

## CARL TROLL ON NATURE AND CULTURE IN THE ANDES

With 4 figures

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*Zusammenfassung:* Carl Troll über die Natur und Kultur in den Anden

Durch sein sehr umfangreiches Gesamtwerk erlangte CARL TROLL (1899–1975) internationale Anerkennung, vor allem aber durch seine Untersuchung der Anpassung des Menschen an die tropischen Anden. Seine wesentlichsten Beiträge auf diesem Gebiet – größtenteils enthalten in drei zwischen 1931 und 1968 publizierten Artikeln – basieren auf nur einer Feldstudie in den späten 20er Jahren. Die Hauptthemen seiner Arbeit waren dreidimensionale Gliederungen von Vegetation und landwirtschaftlicher Nutzung und die ökologischen Grundlagen der Inka-Zivilisation. TROLL verdeutlichte die ungeheure Vielfalt der Anden auf meisterhafte Weise und veranschaulichte die hypsometrische Gliederung des Landes, des Lebens und der Zivilisation.

Eine kritische Betrachtung zeigt jedoch die Überbetonung des Klimas bei der Erklärung der vertikalen Gliederung der natürlichen Vegetation, der Landwirtschaft und des Hirtenwesens. Ungerechtfertigt extrapolierte er von der Gegenwart in die Vergangenheit und vereinfachte die Ursachen, die zum Entstehen einer politischen Gliederung in den Anden führten. Der große Einfluß von TROLLS Ideen beruhte auf seiner Fähigkeit, regionale Feldbeobachtungen zu generalisieren, modellhaft zu abstrahieren und auf seinen äußerst klaren graphischen Darstellungen. Die internationale Verbreitung der Ergebnisse seiner Andenforschung wurde auf dreifache Weise ermöglicht: a) durch Übersetzung zweier wichtiger Arbeiten ins Spanische; b) durch eine in Englisch verfaßte spätere Schrift und c) durch intensive Kontakte zu bekannten Wissenschaftlern. Von größter Bedeutung für TROLLS Einfluß war jedoch die in der Andenforschung der 70er Jahre gesteigerte kritische Auseinandersetzung mit dem Begriff der Anpassung und die in diesem Zusammenhang durchgeführten regionalen Forschungen insbesondere der für ländliche Lebensbedingungen als wichtig erkannten biophysikalischen Phänomene.

### 1 Introduction

Few twentieth century geographers have had as much international influence as CARL TROLL (1899–1975), whose field-based contributions concern mountain phenomena on five continents. His research has been applicable to cognate disciplines from biology and geology on the one hand to ethnology and ethno-

history on the other. Some of the findings from his early fieldwork on South America bridged the epistemological crevasse between the physical and the human. The major achievements and influences of his Andean work are examined here in the context of two main themes, one dealing with pattern, the other with process. New knowledge and the passage of time clarify the nature of TROLL's intellectual influence and offer the opportunity to scrutinize his scientific rhetoric. What TROLL's contributions purport to say, how others have reacted to them and why they gained so much international attention should all be part of an evaluation of his work. In that quest, I have sought to avoid the extreme positions of both an unexamined scientism and a poststructuralist nihilism.

The results of CARL TROLL's research in the Central Andes continue to elicit substantial interest. Yet only about two years at an early period of his geographer's life were actually spent there.<sup>1)</sup> In the Forschungsreise tradition of German geography, TROLL travelled to Bolivia in 1926 to initiate field studies on flora and vegetation. His botany professor at Munich, THEODOR HERZOG (1923), possibly influenced his choice of that destination, though a research interest of bringing together various physical processes in highland settings had already been revealed in his graduate dissertation on the Alpine Foreland.

TROLL's professorial career, which began in Berlin soon after his return to Germany in 1929, took him on research trips to East Africa, the Himalaya, and later Mexico. From that comparative perspective emerged his renowned observations on convergent life forms in tropical highlands. In 1938 he gave the term "Landschaftsökologie" to geo-biophysical integration of geographical space. TROLL's pioneering role in landscape ecology and in a subset of it known as mountain geology is widely acknowledged (FURMAN a. GODRON 1986; GERRARD 1990, 36–37). Less well known to the larger scientific community are TROLL's contributions to the study of Andean cultural geography. Overshadowed by his numerous other accomplishments, the

<sup>1)</sup> One year of the 3 and 1/2 in South America was spent in employment in Colombia, Ecuador and Panama; most of that year was in the lowlands not highlands.

Andean work has received scant or no mention in some characterizations of his life's work (SCHWEINFURTH 1975; LOUIS 1976; TILLEY 1984; RATHJENS 1988). LAUER's (1976) memorial and BÄHR a. GORMSEN's (1988, 53–54) survey of Latin American research conducted by German-speaking geographers are among the few who have given his Andeanist phase special comment.

After the age of 30, TROLL had no on-site projects in Western South America. Nevertheless he made durable observations of the way Andean space was structured and how humans made use of it. This essay examines two principal ideas from that one field period which resulted in 22 publications appearing between 1927 and 1943 (LAUTENSACH 1959). Over the years only two of those 22 articles have commanded sustained attention (TROLL 1931; 1943). The latter piece had insights which benefited from the author's experience in other tropical highlands and more than a decade of reflection. But the most influential publication appeared 25 years later when TROLL (1968) recapitulated certain aspects of his Andean work in a larger hemispheric context.

## 2 *Pathfinding insights*

TROLL's thinking about highland adaptation was part of a forceful exposition of Andean space, time and ecology. It was not that he was the first to present these facts. SCHWALM (1927), for example, had previously published a thick description of Andean land and life. A decade earlier BOWMAN (1916) had prepared a treatise on southern highland Peru that joined naturalistic observation and socio-economic assessment of human adaptation. Neither, however, conceptualized the Andes in the same compelling way as did TROLL.

### 2.1 *Vertical landscape arrangement*

The vertical arrangement of landscapes is a concept that goes back to HUMBOLDT's landmark observations in 1802 on Mt. Chimborazo in Ecuador. TROLL greatly refined HUMBOLDT's brilliant insight that plants appear in landscape configurations that changed not only with changing altitude, but also latitude. As did HUMBOLDT, TROLL surmised climate from the plant cover because weather records for the Andes were still sparse. To delineate regional frost boundaries, TROLL extrapolated fragmentary local data on freezing temperatures at different elevations (Fig. 1). Into the same naturalistic discussion of vegetation and climate,

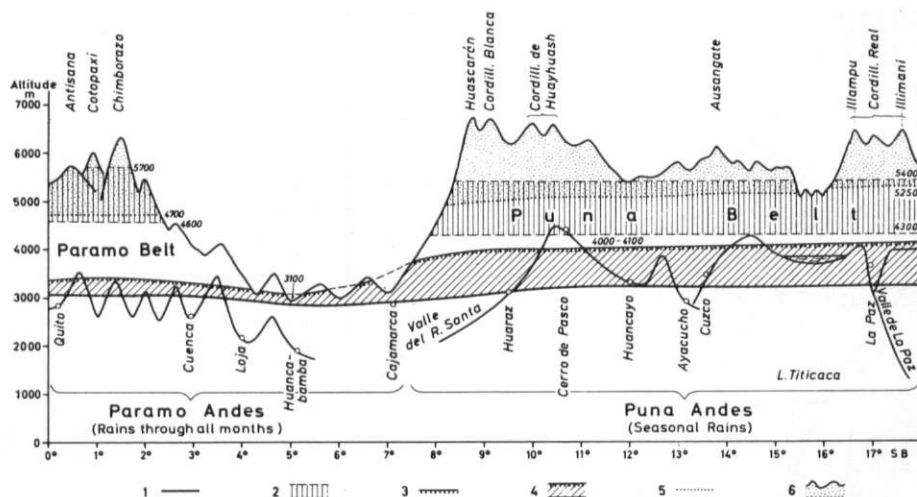
TROLL, as HUMBOLDT had done before him, brought cultivated plants, land-use and settlement.

TROLL saw Andean culture as a syncretistic complex of indigenous and colonial Spanish traits. He was especially conscious of the technological differences in farming that EDUARD HAHN had previously elaborated (TROLL 1931, 262). Native Andean farming used hand tools in sowing, weeding and harvesting plants as individual entities, quite unlike the plow agriculture brought from Europe which not only used animal power, but also conceptualized the grain field as an ensemble. The indigenous adaptations interested TROLL the most, for they were superior in producing food at elevations above 3500 m and are the ones that clearly dominate there even today. Differing from many Western scientific geographers, TROLL brought another salutary perspective to the study of this the poorest part of Latin America: he did not make developmentalist assumptions nor is there evidence of the triumphalism of Western science in his Andean work.<sup>2)</sup>

TROLL's skill in formulating maps and diagrams may have grown out of his talent for field sketching (MONHEIM, I. a. MONHEIM, F. 1985). His three-dimensional profiles fit into a tradition which have distinguished German geocology since HUMBOLDT (UHLIG 1984; LAUER 1984, 186; 1993). That concept of incorporating latitude and altitude into landscape arrangement was later used to good effect in mountain chains elsewhere in the world (TROLL 1966). Comparing vertical profiles of vegetation patterns from different mountains led to major insights in conceptualizing how, through evolution, life forms converge in highlands which are widely separated but which show similar climates.

TROLL also made one of the best-known and widely applied vegetation maps of South America or parts thereof. Published at a scale of 1:30 000 000, it displayed 13 vegetation types from southern Colombia to south-central Chile (Fig. 2). At such a scale, the discontinuity that marked the upper limit of forest on the eastern Andean slope was starkly manifest. TROLL (1931, 281–289) identified that boundary to be a fundamental division between ways of life that partly

<sup>2)</sup> DOLLFUS (1978a) contrasted TROLL with the geographer I. BOWMAN, also a keen field observer, who perceived the South American Highlands through a melioristic lens, with a judgmental attitude, and little appreciation of the life of peasants (a category which has never existed in the USA). But beyond personality differences, some of this antithesis might reflect the differing world views of a Bavarian steeped in Catholic tradition versus those of a North American puritan intolerant of dirt, sloth and backwardness.



Vertical zonation of the frost climates in the equatorial and tropical Andes in its relation to the upper limit of agriculture and to the snow line.

1. Limit of regular occurrence of frost, 2. Altitudinal belt with the maximum number of days with change of frost and thaw (330—350 per annum), 3. Upper limit of cultivation, 4. Belt of cultivation with regular occurrence of frost, 5. Snow line, 6. Nival belt.

*Fig. 1:* This three-dimensional profile effectively incorporates settlement and land-use into latitudinal and altitudinal dimensions. Its relative detail provokes sustained reflection, yet it is not so complicated as to hinder an immediate grasp of the main variables in the 1000-km long expanse from Ecuador to Bolivia. The published English-language version of this profile (TROLL 1968, 34) has been somewhat simplified from the map in his 1943 paper (TROLL 1943, 125)

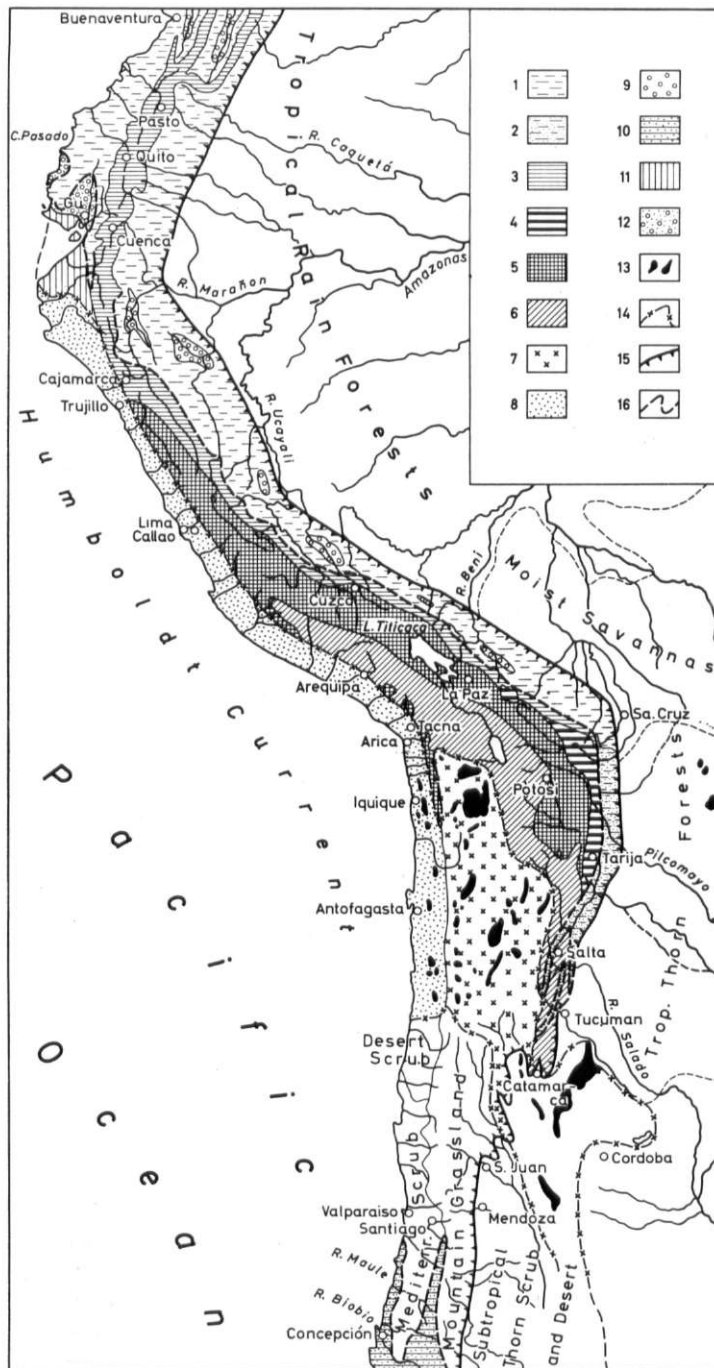
explain the general failure of the Inca to expand their empire east of the piedmont except to grow coca (RENARD-CASEVITZ et al. 1986, 21; GUHL 1991, 87). Some of the first perspicacious remarks on the nature of the eastern limit of the Inca Empire emerged from this geographer's cartographic visualization (TROLL 1931, 281–285). TOSI's (1960) ecological map of Peru at a 1:1 000 000 scale presents so much complexity with its 34 categories that it could not have the same kind of impact on the geographical imagination. By contrast, TROLL's maps and diagrams served as an intelligible backdrop on which Andean culture history has been played at the same time they provided a functionalist interpretation that distinguished contemporary livelihoods.

## 2.2 Subsistence and civilization

TROLL also contributed original ideas about agropastoral subsistence as a way of explaining the remark-

Dieses dreidimensionale Profil integriert Siedlungen und Landnutzung eindrucksvoll in die Dimensionen der Höhe und geographischen Breite. Seine Detailliertheit erweckt den Eindruck genauer Untersuchungen, dennoch ist es nicht so kompliziert, daß die direkte Erfassung der für die 1000 km-Distanz zwischen Ecuador und Bolivien wichtigen Variablen erschwert würde. Die englisch-sprachige Version (TROLL 1968, 34) ist gegenüber dem Original von 1943 geringfügig vereinfacht (TROLL 1943, 125)

able expansion of the Inca Empire. TROLL's interest in the Inca seems to have developed during slow travel on horseback through Bolivia and part of Peru, which enabled him to glimpse and occasionally inspect some of the abundant ruins of a pre-Columbian past. Years before extinct civilizations were dissected in this way, he reflected on the material bases of the Inca. Nutritional foundations are near the heart of understanding the Inca or any civilization although anthropologists even now may choose to essentially ignore its importance (e.g. DAVIES 1995). TROLL sought to understand why this polity that before the Spanish Conquest had extended over so much Andean territory emerged in southern highland Peru and retained there its administrative and cultural core. He viewed the puna of southern highland Peru as crucial to the emergence of the Inca. His assertion that the high country held the key to cultural and political florescence reflected a then novel perspective: difficult habitats sparked human ingenuity to invent solutions that sustained human life. In TROLL's (1943) view, three elements –



The landscape belts of the tropical Andes.

1. Tropical rain forest (incl. montane forests),
2. Tropical-subtropical semideciduous forests ("Tucumano-Bolivian forests") incl. evergreen and deciduous subtropical montane forests,
3. Equatorial Paramo-belt and tropical semi-evergreen high mountain grassland ("Pajonales"),
4. Subtropical mountain meadows,
5. Moist Puna belt, 6. Dry Puna belt ("Tola"-belt of *Lepidophyllum quadrangulare*),
7. Thorn Puna and desert Puna (Puna de Atacama),
8. Atacama desert, 9. Open savannas within the rain forests,
10. Sclerophyllous woodland and shrubland of Central Chile, 11. Thorn savannas (forest and grassland) in the Peruvian and Ecuadorian coastal regions,
12. Moist savannas (deciduous forest and grassland) in the coastal region of Ecuador, 13. Salt pans,
14. Arheic areas, 15. Eastern margin of the Andes, 16. Western boundary of hygrophytic vegetation areas.

Die Landschaftsgürtel der tropischen Anden.

- 1/ Tropischer Regenwald (incl. Berg- u. Nebelwald)
  - 2/ Subtropischer Regenwaldgürtel (Monsunwald mit Nebelstufe)
  - 3/ Paramogürtel
  - 4/ Subtropischer Paramogürtel
  - 5/ Gürtel der Normalen Puna
  - 6/ Gürtel der Trocken-Puna (Tola Zone)
  - 7/ Salzpuna
  - 8/ Wüste
  - 9/ Savannen-Inseln im Regenwald
  - 10/ Mitteldänisches Waldland
  - 11/ Dornbuschsteppe
  - 12/ Savanne u. Trockenwald
- Salzpflanzen  
 — Grenze des abflusslosen Gebietes  
 ~~~~~ Oststrand der Anden  
 - - - - Westgrenze des Regenwaldes

páramo. The same reason presumably explains why the montane forest and tropical rain forest types, structurally and floristically different, are not distinguished

Die Vegetationskarte wurde als englisch-sprachige Version (TROLL 1968, 37) des 1931 veröffentlichten Originals publiziert (TROLL 1931, 273; die gleiche Karte wurde später (1943, 109) ohne Hinweis auf die Erstveröffentlichung abgedruckt). Die Karte enthält weder Maßstabsangaben noch geographische Koordinaten.

Fig. 2: This vegetation map was published in TROLL (1968, 37) as the English-language version of the same map (TROLL 1931, 273; same map was later (1943, 109) published without attribution to the first). No graphic scale or even coordinates were provided on any of them. Mistitled "landscape belts" (*Landschaftsgürtel* in the original), this map actually displays physiognomic formations. However, the map was prepared at too small of a scale to show the plant cover of intermontane valleys below the puna/

Fälschlicherweise "landscape belts" (als Übersetzung von Landschaftsgürtel im Original) betitelt, stellt die Karte eigentlich physiognomische Formationen dar. Für die Darstellung der Pflanzendecke in den intermontanen Becken unterhalb der Puna/Paramo-Stufe wurde die Karte jedoch in einem zu kleinen Maßstab entworfen. Daraus erklärt sich auch, warum die strukturell und floristisch differierenden montanen und tropischen Regenwälder nicht unterschieden wurden



irrigation, tuber dehydration and domesticated camelids – were instrumental in creating the regional advantage.

Canal irrigation was one of these developments in the subhumid highlands of southern Peru. Since evaporation exceeds precipitation for seven months of the year, irrigation increased the predictability of crop yields of such a water-demanding plant as maize. Assurances of surpluses of this favorite staple compensated for the effort required to build canals. To facilitate irrigation of slope lands and to check erosion, stone-faced bank terraces sometimes covered whole mountain sides (TREACY 1994). Maize produced on these irrigated benches yielded in excess of 2000 kg/ha and was an important food during Inca times.

TROLL spelled out the larger significance of the processing of root crops more lucidly than had any previous scholar. If set aside after being dug up, tubers begin to sprout, but if their water content is removed, the resulting hard lumps of starch (*chuño*, *moraya* and *tunta* from the potato; *ccaya* from oca) can be stored indefinitely. TROLL contended that tuber preservation allowed people to permanently settle the high elevations of southern Peru and Bolivia where maize could not profitably be grown. Above 3900 m on the puna, hard night freezes alternating with warm sunny days occur between June and September. This combination facilitates the break-down of cell walls of the tubers and the removal through trampling of their moisture. Freeze drying is not practiced in northern Peru and Ecuador, for even in the highest agricultural zones, night frosts in those lower latitudes do not occur and the days are often cloudy.

HUMBOLDT had wondered why Andean people would cultivate poor land at high altitudes when fertile, uninhabited lands were available on the Andean piedmont a day's walk below (NUNEZ a. PETERSEN 1971, 140). The earliest solid answer to this question lies in TROLL's suggestion that the high country provided a preservable food surplus, one dependent on special kinds of tubers. Potatoes of two species complexes, (*Solanum x. juzepczukii* and *S. x. curtilobum*), can successfully grow on the puna of southern Peru even with temperatures down to  $-5^{\circ}\text{C}$ . The glycoalkaloid that makes them inedible as fresh tubers is removed when the moisture is squeezed out. Frost, normally inimical to agriculture, was ingeniously used to process a food that could be stored and used to feed the troops amassed for war, conquest and large public works projects.

The llama was another key element in the cultural ecology of the Inca core. As beast of burden and provider of meat, wool and dung for fuel, this camelid was

an uncommonly useful domesticate.<sup>3)</sup> Fresh llama flesh was also freeze-dried to make *charki*. TROLL placed the prehistoric distribution of the llama in the puna grasslands from central Peru to southern Bolivia. By contrast, the páramos, perpetually cloaked in clouds and soaked with mist, were scantily used by pastoralists until the Spaniards arrived with sheep and cattle. Although both the puna and páramo lacked trees, they each had different land uses.

Wishing not to be misinterpreted, TROLL affirmed in his 1943 paper that culture, not habitat, ultimately explains Inca civilization. What TROLL actually wrote and others have interpreted him to say have sometimes diverged. Contrary to GUILLET (1983, 565) and YAMAMOTO (1988, 112), TROLL nowhere asserted that Inca civilization could not have emerged without the potato.

Rather, tuber dehydration was one of the inventions that stimulated („gefördert“ was the exact word) the rise of Andean civilization (TROLL 1943, 127). Freeze-dried potatoes offered the possibility of a settled existence at high elevations by providing an imperishable food supply that tided people over until the next harvest. Ideas attributed to TROLL by invocation or misapplication reflect to some extent his posthumous standing in Andean studies rather than a careful reading of his work.

### 3 Intellectual impact on Andean studies

CARL TROLL's work, especially in the two decades after his death, has offered a conceptual foundation for many national and foreign scholars and scientists of the Andean realm seeking to make sense of its extravagant geographical diversity. Andeanists in ethnology, ethnohistory, cultural geography and to a lesser extent archaeology applied or at least took note of TROLL's intellectual contribution. Most of this work has spatially focused on the area from modern Ecuador to Bolivia which is still dominated by a peasantry that has conserved many indigenous traits (GADE 1992). The relative cultural unity of this central Andean core owes much to the Inca imprint and stands in contrast to the local ethnic diversity of most

<sup>3)</sup> TROLL (1931, 262; 1943, 116), who had read the work of EDUARD HAHN on animal domestication, alluded to the durability of the fallacy of llamas or alpacas as a human source of milk. Persistence of this misconception may correspond to a deep-seated Western conceit that unconsciously transposes the Old World pattern of milking large domesticates to these New World herd animals (GADE 1993).

other inhabited mountain areas of the world. Cultural continuity through space and time has helped to clarify adaptations to the cascade of vertical environments.

Placing a regional focus on the Andes as a definable sphere of scholarly and scientific endeavor did not begin to crystallize until the 1940s when the Smithsonian Institution in Washington published the Handbook of South American Indians. This ambitious compendium organized the Andean realm as having a distinctive identity within Latin America. Today more than 2000 individuals in the world have research-based degrees in all disciplines that resulted from investigations in the Andes or on Andean themes. About half of these are citizens of the central Andean countries; the other half are mainly from North America, Europe and Japan. Anthropologists from the USA form the largest single foreign contingent; in the decade 1982–1992, close to 235 doctorate degrees were awarded in Andeanist anthropology.

### 3.1 Linguistic filters

Four years after TROLL's 1931 article appeared, the Arequipean geographer CARLOS NICHOLSON prepared a translation of the text and captions (TROLL 1935). More than two decades later, NICHOLSON next produced at TROLL's request a Spanish version of the 1943 paper (TROLL 1958). That same translation was later reprinted (TROLL 1980). Substantial interest in the more accessible renditions led to citation confusion. Several authors mistook the 1958 TROLL paper as a translation of the 1931 article in the Ibero-Amerikanisches Archiv (BRUSH 1976, 166; DOLLFUS 1981, 140; SALOMON 1986, 22). NICHOLSON's versions introduced TROLL's ideas on the cultural geography of the Andes to many Latin Americans and others who had been blocked access, whether by unavailability or language, to the original. TROLL's thinking influenced scholars within Western South America to conceptualize their countries in terms of altitude rather than longitude. In Peru, JAVIER PULGAR VIDAL (1939; 1987) replaced the classic but unduly broad tripartition of coast, highlands and selva with an organization of eight vertical zones defined in terms of elevation, climate, vegetation cover, fauna, domesticated resources, and toponymy. Although it ignored much geographical knowledge about the country, PULGAR VIDAL's scheme nevertheless synthesized indigenous knowledge into readily-grasped categories which made it a widely-adopted teaching manual. Nine editions of this book appeared in half a century.

The Spanish translations were followed in 1968 by TROLL's publication of his illustrated article prepared for the 1966 I.G.U. geocology symposium in Mexico, but which he could not attend. Written in English, that paper introduced TROLL's ideas to many hundreds of younger scholars. The German journals in which he had published his earlier work reached no more than 25 North American libraries and during the war years those subscriptions were not delivered. Even more than lack of availability was the inability of most anglophones to read German. That barrier largely explains why the 1968 paper in English, though clumsily written and mostly a derivative of his earlier work, has been among the most cited of his many publications.<sup>4)</sup>

### 3.2 Intellectual advocacy

JOHN V. MURRA, a Rumanian-American ethnohistorian at Cornell University with wide international connections, further spurred acceptance of TROLL's ideas and reputation. By the mid-1950s, MURRA had incisively pondered the relationship between ecological zonation and the economic structure of Andean society before the Spanish Conquest. Early colonial documents revealed that pre-Hispanic communities had integrated several ecological zones, not necessarily contiguous, into a livelihood that provided for their own needs and met tribute obligations to the Inca state (MURRA 1972). Multi-zonal use was a uniquely Andean solution to minimizing subsistence risk: if some crops failed at certain altitudes, other products at different elevations would likely yield. MURRA (1965, 187–188; 1980, xxv; 1984, 122; 1985, 8; 1989, 205) repeatedly acknowledged his intellectual debt to TROLL's elaboration of the biophysical and agropastoral diversity that characterizes the Andean Highlands.

MURRA advanced the neologism "verticality" to describe a configuration of diverse ecological zones used by the same group. In subsequent usage, the semantic field of verticality expanded. For example, PARSONS a. HASTINGS (1988, 190) view it primarily in activist terms as "a strategy of economic self-sufficiency implemented at the household, community or

<sup>4)</sup> An English-language text was by itself insufficient to create interest in his work. TROLL's (1929) desultory account in the Geographical Review of his trip through Bolivia, which included corrections to the American Geographical Society's Millionth Map of Hispanic America, received by comparison minimal attention.

regional levels." Verticality may also imply the ideological aspects of multi-levelled environments along with their morphological and economic features. Most generally, verticality connotes the idea of vertical ecological zonation. However defined, verticality became the prevailing paradigm for Andean studies. MURRA did not himself publish a sophisticated examination of biophysical and land use diversity to match his considerable talent for ethnohistorical reconstruction. In spite of its lack of detail, TROLL's work on Andean ecology remained a source to be referred to over and over again.<sup>5)</sup>

In the 1970s as cultural ecology became a strong research perspective in anthropology and geography, TROLL's explicator position was enhanced. Anthropologist BRUSH (1977, 4) considered TROLL's 1968 paper to be "perhaps the most useful attempt at a geographic overview and synthesis." Andeanists from Western South America as well as those from North America, Japan and France, cited TROLL either in the 1958 Spanish translation (e.g. ORLOVE 1977, 66; MATOS 1980, 92; DOLLFUS 1981, 87; CARDICH 1984/1985, 64) or the 1968 English-language synopsis (e.g. FORMAN 1976, 233; BRUSH 1982, 20; GUILLET 1983, 562; GODOY 1984, 362; BASTIAN 1986; LARSON 1988, 17; SKAR 1988, 108; BAUER 1992, 53; KOLATA 1993, 51). German geographers have not only abundantly cited TROLL in the original, but also have most faithfully incorporated, as he did, land use into studies of physical processes (e.g. MAHNKE 1982; LAUER 1984, 1993; ERIKSEN 1984).

TROLL's maps and diagrams have been borrowed, either intact (WINTERHALDER a. THOMAS 1978, 22; MURRA 1980, 207, 208; GOMEZ MOLINA a. LITTLE 1981, 127, 133; YAMAMOTO 1988, 114; SALOMON 1986, 23, 25, 26; GUHL 1991, 82) or redrawn (THOMAS a. WINTERHALDER 1976, 38; DOLLFUS 1978 b, 905; 1981, 19; LEHMAN 1982, viii; ACOSTA-SOLIS 1984, 32; FIORAVANTI-MOLINIÉ 1986/1987, 254; MURRA 1989, 206; LARSON et. al. 1995, 4). When effective, cartographic reformulation may outlive other forms of his legacy (Fig. 3).

To evoke a conceptual or authoritative underpinning, a TROLL reference has often been intercalated into a bibliography without any specific textual mention (e.g. FLORES OCHOA 1968; BROWMAN 1974; GOLTE 1980; YAMAMOTO 1982; LEVINE 1987; MORLON 1991;

MITCHELL 1991; TREACY 1994; DAVIES 1995). Increasingly, however, scholars have begun to bypass attribution of the verticality idea or cartographic presentations of it to incorporate them – as the ultimate fate of all knowledge – into the public domain.

### 3.3 Nature on culture: disciplinary divergence

TROLL's role in Andean studies must partly be seen as a transdisciplinary search for authority on matters in which anthropologists had interest but no special training. They embraced a commanding role of the environment in human adaptation, but were nevertheless disinclined and unprepared to evaluate biophysical processes with critical discernment. The tendency among archaeologists to propose environmental causation offers neat closure to puzzling permutations in the organization of an ancient Andean society. For example, PAULSEN (1976) and CARDICH (1985) interpreted the last surges of Inca expansion as having been triggered by a putative climatic deterioration in the fifteenth century. KENT (1987) suggested that aridity in the Peruvian-Bolivian Altiplano between 750 B.C. and A.D. 350 led to the contraction and thus centralization of the pre-Inca polities of Tiwanaku and Pukara. KOLATA (1992) has placed the demise of the Tiwanaku civilization as the result of an eleventh-century drought that led to agrarian collapse. The above assertions are useful for their heuristic value in stimulating further research, but are based on very slender evidence of climatic change. Anthropological studies of human adaptation in past or present environments often do not effectively evaluate the non-human data needed to test their hypotheses (WINTERHALDER 1980).

Geographers, on the other hand, have been circumspect about elevating poorly-known climatic changes or other natural processes to explain the course of human events. In North American geography, where deterministic rhetoric had been abused and then soundly discredited, research questions on environmental causation or even simply influences were often sidestepped as intellectual quicksand to avoid. Most post-war geographical studies on the Andes chose to push physical factors in the background. DYER (1962) analyzed the vertical distribution of population in Peru as a function primarily of agricultural intensification. In his vertical analyses in Ecuador, STADEL (1986; 1992) gave the natural environment a largely passive role. Instead, settlement, irrigation, seasonal crop rotations, productivity and land prices were given explan-

<sup>5)</sup> MURRA's discovery of the relevance of TROLL contrasts with two other distinguished Latin Americanist scholars, both at the University of California at Berkeley. Neither the anthropologist JOHN H. ROWE nor the geographer CARL O. SAUER referenced TROLL in any of their publications.

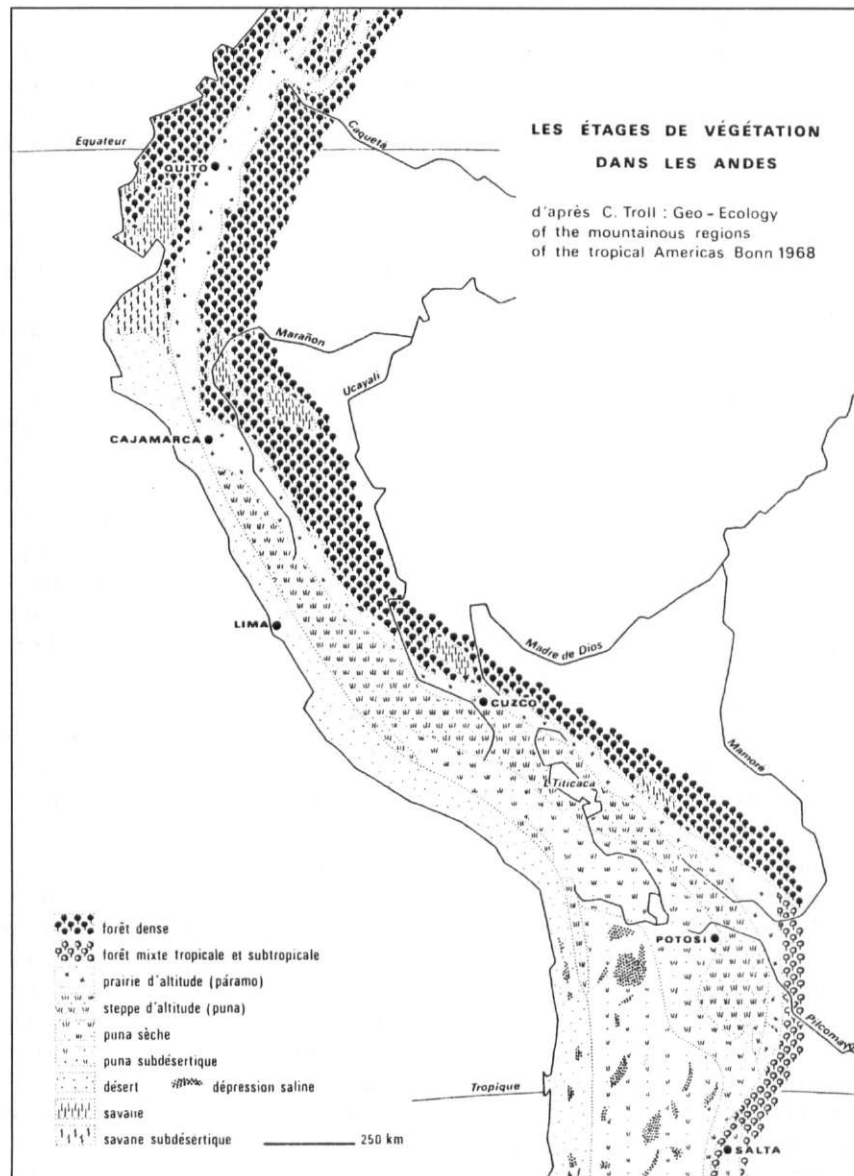


Fig. 3: This map (DOLLFUS, 1978b; which has sparked its own imitators) presents a glossed and truncated version of TROLL's famous piece of cartography in Fig. 2. An effective symbolization enhances its ready comprehension to a general audience. By not defining the eastern boundary of the Andes (which was shown on TROLL's original), this reformulation risks misinterpretation, for the rainforest (*forêt dense*) extends of course through the Amazon Basin

atory power along with peasant perceptions of stresses in their livelihood systems. GADE (1979) examined how climate was specifically related to the ecology of disease, but placed in the context of human decisions circumventing the dangers of contracting vector-borne maladies.

Diese Karte (DOLLFUS 1978b, die auch wieder Nachahmer fand) ist eine erläuternde und verkürzte Fassung der hervorragenden kartographischen Arbeit TROLLS (Fig. 2). Die effektvolleren Signaturen verbessern das Verständnis für jedermann. Dadurch, daß die Ostgrenze der Anden (die TROLLS Original beinhaltet) nicht eingetragen ist, kann diese Reformulierung Anlaß zu Fehlinterpretationen geben, denn der Regenwald (*forêt dense*) erstreckt sich in das Amazonas-Becken

In general, CARL TROLL's ideas on the ecological basis of the Inca Empire garnered less acclaim than did his work on vertical zonation. However, some Andean specialists with cultural-historical interests were intrigued with his insight on how the distinction between the puna and páramo had implications for



sustainability of past and present human populations (DOLLFUS 1981; SALOMON, 1986). The specific connection he made between settled life and tuber cultivation on the high plateaus has been frequently repeated, though not always with attribution (e.g. WACHTEL 1972, 106). The prominence TROLL gave pastoralism in Andean civilization was invoked as a departure from the standard view of agriculture as the only important bases of subsistence (FLORES OCHOA 1983, 177).

#### 4 Critical assessment of ideas

CARL TROLL's influence on two generations of Andeanists warrants an analysis of his relevant writings. The benefit of retrospection, new findings, and a reflexive perspective that appreciates how the *Zeitgeist* has played its part in the social construction of knowledge form the bases of this critique.

##### 4.1 Vertical zonation

The scale of his presentation enabled TROLL to consider vertical zonation with only the broadest brush. Ecological categories covered Andean space at a scale so small that aspects of Andean natural diversity important to cultural understandings were omitted. The distinction between the lower puna (3900–4300 m), where agriculture is possible though risky, and the upper puna (4300–4700 m), where only grazing is feasible, was not clearly delineated. His classification also ignored the segregation of the *chaupiyunga* (800–2400 m) as a vertical zone with a distinct thermal individuality that early colonial observers described as neither hot nor cold (VAZQUEZ DE ESPINOSA 1992, 588).

At TROLL's scale a broad correspondence of vegetation, land use and climate zone seemed evident. However, at substantially larger scales, climate becomes only one of several factors that account for either plant cover or land use patterns. ZIMMERER's (1996) remark that TROLL misconstrued "local space as the morphological artifact of purely environmental parameters" is largely a criticism of scale. Not surprisingly, when anthropologists misapplied TROLL's Andean-wide information to a locality, distortion of boundaries and meaning of categories was inevitable (e.g. PLATT 1978, 1085–1096; MITCHELL 1991, 39–43).

Climate set the altitudinal limits in TROLL's scheme of agropastoral zonation. His empirical assumption

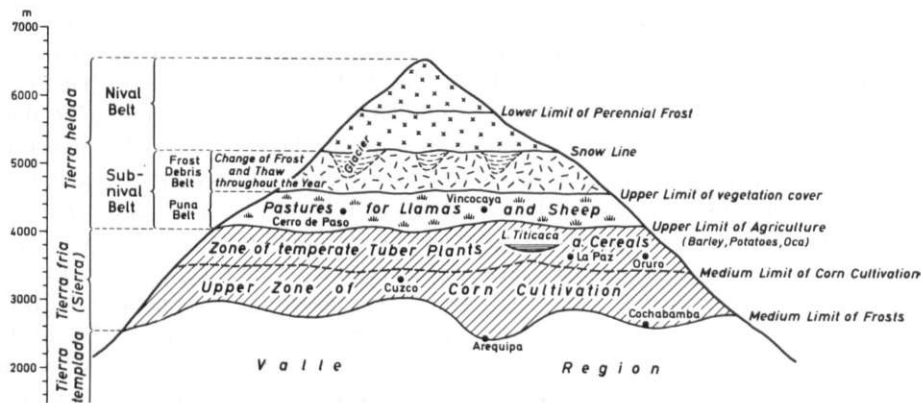
was that since cultivated plants each had their own thermal tolerances, they spatially clustered to impart a visible landscape expression (Fig. 4). TROLL considered freezing temperatures to be the critical element in Andean farming. He generalized that at 3000 m, night temperatures began to drop below 0°C; at 4000 m that threshold was met on 300 days and every month of the year. Subsequent long-period observations reveal that several factors in addition to elevation above sea level control the freeze phenomenon. Thus as an example, La Paz-El Alto (4105 m) has 129 days with frost, but at Charaña, somewhat lower at 4057 m, freezing temperatures fall on 307 nights (ERIKSEN 1984). Intensity of freeze also is more complicated than simple altitude. For example, at Yauri and Yanaoca both at 3915 m elevation in the Department of Cusco, temperatures between May and September can fall below -15°C in the former, but rarely below -10°C in the latter.

TROLL's emphasis on the effect of high-altitude frost on agriculture is ironic, for it is not necessarily the defining element in explaining cultivational limits. An inventory of ten crop species more frost resistant than those of anywhere else in the world is one of the grand achievements of Andean plant domestication (NATIONAL RESEARCH COUNCIL 1989). Even for crops vulnerable to freezing air temperatures, KNAPP (1988) pointed to the length of crop maturation which, in turn, is tied to mean annual temperature as most plausibly setting the upper limit. If causative factors in boundary formation are unclear, so is the more simple matter of pattern.

The drawing of boundaries of cultivation is less straightforward than TROLL implied (GADE 1975, 104). Undefined in his scheme was which kind of crop boundary he was using: the effective limit – at which cultivated fields cease to be continuous in the landscape – or the absolute limit of even the highest scattered fields.

At a microscale, factors other than climate, e.g. local availability of crop land, land tenure, or introduction of hardy crop varieties set the vertical upper limit. Only at a scale smaller than 1:200 000 is climate the major controlling factor in explaining crop and field boundaries. Over the long term, these limits are dynamic. The Central Andean puna shows evidence of relict fields above the present upper limits of agriculture (CARDICH 1985). Several explanations may explain shifting vertical boundaries of fields, of which climatic fluctuations are only one.

Crop zones, where a specific crop or combination of them dominate a vertical space, may be tied even less to thermal regimes than plant boundaries. Maize



Climato-ecological gradation of the high Andes of southern Peru and Northern Bolivia.

Fig. 4: TROLL (1968, 33) published this profile as a composite of contemporary land-use from southern Peru and northern Bolivia. The distinctions made between the *tierra fría* and *tierra helada* above it help to clarify some basic differences in high mountain land use. However, the illustration opens the possibility of misinterpretation about crop limits and land-use boundaries

TROLL (1968, 33) veröffentlichte dieses Profil zur Darstellung der zeitgenössischen Landnutzung im südlichen Peru und nördlichen Bolivien. Die hier vorgenommene Differenzierung von *tierra fría* und der darüber gelegenen *tierra helada* ist hilfreich zur Erklärung einiger grundsätzlicher Unterschiede der Landnutzung im Hochgebirge. Jedoch eröffnet die Abbildung Möglichkeiten zur Fehlinterpretation des Zusammenhanges von Anbaugrenzen und Landnutzungszonen

dominates southern Peruvian valleys between 2700 and 3200 m, but that is not a simple matter of suitable temperatures. Valley floors and terraced slopes facilitate irrigation on which successful maize production depends. Potatoes, which TROLL assigned to a vertical space above maize, are grown over a broad range of elevations and in places form the dominant crop plants below the so-called tuber zone. Their limits vary from place to place; to fix them for a whole region without extensive field checking invariably results in overgeneralization. YAMAMOTO (1988, 128), not finding potatoes growing below 3000 m at his Marcapata (Peru) study site, placed that as the lower limit of potato growing for the entire Central Andes.

Andean crop distributions have a past that can not necessarily be inferred from the present. Coca (*Erythroxylon spp.*) reveals the pitfalls of this approach in the Andes with its rich prehistory and documentary evidence that begins only in the sixteenth century. Coca cultivation was not limited to the eastern Andean slope as TROLL (1931, 286) had assumed. The sacred leaf was also grown under irrigation in many coastal and intermontane valleys. Early colonial records indicate its presence near Lima until, by the seventeenth century, it had disappeared (ROSTWOROWSKI DE DIEZ CANSECO 1973; NETHERLY 1988). Farther north, a few remnants of it survive in the lower western slope east of Chiclayo.

Central Andean agriculture is more spatially complex than any of the diagrammatic models that have been proposed over the years. Vertical arrangement of crops reveals broad differences in farming, but this aspect of Andean land-use is actually less important to understanding human adaptations than the cultural-ecological attention to it has warranted (CAMINO 1982, 28–29). Diversification of Andean agriculture in which crop species and varieties are mixed within a given parcel or farm reveals the basic adaptation to risk which gets at the core of understanding the Andean agroecosystem at whatever elevation. TROLL was surely aware of such diversity, but did not incorporate it into his presentation. The range of crop varieties (cultivars and landraces) within a given space and their functional uses has become of international interest, for the germplasm they represent has particular significance for future crop improvement around the world (ZIMMERER 1991; 1992). TROLL's Andean work predated this conservation issue, although he subsequently became more aware of Andean agronomic diversity as a result of the Russian plant collections in South America.

The crop zone as a category of analysis did not incorporate the social or economic dimensions of Andean verticality. Trained as a physical geographer, TROLL did not elaborate the human dimension which led MAYER (1985) to recast it as a man-made phenom-

enon superimposed on the environment's natural variation. Called a "production zone", it considered agricultural specialization in terms of distance of fields from the village, population size, and access to labor as much as temperatures, hailstorms or soils. How production zones were created, managed, and maintained led to the realization that only at the level of the peasant household could they be understood (BRUSH 1977, 136; CUSTRED 1977, 128). A composite of family decisions made on many hundreds of tiny farms shapes the agrarian landscape that characterizes a specific production zone. A controversial element in this formation has been the role of the much-discussed Andean community. Scholars with leftist perspectives sought to emphasize its role in local production as decisive in establishing agricultural patterns. Through the twentieth century, the influence of the Andean community has been primarily in the realm of the common-held resources of pasture and water.

TROLL's vertical zonation of Andean livelihood is a static representation. Nature is seen to be in control, and her rules change only when the mountain architecture is reconfigured. In criticism of that view, ALLAN (1986) proposed recasting land use of the world's highlands as a function of man-made accessibility. He argued that roads have so transformed mountain life that physical factors can no longer account for land use patterns. Such an egregious bypass of the natural environment prompted UHLIG a. KREUTZMANN (1995, 200) to protest the narrowness of that view. Certainly in the Andes, a balanced perspective that incorporates all relevant factors, physical and human, is still particularly relevant. Climate there continues to constrain land-use choices and introduces risk into peasant livelihood. At the same time, vertical land-use zonations of which climate is one element has been and will be in a continual state of flux. New crops and varieties are adopted. Low-yielding cultivars disappear. Land use undergoes reevaluation. Where peasant subsistence prevails, attention to physical factors persists. Vertical zonation is evident, and it is not at all the "useful fiction" that HEWITT (1988, 22) would have us accept.

#### 4.2 Human impact on vegetation

On another front, TROLL failed to appreciate the decisive role of anthropogenic factors on natural vegetation. In the naturalistic tradition of his academic formation, TROLL used plant cover as a surrogate for climate. The tropical rainforest and montane cloudforest above it were indeed vegetative responses to tempera-

ture and rainfall. But TROLL also made other correlations that are no longer accepted. The shrub cover of much of the central Andean highlands between 2500 and 4000 m is not a function of insufficient moisture.

Weight of the evidence has clearly shifted to human agency, not climate, to explain the general treelessness of the Andes. TOSI (1960), using HOLDRIDGE's formula that incorporated evapotranspiration, made a strong case that the Andes could indeed support forest cover over most of its extent. An early lone voice on the matter was COOK (1916) who, observing spontaneous tree regeneration on abandoned bank terraces, argued in favor of the prehistoric removal of a generalized Andean woodland cover. In the 1950s, the ecologist ELLENBERG (1958; 1979) became convinced of a general anthropogenic transformation of the Andes. Research since then has corroborated that viewpoint; for example, SEIBERT (1994) analyzed the vegetation of northern Bolivia from that assumption.

TROLL's mind-set, which sought a causal link between the observable vegetation and climatic factors, was firm. After the accumulation of weather records suggested that rainfall in intermontane valleys was indeed sufficient for tree growth, he elaborated a microclimatic explanation for shrub cover based on desiccating valley winds (TROLL 1952). Overgrazing to explain the vegetation cover was not considered in his scheme. Like his teacher HERZOG, TROLL's naturalistic perspective blinded him to the deterioration of the highland environment everywhere observable. In it, human impact on the Andean environment received minimal attention. His Bolivian travel journal provides insight into the way his mind was working on phenomena observed (MONHEIM, I. a. MONHEIM, F. 1985). Yet much of the Andes has serious soil erosion that in other field observers has unleashed a barrage of questions that find answers in the wholesale removal of tree growth, not just the unwise farming practices of today. Even eyes untrained in physical processes have made the link between past deforestation and rural poverty (GODOY 1984).

Whether the puna and páramo zones are anthropogenic or a response to climate is still controversial. Complicating the discussion is the certain knowledge that these windy cold heights also underwent past climatic fluctuations. TROLL explained the groves of *Polylepis* trees growing in the puna and páramo from Ecuador to Bolivia as relicts of a warmer period that have survived in protected microclimates. LAUER (1981; 1988), continuing TROLL's line of thought, has sought to reinforce the importance of climatic change in explaining this vegetation enigma. Yet abundant evidence of fire, grazing, and cutting have persuaded



many observers that most of these grassy zones were once forested to near the snowline (LAEGAARD 1992). With no thermal threshold to fix tree growth, a now broadly accepted conclusion is that a sweeping human intervention transformed the face of the Andes.

#### 4.3 Cultural ecology of Andean civilization

Accrual of knowledge has clarified some aspects of the ecological basis of the Incas. TROLL's assumptions about a high level of Inca inventiveness in its subsistence base were made before archaeological dating clarified chronologies and technological origins. Early in the century the German archaeologist MAX UHLE had established the pre-Inca reality of the Andes, but not until the 1950s did comparative dating reveal that domestication, irrigation, terracing and food dehydration had emerged more than 2,000 years before the Inca. With their prodigious organizational skills, the Inca refined this agricultural technology and enhanced subsistence efficiency (ZIMMERER 1993).

While acknowledging that irrigation in western South America preceded the rise of the Inca, later finds make TROLL's presuppositions about Andean water management largely obsolete. One is its much greater antiquity than he supposed: studies of sedimentology near Tarata, Bolivia have shown that an integrated system of canal irrigation functioned there as early as 1500 B.C. (ZIMMERER 1995). TROLL's assertion that irrigated areas of pre-Inca origin were later taken over by the Inca is not justified by findings of recent decades. Much water management in western South America is now seen as having nothing to do with the Inca (PARSONS a. DENEVAN 1967; DENEVAN, MATHEWSON a. KNAPP 1987).

On the Altiplano of Peru and Bolivia, earthen platforms covering thousands of hectares were intensively cultivated in one of the riskiest zones for farming in the Andes (ERICKSON 1993). The five to ten meter-wide ridges were separated by canals which alternately drained the fields and supplied water when rainfall did not. These watery interstitches also created a microclimate to lessen the frost risk. Food surpluses produced in this intensive agricultural system unlocks the long-puzzling mystery of the subsistence base of the Tiwanaku civilization in such an inhospitable environment. Elsewhere, in the Guayas Basin and nearby Ecuadorian highlands, areas of ridged fields have been reconstructed from aerial photography. Other man-made corrugated landscapes of that sort were constructed outside the Inca realm in the Llanos de Mojos of eastern Bolivia and the Sabana of Bogotá and San

Jorge Lowlands of Colombia. In all cases rainless periods characterize the climates of those areas. To assure crop growth, the raised soil beds separated by water-filled canals received part of their moisture needs from the bottom by capillary movement.

TROLL suggested that the Inca Empire was an example of a hydraulic civilization with irrigation as the motor force in the origins of the state. KARL WITTFOGEL's (1938) early papers, which argued how irrigation was the centralizing mechanism that led to state formation, were, however, not cited in this context. Though centralized and despotic, the Inca could not be rightfully described as a hydraulic civilization. Water management certainly contributed to food surpluses during the Inca period, but power did not derive from state control of irrigation as did that of ancient China or Egypt nor was the state responsible for their construction. The most that can be said is that irrigated fields in southern Peru contributed to food surpluses that strengthened the power of the Inca core.

TROLL's assertion that preserved tubers were vital to the rise of the Inca is questionable. Chuño was stored, but so were fresh tubers which were kept from harvest to the next sowing in ventilated and insulated storehouses (MORRIS 1981). Maize was at least as important as the potato in Inca nutrition, as a stored food and in explaining the rise of this polity (SHERBONDY 1993). Maize, nutritionally preferred as a food wherever available, was grown where better soils below 3500 m had access to water. Unlike tubers, maize was fermented into alcohol which acquired great symbolic value in Andean society and political organization during the Inca period (HASTORF a. JOHANNESSEN 1993).

As for llamas, TROLL reasoned that since they are herbivores, their ecological niche on the puna was obvious, especially since that is where he found them. In fact, llamas are relictual on the puna. Within the century following 1532, their numbers over the Andes declined 90 percent. Because Europeans never accepted them and had their own large livestock inventory to promote, llamas and Indians were closely linked after the Spanish Conquest. As a zone of Indian refuge, the puna harbored the surviving 10 percent (WHEELER 1995). In the absence of much outside interference, traditional patterns of life that includes camelid husbandry have persisted there. Over the years a convention emerged that led to erroneous conclusions about their distribution and supposed ecological requirements (e.g. DOLLFUS 1981). The adaptability of both llamas and alpacas is evident in their success when introduced to a wide range of elevations, climates and herbage conditions (WHITE a. MALDO-



NADO 1991, 50). Even in hot summer climates of North America they do well, just as they once thrived on the dry Peruvian coast.

TROLL made a corollary error of segregating Andean pastoralism into a zone above that of agriculture. Llamas were matched to the puna characterized as a pastoral zone. However, in its lower portion the puna has been as much agricultural as pastoral. By owning a llama herd an agriculturalist minimized his subsistence risk in a zone where frost and hail endanger crops. Llama excrement was an essential fertilizer for potato cultivation and llamas transported the harvest. Close farming-pastoral relationships may go back deep into Andean prehistory. Llama herders were plausible domesticators of quinoa, whose weedy ancestors could have undergone initial cultivation and selection after they volunteered in nitrogen-rich corrals (KUZNAR 1993).

### 5 Conclusion

That CARL TROLL's Andean contributions have evoked so much interest can be seen as a convergence of different factors. His penetrating field observations as a young scholar grounded the quality of his work. At a time when very few geographers conducted research in the Andes, he soon established himself as a scientific authority on that part of the world. Equally important was his ability to abstract field data into regional-scaled patterns and processes. Lucid maps and diagrams presented a synoptic view of the central Andean realm at the same time they vividly portrayed regional particularism. Readily grasped by the uninitiated, TROLL's presentation also spurred fertile reflection on the complex meanings of mountain diversity and adaptation.

A close reading of TROLL's cultural geography of the Andes reveals certain defects in his approach. He made unwarranted extrapolations from a thin data base or by projecting present patterns into the past. In addition, certain assumptions were flawed. Combining land use, vegetation and climate as related variables, he linked agropastoral phenomena to the physical in such a way as to make them seem explainable by the same laws. At the same time, however, TROLL conceptualized environment and people as separate entities, which is why he failed to appreciate plant cover as the result of human agency. Cause and effect in the culture-nature interplay is more multidimensional and cumulative than could be perceived at the time.

Its strengths celebrated and shortcomings overlooked, TROLL's published work on this realm owed

much of its acceptance to a favorable conjuncture of factors. By the 1970s when interest in his work accelerated, translations and photocopying facilitated its availability to scholars. Cultural ecologists found in TROLL the description and rationale for integrating Andean verticality into their research agendas. A leading Andean specialist in North America, with well-branched connections between the Old World and the New, promoted TROLL's insights to a new generation. Personal factors played a part in the intellectual radiation of his ideas. TROLL, whose Andean work revealed no apparent ideological content, emerged as a postwar spokesman for a German geographical scholarship cleansed of its hypernationalistic elements. His own forceful personality must also be considered, for like HUMBOLDT, TROLL had a flair for self-publicity.

The resonance of TROLL's work on people and nature in the Andes is thus not a simple case of scientific brilliance vindicated. Timing and fortuitous interventions suggest that content itself can account for only part of the success of geographical interpretations. The narrative of geography goes far beyond pure functional notation of objective knowledge. TROLL's work, like all science, is embedded in a textuality that elucidates how and why those results and interpretations are regarded and what impact they make.

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