa volcano, more than 19 active volcanoes surround the territory that the Lickanantay people have inhabited for at least 11,000 years (Núñez, 1992). Over this period, different phases of occupations can be identified, each one characterized by specific patterns of resource utilization and human–land interactions, such as hunting, fishing, animal domestication, agriculture, animal husbandry, mining, commerce, and trade (Nuñez et al., 2010). Common to these phases, however, is the role of volcanoes articulating ecological, economic, and spiritual life in the puna (Grebe and Hidalgo, 1988; Berenguer, 2004; Valenzuela and Moyano, 2021).

This long history of volcano–human relations in the Salar has materialized into a robust knowledge system on volcanic activity and relations based on both observational and ceremonial knowledge-making. This includes general hypotheses on volcanic formations (Contreras, 1994; Barros, 1997), knowledge on climatic–volcanic interactions (Sanhueza, 2004; Moyano and Uribe, 2012), and on water–agriculture–cattle–volcanic nexuses (Redin, 2018). By all measures, then, the Lickanantay people have articulated their own geosciences.[2]

This knowledge, however, has been hardly recognized, let alone incorporated in Western volcanic research and policy. This is particularly troublesome when we recognize the twin histories of geological sciences and colonialism (Yusoff, 2019) and the concomitant imperative to treat Indigenous knowledge as proper, robust, and time-tested expertise (Liboiron, 2021).

Substantive collaborations between mainstream and Likanantay volcanologies are ever more important as the Salar de Atacama Basin is under intensive environmental pressure. A long history of extractivism in the area has materialized in the accumulation of multiple environmental effects. Copper and, more recently, lithium mining, have meant direct damage to aquifers, salt flats, rivers, and other geological formations and processes (Bolados and Babidge, 2017; Bustos–Gallardo et al., 2021). Consequently, conflicts between the state and corporations on one side, and communities on the other, have multiplied. In these conflicts, Atacameño hydrological understandings of the Salar, for example, have been largely neglected. So, at the heart of the frictions with the Indigenous communities lies not only the irreparable harm inflicted to unique ecosystems and Indigenous and peasant life projects, but also the systematic denial of Lickanantay geological knowledge, including knowledge about volcano–land–human relations that could be useful in water, land, and volcanic risk management.

This article is an attempt at bridging the gap between mainstream and Lickanantay volcanological knowledge. We do so by presenting what we call *Lickanantay volcanology*, or the ancestral principles by which volcanoes are known in the Salar and understood as partaking in larger processes of the cosmo-ecological formation. Our objective is not to give a definitive explanation of the Lickanantay knowledge on volcanoes—since such knowledge is always embodied and emplaced. It is neither to replace Western volcanological knowledge on the CVZA. Rather, our aim is to give a glimpse of some of the principles guiding Lickanantay volcanology and to present them to the volcanological community. This much-needed communication is crucial, we argue, in order to articulate more robust and just accounts on volcanic behavior and volcanic risk management in Indigenous territories.

The article is the collaboration between a Lickanantay elder and healer (Sonia Ramos) and a Chilean scholar (Manuel Tironi). The partnership is based on an ongoing relation of mutual learning over the last 4 years. In this period, we have established land-based protocols of intercultural collaboration and co-production, including joint fieldwork, co-writing, and ceremonies. We recognize that a scientific article does not problematize—actually it reinforces—current systems of knowledge-making. We also acknowledge that by presenting the basic features of Lickanantay volcanology in a scientific article, we are facilitating a first encounter between otherwise unconnected sets of expertise. Our objective is precisely to help in the cultivation of an inter-scientific dialogue for the articulation of an epistemologically plural strategy for volcanic risk management in the Salar and basins elsewhere. Our description can be helpful for the articulation of intercultural exchanges and plans in Perú, Ecuador, Colombia, and other volcanic zones in Latin America. By rendering visible Lickanantay volcanological knowledge, we also aim at hopefully limiting the increasing aggression to the Salar.

The article is organized as follows. In the next section, we introduce the Salar de Atacama's territory and the social challenges it faces in the words of Sonia Ramos as a Lickanantay elder. We also articulate a brief literature review to situate Lickanantay volcanology in the context of social, community, and Indigenous debates on volcanology and volcanic risk. In the third section, we present our materials and methods. In the fourth and main section, we present the basic features of Lickanantay volcanology as understood and

[1]Lickanantay is the kunza ethnonym of what in Chile is known as Atacameño people. It is composed by *lickan* (territory, country, or land) and *antay* (people), roughly translating as "people of the territory". The prefix *lickan* is appears extensively in Atacameño toponyms, for example Lickancabur ("Mountain of the people").

[2]If science is "the careful study of the structure and behavior of the physical world, especially by watching, measuring, and doing experiments", as defined by the Cambridge Dictionary, then the term should not be exclusive to Western knowledge, as argued by several Indigenous intellectuals (Deloria et al., 2018).

systematized by Sonia Ramos after decades of land-based and intergenerational observation and learning. Finally, in our conclusion, we reflect on the challenge of pluralizing volcanological knowledge when working in the CVZA and other Indigenous territories.

2 CASE STUDY AND LITERATURE REVIEW

2.1 The Salar de Atacama Basin: A Lickanantay Territory Under Pressure

The Salar is the central element around which the Lickanantay or Atacameño people have thrived for at least 11,000 years. The Lickanantay people speak *kunza* and have developed complex socio-cultural systems of knowledge-making and territorial occupation. From an ancestral perspective, the Salar is a complex entity interconnected with the surrounding volcanoes and the *aguadas* (water springs) that flow from mountains and volcanoes to the Salar. That is, the Salar is a embroiled eco-geological web that cannot be restricted to the figure of a salt flat. The Salar has been recognized as Indigenous land through the rights granted by the Indigenous Law of Chile (19.253) and Convention 169 on Indigenous and Tribal Peoples of the Labor Organization (ILO).

The process of *Chilenización*[3] since the late 19th century entailed the ever-increasing development of the mining industry in the Atacama Desert (Acuña and Tironi, 2021), disrupting the traditional agro-alimentary practices that otherwise sustain family economies in the Salar. Half of the copper mined in Chile comes from the Antofagasta region (Babidge and Bolados, 2018) and four of the largest operations are located in the surroundings of the Salar: Minera Escondida, Compañía Minera, Zaldívar, and CODELCO.

In the last few decades, the Salar has become the world's principal source of lithium (USGS, 2019), which has in turn increased current tensions. Lithium is industrially unearthed by pumping saline groundwater from beneath the Salar and extracting its dissolved lithium content (Bustos-Gallardo et al., 2021). The *salmuera* (brine) is then left to evaporate in shallow open-air ponds. For every ton of lithium, about two million liters of extracted water are needed to evaporate. This has not only radically changed the hydrological equilibrium of the Salar, but also disturbed fragile highland ecosystems and impacted ancestral sites and practices. From the perspective of Lickanantay knowledge, extractivism in the Salar affects the complex relational systems that connect humans, ancestors, and land—including surrounding volcanoes, rivers, and geothermal fields—in ways that Western science and policy-making are yet to fully appreciate.

[3]"Chilenization" is the name given to the period between 1880 and 1930 in which the territory annexed after the war against Perú and Bolivia was culturally, institutionally, and socially incorporated to Chile. In the Lickanantay territory, this included the inculcation of national sentiments, the Christianization of the population, and the deliberate erasure of any Indigenous cultures (González, 2012).

2.2 Shifting Perspectives: From Social Volcanology to Indigenous Sovereignty

The colonial origins of the Earth sciences in general, and volcanology in particular, have been widely acknowledged (Stone, 1988; Home, 2006; Donovan et al., 2011; Atkinson, 2016; Kophamel, 2020; Pico et al., 2020; Cartier, 2021; Donovan, 2021; Scarlett, 2022). To survey, map, and ultimately exploit natural resources in colonized territories for the benefit of the empire was a crucial factor energizing geosciences as a scientific field in 17th century Europe (Driver, 1992; Stafford, 2017). Colonized societies had—and still have—their own geological and volcanological knowledge systems, articulated after millennia of close co-habitation and observation of terrestrial phenomena (Swanson, 2008). Indigenous knowledge, however, has been deemed as inferior, partial, magical, or, in the best of cases, supplemental by Western sciences (Whyte, 2020). As Haudenosaunee and Anishinaabe scholar Vanessa Watts (2013) suggests, Indigenous explanations of the world are often viewed as mythic by "modern" society, representing alternative modes of interpretation rather than "real" events. This neglect has been crucial for positioning Western science as the sole frame of reference for appraising reality. Aymara sociologist Silvia Rivera Cusicanqui (1993) coined the term "coloniality of knowledge" precisely to indicate that the process of universalizing a vision of the world after the principles of the Enlightenment Project[4] was sustained on epistemological impositions and erasures—and that the process, far from being in the past, is still ongoing with important ramifications.

These critiques do not aim at undermining the validity of Western volcanology. Rather, they call for the validation of other knowledge systems in the search for more diverse dialogues within the scientific field. And at least in the field of volcanology, there have been important progresses. An important development has been the integration of social and cultural perspectives on the production of socio-natural disasters (Quarantelli, 1987; Wisner et al., 2004; Hilhorst, 2006; Tierney, 2012; Bretton et al., 2018). This allowed the inclusion of notions such as geopolitics, vulnerability, and community into the understanding of volcanic hazards and their impacts (Cashman and Cronin, 2008; Chester et al., 2008; Haynes et al., 2008; Paton et al., 2008; Barclay et al., 2015; Donovan, 2019), giving birth to a sub-discipline sometimes called social volcanology (Donovan, 2010).

These approaches complement the anthropological research on the interpretation of volcanism according to Indigenous cosmovisions, the representations of volcanoes in belief systems, and the impacts of eruptions on traditions and

[4]Referred to the European intellectual movement of the 17th and 18th centuries in which ideas concerning God, reason, nature, and humanity were synthesized into a worldview that gained wide assent in the West. Central to Enlightenment thought were the use and celebration of reason, the faith in progress, its focus on the scientific method, and reductionism—the breaking down of problems and systems into their components in order to find a solution and/or better understand how the system or problem works.

cultural identities (e.g., Peraldo and Mora, 1995; Skinner, 2004; Spoon, 2007; Aedo, 2008; Juárez, 2012; Moyano and Uribe, 2012; Schwartz-Marin et al., 2020; Socha et al., 2021). Importantly, this line of research attempts at problematizing the often rigid boundaries with which studies of volcanism and indigeneity are traditionally approached as two incompatible knowledge systems. It emphasizes the existence of a dual rather than a dichotomous relation between the symbolic—beliefs, norms, and imaginaries—and the material—natural and physical phenomena. From this vantage point, volcanoes are both physical entities *and* beings with volition and the capacity to intermediate in ecological, meteorological, and social relations (Juárez, 2012). For example, Moyano and Uribe (2012) showed that the Chiliques volcano (23°35′00″S 67°42′00″O) plays a central role within a system of sacred mountains that are invoked by the Atacameño community of Socaire during the canal cleaning ceremony, in which the volcano is invoked as an intermediator of meteorological phenomena.

Our attempt at presenting Lickanantay volcanology is aligned to these approaches, as it also points at opening volcanological research beyond strict scientificism. Inspired by the decolonial turn in the geosciences (Pico et al., 2020), we also diverge from these scholarships. Rather than trying to *interpret* what Lickanantay experts have to say about volcanism—restricting the labor of comparison to the Western scientists—the task of interpretation is conducted by Indigenous experts themselves (see for example Kopenawa and Albert, 2013). By doing this, we take Lickanantay volcanology as a proper, irreducible form of science that serves as a crucial source of guidance for Lickanantay resurgence. We aim to build a bridge between Western and Lickanantay volcanologies, neither by transforming the latter into "geomythology" (Donovan, 2010; Riede, 2015) nor massaging it to fit into an otherwise conventional science, but by validating it as a scientific system with ad hoc research questions and methods.

3 MATERIAL AND METHODS

The material of this article is the knowledge of Sonia Ramos and was collected during 4 years of conversations between the authors. This included formal interviews but also multiple exchanges during walks, meetings, and ceremonies in San Pedro de Atacama, El Tatio, Calama, and the Domeyko Cordillera. The records of these conversations were systematized and iteratively discussed in an open, collaborative process between the authors.

The methodology utilized is aligned with the Indigenous principles of knowledge and research (Smith, 1999). It takes conversation as the main method for data gathering, provided that, as in the Mapuche *güxam*,[5] conversation is not just a form of verbal exchange but an in-place process to communicate vernacular knowledge cultivated by the ancestors (Quilaqueo and Quintriqueo, 2017). It is also a process of sharing knowledge which, similar to what is known as *yarning* in the Australian context, is reliant upon relationships, responsibility, and accountability between the participants (Barlo et al., 2020). In this sense, the methodology of this article—including data collection, interpretation, and writing—is in itself a practice of historical and epistemological reclamation. For example, several conversations about volcanic and geothermal activities were conducted with volcanoes and geysers, traveling to their surroundings and invoking their presence through ceremonies—because in the Lickanantay epistemological systems, knowledge is always land-based or cultivated *in-place* (De la Cadena, 2015). Both Sonia Ramos and Manuel Tironi participated in these conversations, being guided by the former and recorded by the latter.

Following the Oral History methodology developed by Rivera Cusicanqui (1987), the conversational and relational methodologies we followed were aimed at coping with the ontological differences that constantly punctured the communication between a Lickanantay elder and a white scholar. This was also aimed at creating a systematic process of information feedback and validation in terms of the interests and expectations of doña Sonia as an ancestral authority. The process paid attention to doña Sonia's vision of history, society, and land. If some statements sound too politically charged, it is because Indigenous knowledge is always principled, that is, normative (oriented toward ethical and moral goals) and prescriptive (oriented toward informing conducts) (Teillier et al., 2018). In contrast to Western knowledge, there is no division between the observation of "what is" and the reflection of "what ought to be", and therefore between the objective and the subjective (González-Gálvez, 2016). To separate the factual and the normative in the results that follow would not only hamper a proper understanding of the Lickanantay volcanological principles presented here, but also the possibility of integrating Indigenous philosophies of science in their own right (Whyte, 2020). As discussed by Rivera Cusicanqui, what matters in the method of relational oral histories that we follow is not so much to identify "what happened" but *why* it happened and *how* what happened fits in the larger assessments of justice and *buen vivir*.[6]

4 RESULTS: LICKANANTAY VOLCANOLOGY

Following our methodological principles, the results that follow will not be presented as "findings", that is, as propositions

[5]*Güxam* is the Mapuche art of conversation in which an older person talks about his or her life and the history of his/her people, intertwining storytelling, memories, and teachings.

[6]*Buen vivir* ("good living") is the translation of *sumak kawsay* (Aymara), *suma qamaña* (Quechua), or *kume mongen* (Mapuche). It represents a fundamental philosophical pillar for Andean–Amazonian peoples by which there is an indissoluble and interdependent relationship between the universe, nature, and humanity that informs the ethical and practical bases of development and society (Acosta and Martínez, 2009).

analytically induced from observations and abstracted from their locus of enunciation. Instead, we present the words of doña Sonia herself. We have organized and edited them for consistency and to convey a coherent narration of what Lickanantay volcanology is—but they otherwise retain their situated and embodied meaning. As a result, arguments are not organized in a fully linear mode, but are articulated circularly, appearing in different passages throughout the narration. In addition, to retain the indigenous meaning of doña Sonia's words, all relevant commentaries, whether contextual explanations or engagements with archaeological, anthropological, and geological insights, will be presented as footnotes. It is important to note that we have retained the Spanish grammatical gender of those nouns whose meaning play a fundamental role in Lickanantay philosophy—and for which, neutralizing their gender would entail losing their significance. For example, "*naturaleza*" (nature) will be treated as feminine (*la naturaleza*, *la madre naturaleza*, and *la Pachamama*) and "*volcán*" (volcano) as masculine (*el volcán*).

The results are organized as follows. First, we present some of the main hypotheses and definitions articulating what we call Lickanantay volcanology. We then discuss Lickanantay volcanological knowledge within the broader Lickanantay philosophical system on nature and humans. Finally, we discuss what this knowledge reveals with regards to volcanic risk management from an Atacameño perspective. Taken together, these propositions need to be assessed as specific materializations of Lickanantay knowledge on the volcano–cosmos–human nexus, not as a comprehensive nor institutional articulation of a definitive Lickanantay canon on the matter.

4.1 Three Worlds: Lickanantay Volcanological Knowledge

4.1.1 The Above and Below: The Inside Sun

The universe that we see above is also below. Ancestrality refers to the cosmic, but also to that which is above is below. This is the basic unity-in-duality of ancestral knowledge, the doubling, and the pairs. We humans are in this intermediate layer. Let us call this intermediate the *visible* layer, the layer that we can see.

This is why we talk about three worlds: the world above, the human world, and the world beneath. But the above and below worlds have many great connections between them, and their gift to us is that they offer life to the intermediate world—a gift that we do not appreciate nor see. We break everything into pieces because we think that only science can see—but we do not dare to see these other worlds differently, interconnectedly.

So, as there is a sun above, there is an *inside Sun*, the one that exists below the land and that is able to give nature the needed energy to develop and create all the ecological systems. From an ancestral perspective, there is a constant interaction between the four elements: Earth, air, *puri*,[7] and fire. The fire element is an internal Sun, alive, situated in the bowels of the Earth. And this inside Sun is vital. It is this inside Sun which prevents the desert from becoming dead land, which gives us an adequate temperature, and which creates an equilibrium between the in-between world and the cosmic sun. We talk about the cosmic sun a lot, about its changes, waves, and explosions, but the same movements are being replicated in the interior of the Earth, which is giving us a seismic dynamism as an indicator of Earth movements, of *puri* movements in the planet.

It is this inside Sun that we need to start understanding, the one that is below us, and whose force some might call magma. Sometimes people talk about the infra-world—or the below world—as something dense and bad, but from our ancestral knowledge, we aim at trying to care for it and making it thrive. It is this inside Sun which prevents stagnation. And it is quite clear: if we have this inside Sun reverberating, nothing can be stagnant, it is us who hamper the free will of nature, and it is us humans that are stagnating and stopping the force of the inside Sun.

4.1.2 Body-Territory Circulations

Actually, the inside Sun moves through us, is a part of us. We have its magma in our bodies in the form of iron. In Lickanantay healing, we work a lot around those movements of the elements, because we are part of that wholeness. So, when nature is healthy, when the inside Sun is vibrant, we are healthy. This is what El Tatio teaches us.[8] El Tatio is a sacred place because it is an encounter of the four elements: fire, Earth, air, and *puri*. After a period of relentless change in the territory, the *abuelos*,[9] the ancient inhabitants of the territory returned to see if things had calmed after two thousand years of floods and inundations.[10] They needed to return because of the love for of their land and the need for balance and harmony. When they returned, they realized that the spiritual forces had put the four elements in one place, in El Tatio, to give humans an example of harmony.

El Tatio then teaches us how to harmonize our bodies, because we are also constituted by those four elements. When we de-harmonize a territory we also de-harmonize our bodies. Health is

[7] *Puri*, water in Kunza.

[8] El Tatio is the largest geyser field in the southern hemisphere and the third in the world, with more than 100 springs erupting at more than 4,000 m.a.s.l. in the Andes. It is located in the upper part of a tectonic pit about 4 km wide by 6 km long, which make up the El Tatio valley, and is flanked on the eastern sector by a tectonic massif called Serranía Tucle-Loma Lucero, composed of andesitic stratovolcanoes and that make up the natural geographical limit with Bolivia. To the west it is flanked by the so-called El Tatio Volcanic group, made up mainly of rhyolitic domes. The water reservoir of El Tatio is inside the volcanic rocks, covered by impermeable layers, with faults driving the hot waters to the surface. The heat source is unknown, but it may be magma or igneous intrusion.

[9] The concept of *abuelo* is central to Atacameño culture and sociability. Highly ambiguous and modulated by colonial relations, it refers to ancestors in multiple senses and represents the complex relation of Lickanantay people with the past. *Abuelos* include both ancestors in direct relation of kinship, as well as in archaeological reference to the "ancient ones" or *gentiles* about whom oral memory is no longer kept. *Abuelos* also refer to non-human forces—close to the figure of "spirit"— which at the same time animate and protect natural elements such as mountains and rivers (Ayala, 2008; Martínez, 2010; Villanueva et al., 2018).

[10] This episode is part of mythological Lickanantay stories and refers to pre-Hispanic times.

territory. So, how can we convince the sciences that "development" is, that we can find here in El Tatio for example, the answers for planetary challenges?

4.1.3 Basins, Mountains, and El Tatio

When this territory was formed it was just one block. It terraformed through time but it never lost its harmony nor its subterranean equilibrium. Today, the sciences separate the territory into basins, mountain ranges, and aquifers, but they are interconnected from below. And why do we talk about a subterranean equilibrium? Because, there is the inside Sun delivering its warmth, delivering life, and stitching the territory together.

We have also learnt that mountains are not just geological compounds. We say that some mountains communicate with the cosmos, with the above, and some others with the infra, with the below. Those that communicate with the infra, with the inside Sun, it is because the inside Sun renders a livable climate. The mission of the desert is to offer cold to the planet, to cool down the planet, but today the desert is unable to fulfill this mission because it has been extremely intervened.

Many volcanoes are our *maikos mayores*,[11] such as the Licancabur who is a living being, peaceful and kind with his people. He is in constant dialog with humans and allows for a harmonic living on the surface, in the intermediate world. Volcanoes are unique beings because they connect the above and the inside Suns. And they connect different elements, just like El Tatio. El Tatio is known as "The *abuelo* that cries",[12] also as the *abuelo* that sings for the beautiful sounds it makes when the wind blows. You can feel that there is something below here, something shining and warming that makes *puri* to appear [*asomarse*] as fumes. And that is energy. El Tatio is a very powerful energy field. There are other similar fields, but here, it presents itself non-violently because there is harmony between the four elements, there is an equilibrium. El Tatio shows us, every day, how we need to work with nature. When we arrived here, we saw new water springs and new small geysers. That is nature saying to humans that she can regenerate herself, that she does not need us. Mother Nature could be crying of pain for all the transgressions that she has suffered, but she does not; she is giving us answers to live well in the world instead.

This is the reason why El Tatio is such an important sacred place. This is what El Tatio teaches us and this is why it was saved from geothermal intervention. But not everyone can see that, not even some Indigenous communities. Why? Because, there is an installed colonialism [*colonialismo instalado*]. El Tatio is usually seen from the perspective of tourism as a landscape, and not as a consciousness.

4.2 *Buen vivir*: Human–Nature Relations

Crucial to understanding Lickanantay volcanology and creating meaningful collaborations, is to establish a new relation with ancestral knowledge. Ancestrality is not how the West sees it, as something pagan or folkloric. It is the real knowledge of nature. We need to talk from that vantage point. Spirituality is a science, a proper scientific endeavor based on systematic methods, evidence, data contrasting, and purpose. But people see it as something rather magical.

From a Lickanantay perspective, we have to reckon, to start with, that we are spirits in human disguises, and when we dissociate ourselves from that spirit, we dissociate from what we are, from our nature. There is much work to create a new path, because the path humans took is wrong; "industrialization" and "growth" have been wrong paths because they do not sustain nature. To the contrary, they destroy it. And that destruction of "the planet" is our destruction, we endanger our own survival. And Western science is not offering any answers. If we have survived in the desert, it is thanks to this ancestral knowledge, this work of integrality, this capacity to understand the balance between the four elements, and that we are part of them. If we do not realize this connection and what we are, we are destined to disappear.

It is, however, possible to create a *buen vivir*, to create good relations between humans and nature. And this is the relevance of understanding the inside Sun. How can we begin transforming volcanological research on the inside Sun into an inquiry about what we should be and rightly do? This is the fundamental question. By understanding the hydro–Sun connections, the internal, the sub-world, and the below, we can have great responses for these times, *pero la ciencia no está apapachando* [but science is not supporting this task].

El Tatio, again, as a sacred place in which the inside Sun makes itself visible in its interactions with *puri*, the Earth, and the atmosphere, is of great importance. If El Tatio had been destroyed, we would not have that opportunity to witness those interactions.[13] El Tatio is of paramount importance to think about—and find responses to—the changes that the planet is living through: the importance of understanding nature, how she protects us and gives us a *buen vivir*.

When El Tatio was intervened, you could only see the fumes, nothing else, barren. Now you can find water, again, sprouting. So, nature has the capacity and knows how to regenerate herself, how to create, she cannot be a dead being if she gives life. Take the thermophiles that abound in El Tatio. They are able to absorb the arsenic from *puri* and offer us drinkable water, *puri* that is good for humans. This demonstrates that *puri* is something alive, intelligent, self-creating, and searching for the means for human survival. This is crucial: from a Lickanantay

[11]*Maiko* or *mallku* is the name given to sacred mountains, which are in turn associated with spirits and *abuelos* or ancestors. *Maiko mayor* or *Tata-maiko* refers to an especially important ceremonial or tutelar sacred mountain (Grebe and Hidalgo, 1988; Valenzuela and Moyano, 2021). In this case, the Lickancabur (Mountain of the People) is a crucial spiritual figure who center-stages Atacameño ontogenetic narratives. The Fertilization of the Earth, the primary cosmological explanation in the Salar de Atacama, was produced by the copulation between the male Lickancabur and his female partner, Kimal, the largest mountain in the Domeyko Cordillera, parallel to the Andes (Contreras, 1994; Barros, 1997).

[12]*Tata-iu* in Kunza.

[13]The first geothermal exploration in El Tatio was carried out in 1908, and in 1931 two wells were drilled. In 1968 more systematic explorations were carried out in several areas of El Tatio. On 3 July 2008, the Regional Environmental Commission (Corema) of Antofagasta approved the first phase for the exploration of geothermal resources in an area located south of El Tatio. After intense resistance from Lickanantay communities, including a walk made by doña Sonia Ramos and Amelia Mamani from San Pedro de Atacama to Santiago to protest against the intervention of El Tatio, the exploration was stopped.

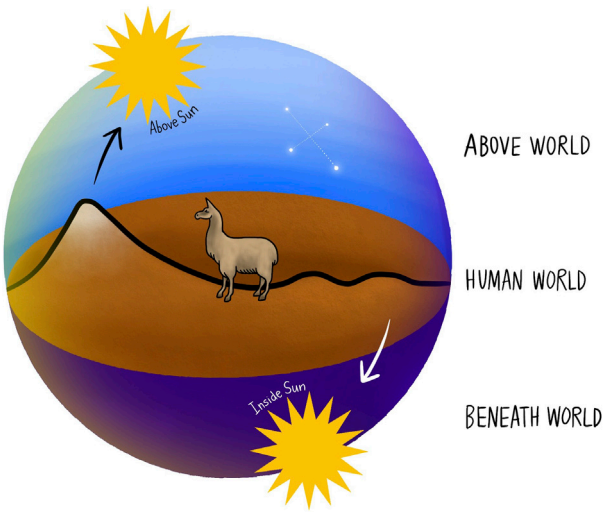

FIGURE 1 | Lickanantay organization of the three worlds. Design: Sergio Iacobelli.

perspective, nature—whether *puri*, volcanoes, plants, animals, and all their relations—is alive, sentient, and generous, creating and giving life abundantly. But we cannot feel it nor see it. It is as if humans were blind.

4.3 Offering as Volcanic Risk Management

Volcanoes are much related to climates, temperatures, and waters.[14] The inside Sun has to be thanked for that. Volcanoes are not something negative, totally to the contrary, it is thanks to them that we have good weather. Volcanoes are in charge of warming the cold desert, hence providing the needed warmth for ecological growth and conservation. Moreover, some volcanoes can attract the rain—the Sairecabur volcano means the Rain Mountain in Kunza (*saire* = rain, *caur/cabur* = mountain)—facilitating life in the world's driest desert. Maybe we have never shown our gratitude to the inside Sun and volcanoes, as they deserve, and we should. And that gratitude and care is the most crucial element to establish a communication channel with them.

Let us illustrate this with an anecdote. When the inside Sun heats the Putana volcano[15] and it manifests, Calama trembles. Some time ago, it would tremble every day in Calama. So people called me, "Doña Sonia, el Putana está tirando mucha fumarola y está temblando mucho así que *comuníquese*" [Doña Sonia, the Putana is emitting a lot of fumes and it's trembling a lot so *communicate yourself*"]. Ok, I said, I will talk to the volcano; I will try to ask him what is going on. So, I went with a cousin and my daughter. I did the offering to him (*ofrenda*), I talked to him, and what he said is that we, humans, were being too disrespectful with regards to his mission, in relation to the warmth that he gives us. So, I offered my apologies on behalf of Calama. When we were going back [to Calama], my cousin and daughter were in shock, saying that they could not believe it, that if they had not come, they would not believe it. The Putana began to calm down, the fumes began to decrease, and the weather changed.

It is this communication that ancestral people have always managed. Actually, I am not sure to call it "communication" since it is too aggressive—this *integrality* or completeness. Here, in the desert, one needs to learn integrality, to embrace integrality, otherwise you are lost, nature "*te hace pebre*" [destroys you]. Take, for example, the Lickancabur volcano. He is lovely and peaceful, and he is a water volcano because he attracts and creates water. So, we have to thank him, we owe him a lot of gratitude, and we need to give back to him—from gratitude. We do not have to go up to the Lickancabur to ask for money, for this or for that, no. We do not have to pay him as if we had a debt with him.[16] We need to thank him.

Thus, volcanic risk management, from an ancestral perspective, is not just about monitoring and evacuating. It is also about establishing *good relations* with volcanoes. It is about cultivating a more integral connection with them as kin, as beings that have feelings and proclivities, and without whom our life in the desert would be impossible. Actually, the notion of "volcanic risk" is misleading, because it assumes that the risk is the volcano himself. What is dangerous and risky is to sever our communication channels with him, to disrupt the warmth and the cycles of the inside Sun, for example by intervening it to extract energy and minerals. When the inside Sun is turned upside down, wretched and incapacitated, we will see the collapse of the Earth through the activity of our volcanoes. In addition, a volcanic eruption does not need to be dangerous. What we call "destruction" is often just nature regenerating herself. What is truly destructive is the overwhelming intervention to rivers, *bofedales* (high altitude wetlands), and *aguadas* (springs), disconnecting the three worlds and leaving behind a barren Earth unable to contain and absorb which are otherwise natural expressions of volcanoes. We need to worry more about extractivism than about volcanoes, which are beautiful creatures.

5 DISCUSSION

Lickanantay volcanology offers relevant insights that need to be considered if volcanology is to establish a respectful and caring relation with other knowledge in the CVZA, a transnational territory in which the Indigenous peoples have made observations

[14]Lickanantay communities have produced robust and time-tested knowledge on the linkages between volcanoes and climate and waters. For example, the Chiliques volcano plays a crucial role as a facilitator of meteorological phenomena (Moyano and Uribe, 2012), while the availability of water has always been related, ecologically and ceremonially, to *mallkus* (Grebe and Hidalgo, 1988; Valenzuela and Moyano, 2021).

[15]Also known as Jorgencal Volcano or Machuca Volcano, it is a stratovolcano located on the southern border between Bolivia and Chile (22°33′S 67°51′W) with an elevation of 5,890 m.a.s.l. and intense fumarolic activity at its summit.

[16]This is in relation to the *pago a la Tierra* (pay the Earth), or making an offering, a ritual guided by a logic of reciprocity between humans and deities. The *pago* is a tribute in exchange of benefits received from *Pachamama* and a propitiatory offering for new benefits requested (land fertility, cattle well-being, and water availability). It is a kind of agreement or an agreement to stay in good relations with the *Pachamama* (Carrasco, 2016; Grebe and Hidalgo, 1988; Ulmer, 2020).

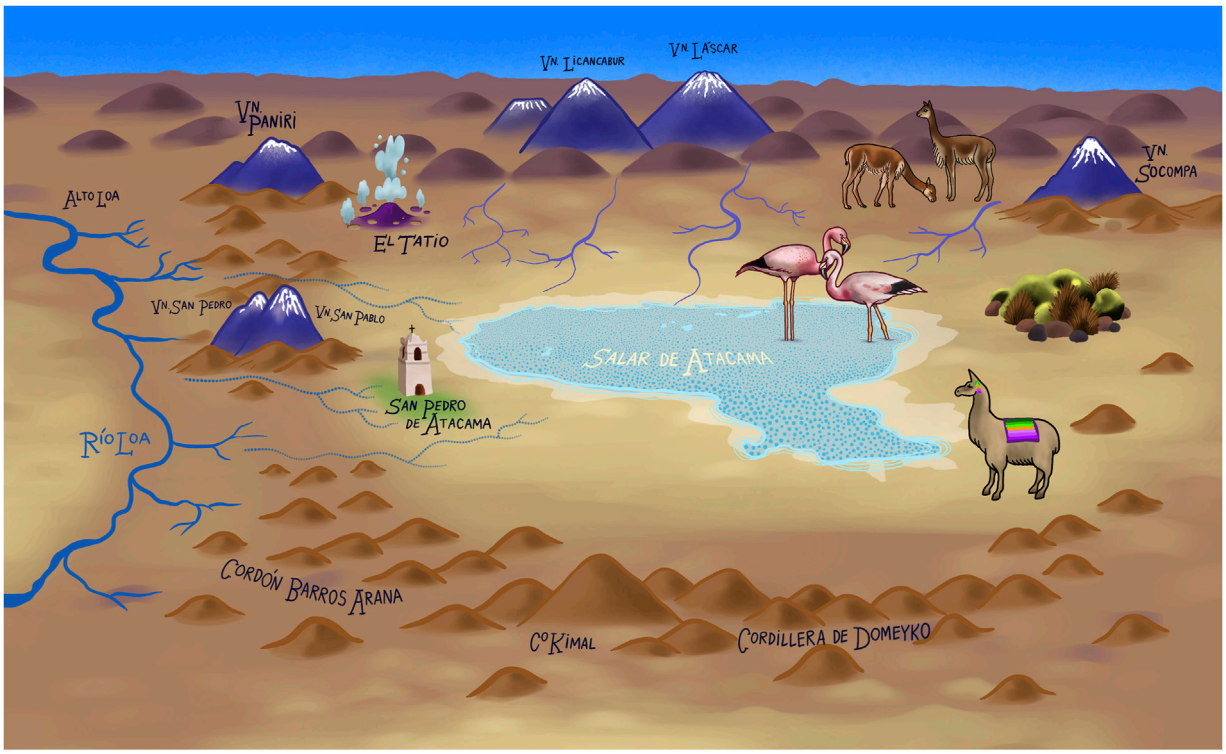

FIGURE 2 | Ancestral Lickanantay volcanic territory according to Sonia Ramos. Design: Sergio Iacobelli.

FIGURE 3 | El Tatio ancestral territory. Author: Manuel Tironi.

FIGURE 4 | Hécar (Iticunza) and Laguna Verde (Iticuna) volcanoes. Author: Manuel Tironi.

about, lived with, and intervened with volcanoes for millennia—and where extractivist damages are accumulating at a worrying speed. For example, Lickanantay volcanology teaches us that volcanoes need to be understood from a broader perspective, thus problematizing separations between volcanology and hydrogeology, ecological conservation, soil sciences, and climatology. Lickanantay volcanology also suggests that usual geological components—basins, aquifers, calderas, and ranges—might need to be revised in terms of their morphology in order to explore the possibility of accounting for subterranean connections that ancestral expertise assumes as extended beyond conventional geological demarcations. And that volcanology needs to integrate extractivism as a shaping geological stressor in its base lines and analyses, particularly for volcanic risk management. Hazards, Lickanantay volcanology suggests, are not related to eruptions or lahars, but due to the effect of extensive extractive operations on soils, waters, and social relations to land.

The most important contribution that Lickanantay volcanology has to offer, however, is epistemological. It renders visible that volcanology needs to understand itself as an open field in which different knowledge systems about volcanological dynamics can meet to co-produce better sciences and policies. This does not mean to invalidate what volcanology has achieved since von Humboldt's seminal observations of Chimborazo's eruption in Ecuador—but to take seriously other, even divergent practices and theories. This is especially important in the CVZA, where volcanological knowledge has been systematically produced for the last 10,000 years. This knowledge is built upon different definitions of what a volcano is and how it is connected to other biophysical systems, actually to where lays the demarcation between nature and culture, volcanology and cosmology, and geology and spirituality—and it is precisely for this kind of interconnections that it offers invaluable expertise. Mainstream volcanology can choose to extend the traditional scientific gesture, deeming the "beliefs" of Indigenous peoples as "mythological" or "folkloric", or it can explore new avenues of research and knowledge-making. Not long ago, the replacement of Indigenous knowledge systems with Western sciences was considered a civilizatory achievement. Today, in the face of the intractable planetary challenges we precisely face as a consequence of modern enlightenment, we need to cultivate an enhanced sense of humility and plurality, acknowledging the limits of our scientific methods—the ways in which the sciences mobilize and reinforce visions of the world that are far from universal. This is not a call to eliminate science as a method for knowledge production, but rather to assume the existence of other valid methods and to realize the urgent need for diverse dialogues among and across knowledge systems **Figures1–4**.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because this is qualitative data own by Indigenous elders. Requests to access the datasets should be directed to metironi@uc.cl.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Comité Ético Científico en Ciencias Sociales Artes y Humanidades UC. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SR contributed with: guiding ethical principles, territorial relations, planning of fieldwork, definition of main ideas, and revision of the final version. MT contributed with: writing the literature review, organizing the results section, organizing the discussion section, overall preparation of the manuscript, and translation into English.

FUNDING

This article was supported by FONDECYT 1190528, FONDECYT 1201373, and CIGIDEN (Research Center for Integrated Disaster Risk Management) ANID/FONDAP/ 15110017.

ACKNOWLEDGMENTS

We would like to express our gratitude to the *Pacha* for her sustenance, and especially to the *tata* El Tatio for being a constant source of guidance and knowledge. We also want to thank Natalia Toledo Ramos, Valentina Acuña, Gabriela Ramirez, and Juan Francisco Salazar for their support throughout the process of researching and writing this manuscript, and to Francisca Vergara for her assistance in the preparation of the literature review.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.