HOLOCENE VEGETATION DYNAMICS IN MEDITERRANEAN IBERIA
Historical Contingency and Climate-Human Interactions

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In this paper we illustrate how different internal and external forcings conditioned postglacial vegetation in southern Mediterranean areas. By comparing seven Holocene sequences, we emphasize the role of glacial refugia as postglacial vegetation dispersal centers. We also identify the importance of the system's inertia in the time lags observed for vegetation response to climate change and human pressure. Finally, we explore the cascade of effects triggered by the human-climate interface, specifically the vegetation and the environmental feedbacks implicated in the collapse of the Argaric culture that emerged in arid southeastern Spain about 4,000 years before the present.

IN MUCH OF THE PALYNOLOGICAL LITERATURE, CHANGES THROUGH TIME IN VEGETATION as measured in stratigraphic columns are viewed as being determined by climate. However, pollen sequences may not show persistent trends through time or correlation with climatic events of local, regional, or global scales. Here we examine this issue in the Mediterranean region of Iberia. This area has been selected because it has a rich archaeological record, including Upper Paleolithic and Neolithic sites as well as a number of paleontological sites from throughout the Plio-Pleistocene, and indications of human presence since at least 1.2 million years ago (Arribas et al. 2004; Oms et al. 2000).

Paleolithic settlements are widespread, especially from the Mousterian on, and, critically, the region is abundant in Gravettian, Solutrean, and Magdalenian enclaves (Barandiarán et al. 2002). Likewise, Mesolithic and Neolithic humans

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left material signs of their presence in many caves in areas with limestone bedrock (Bernabeu et al. 1993; Hernando 1999). Although the impacts of Neolithic communities on the landscape do not appear substantial in the most arid southeastern region (Carrión et al. 2007), and appear locally moderate to the north in the Spanish Levant (Carrión and van Geel 1999), a model of these impacts is still needed.

The southeastern Iberian Peninsula is also one of the zones in western Europe in which metallurgy was first practiced. This activity was associated with a certain degree of urbanization (Delibes and Fernández Miranda 1993) and notable population increase (Chapman 1991). The transition from the Neolithic to metallurgic societies in Spain was not abrupt (Hernando 1999). The majority of Chalcolithic settlements (the Copper Age culture is known in the southeast as "Los Millares") occur between ca. 5,000–4,900 and 4,400–4,200 cal BP (Castro et al. 1999; Nocete 2001). The following period, the Argaric Bronze Age, suggests continuity in many settlements, in some territories with increased number and size as well as urban planning and a more structured organization in accordance with economic, political, and strategic functions. There was also an intensification and diversification in metallurgical production. This period ended abruptly at 3,600–3,500 cal BP, which has been interpreted (e.g., Lull 1983) as suggestive of a socioeconomic debacle owing to the persistence of metallurgy (requiring large amounts of natural fuel) and a pastoral-agricultural system that resulted in the degradation of natural vegetation and soils. The subsequent Iberian period (ca. 3,200–2,200 cal BP), together with the Roman occupation, were times of intensive wood exploitation and agriculture.

This is the context of hypothesized human pressure on the ecosystem since the Neolithic, and the relationships between anthropogenic disturbance and natural vegetation change are worth studying. Our approach is based on the Late Quaternary vegetation changes as observed in palynological records with sufficient resolution to detect the effects of long-term climatic influences and human impacts, as well as short-term disturbances such as fire. Historically contingent analyses of vegetation change shed light on such debates as to what extent equilibrium in the distribution of European trees is a function of climate or range filling (Svenning and Skov 2004). Ultimately, this can help determine whether such distributions were dependent on human actions or on their own inertia and autoecological processes.

ENVIRONMENTAL SETTING

Seven Late Quaternary palynological sites are discussed (Figure 1), all of them located in southeastern Spain—a region of typically Mediterranean climate with temperate winters and dry summers. The primary differences in the local environments are a result of harsher winters in montane areas (Baza and Gádor) and at inland sites (Siles and Carihuela). The characteristics of local vegetation in each case are summarized in Table 1. Modern landscapes are depicted by patchy mosaics of pines, evergreen and deciduous oaks, and, locally, mesophilous trees. Most of the sites have been impacted by intensive cropping that has altered natural vegetation, and this imprint is especially obvious in the lowlands (Padul and Navarrés). In general, scattered *Pinus sylvestris* and *Pinus nigra* are present in the upper mountain belts, where they occur together with a cushion thicket of junipers (*Juniperus communis* subsp. *hemisphaerica, Juniperus sabina*) and *Genisteae.* Deciduous oak forests are restricted to the most humid biotopes on high ground, being dominated by *Quercus faginea* and occasionally by *Quercus pyrenaica* on siliceous outcrops. The holm oak (*Quercus ilex* subsp. *ballota* = *Quercus rotundifolia*) is relatively abundant from 1,000 m up to 1,800 m in elevation, often mixed with pines (*Pinus pinaster, Pinus halepensis*) and scrub species such as *Crataegus monogyna, Berberis hispanica, Prunus ramburii, Cytisus reverchonii, Adenocarpus decorticans,* and *Genista cinerea* subsp. *speciosa.* Thermophilous *Quercus coccifera, Pistacia lentiscus,* and *Phillyrea angustifolia* understory communities are characteristic of the lower, more xerophytic areas.

INTERPRETATION OF THE RECORDS

The palynological records and the radiocarbon dates presented here have been published elsewhere (Table 1). The dates are in uncalibrated years BP.

Postglacial Development Is Contingent on Glacial Context

We hypothesize that postglacial changes in vegetation were influenced by the

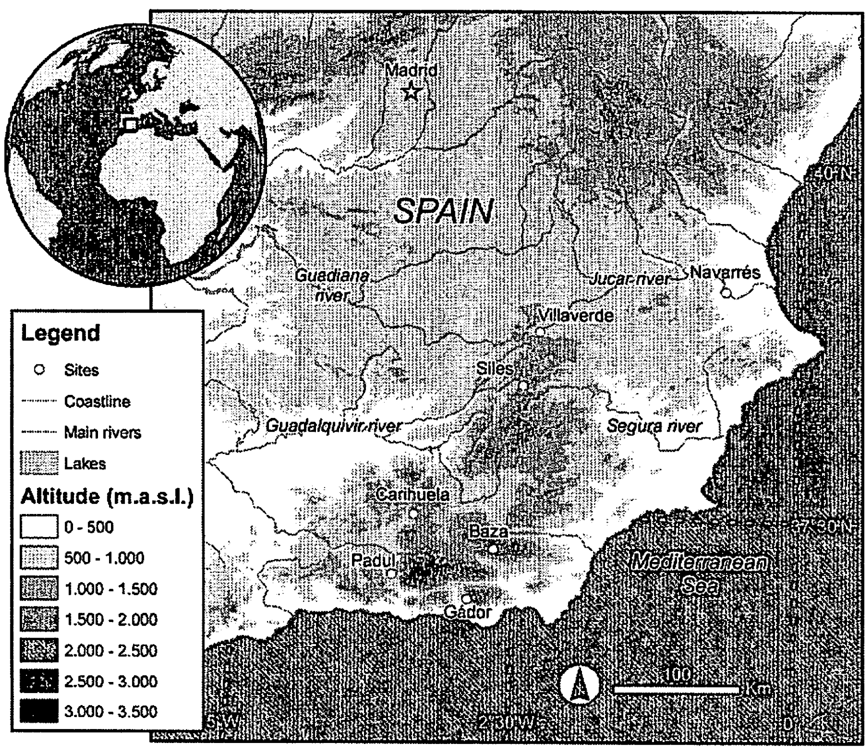

Figure 1. Location of sites discussed in the text.

TABLE 1
Site characteristics

Location	Deposit Type	Lat (N)	Long (W)	Elevation (masl)	Modern Vegetation	Mediterranean Climate Type	Mean Annual Temp (°C)	Mean Annual Rainfall (mm)	References
Baza	Peat	37°4′	2°42′	1,900	Mosaic of pine, oak, and mixed pine-oak woodlands	Supra, cold continental	4–8	500–600	Carrión et al. 2007
Gádor	Shallow lacustrine	36°52′	2°55′	1,530	Shrubby thermo-Mediterranean. Sparse trees: *Pinus, Quercus*	Supra, cold continental	11–12	450–500	Carrión et al. 2003
Siles	Lake	38°24′	2°30′	1,320	Local hydrophytes; patches of *Pinus nigra, P. pinaster,* and evergreen *Quercus;* several *Juniperus* sp.	Meso, cold subhumid	10–11	800–1,000	Carrión 2002
Carihuela	Cave	37°27′	3°26′	1,020	Oaks: *Quercus rotundifolia, Q. coccifer, Q. faginea. Pinus nigra* and *P. sylvestris* found at higher elevations; Mediterranean scrub spread in lower elevations	Meso, warm continental	10–12	570–600	Fernández et al. 2007
Villaverde	Karst wetland	38°47′	2°22′	870	Patches of evergreen *Quercus,* scattered *Juniperus* and *Pinus* (*pinaster* and *nigra*) woodlands in adjacent mountains	Meso, dry continental	13–14	400–450	Carrión et al. 2001
Padul	Lacustrine peaty	37°1′	3°36′	760	Deeply disturbed by cropping. S. Nevada lowlands have patches of oaks; *Pinus sylvestris* common in upper belts	Dry meso	15–16	470–500	Florschütz et al. 1971; Menéndez Amor and Florschütz 1961; Pons and Reille 1988
Navarrés	Shallow lacustrine	39°7′	0°41′	225	Garrigue (low, soft-leaved scrubland) and agriculture with patches of evergreen *Quercus*	Thermo	15–16	500–550	Carrión and van Geel 1999

composition, location, and structure of Late Glacial plant communities. This could explain the early Holocene prevalence of pine forests in areas where pines were featured in Late Glacial landscapes, which include coastal territories and interior plateaus (Carrión et al. 2000a; Dupré 1988; García-Antón et al. 1995, 1997) as well as high- and mid-elevation mountain zones (Alcalde Olivares et al. 2003; Andrade 1994; Carrión and van Geel 1999; Franco et al. 2001, 2004; García-Antón et al. 1997; Ruiz-Zapata et al. 1997; Sánchez-Goñi and Hannon 1999; Stevenson 2000; Tapias et al. 2003). Given this complex picture of forest distributions during the last glaciation, we cannot expect simplicity to be a primary feature of postglacial vegetation developments. Proximity to different glacial refugia is one of the Late Glacial triggers that determines the system's dynamics during the postglacial. To illustrate this point, we will compare the vegetation changes observed in the Carihuela, Padul, and Navarrés pollen sequences (Figure 2).

Late Glacial vegetation in Carihuela (Fernández et al. 2007) fails to show any significant change at the onset of the Early Holocene. The woody component exhibits a noticeable diversity of trees and shrubs, including both deciduous and evergreen oaks, as well as mesothermophilous components (e.g. *Olea, Corylus, Fraxinus*). However, oak forests dominate the Late Glacial and Early to Mid-Holocene phases. The pollen record of Padul (Pons and Reille 1988) shows a Late Glacial landscape with *Pinus* and xerophytic herbs and shrubs—similar to nearby Carihuela, which also shows an early spread of *Quercus* during the Late Glacial.

The Navarrés pollen record shows pine forests dominating glacial landscapes, and there is evidence for a short-term, inter-pleniglacial expansion of *Pinus pinaster, Quercus faginea, Quercus rotundifolia,* and *Erica arborea* at about 30,200–27,900 BP (Carrión and Dupré 1997; Carrión and van Geel 1999). During the Late Glacial and early Holocene, *Pinus* continues to be the dominant arboreal component.

The floristic composition and the underlying structure of glacial tree populations may have been a primary control on these developments. Refugia oak populations in the Baetic cordilleras (Carrión 2002) would have been the source of early Late Glacial oak expansions registered in the Carihuela and Padul vegetation records. This situation parallels other southern Europe mountain chains (Benito Garzón et al. 2007; Brewer et al. 2002; Roucoux et al. 2001; Taberlet and Cheddadi 2002; Tzedakis 2003; Tzedakis et al. 2004). The Late Glacial in Navarrés, further north and east, shows more xerophytic vegetation reflected by the spread of *Artemisia,* which progressively declines as the Holocene nears, while *Pinus* remains the dominant arboreal type. Therefore, oak woodlands in Padul and Carihuela, and pine forests in Navarrés, can be primarily interpreted as a consequence of the floristic composition of nearby glacial tree populations. The secondary dynamic would have been a particular system's inertia—the ability of local forests to withstand climatic forcings during the Late Glacial and Early Holocene.

Lags in the Response of Vegetation to Holocene Climatic Changes

Ecological interactions mediated by disturbance events are often difficult to detect in the paleoecological sequence. However, these events shape much of the current typology and distribution of plant communities. The Holocene history of Navarrés

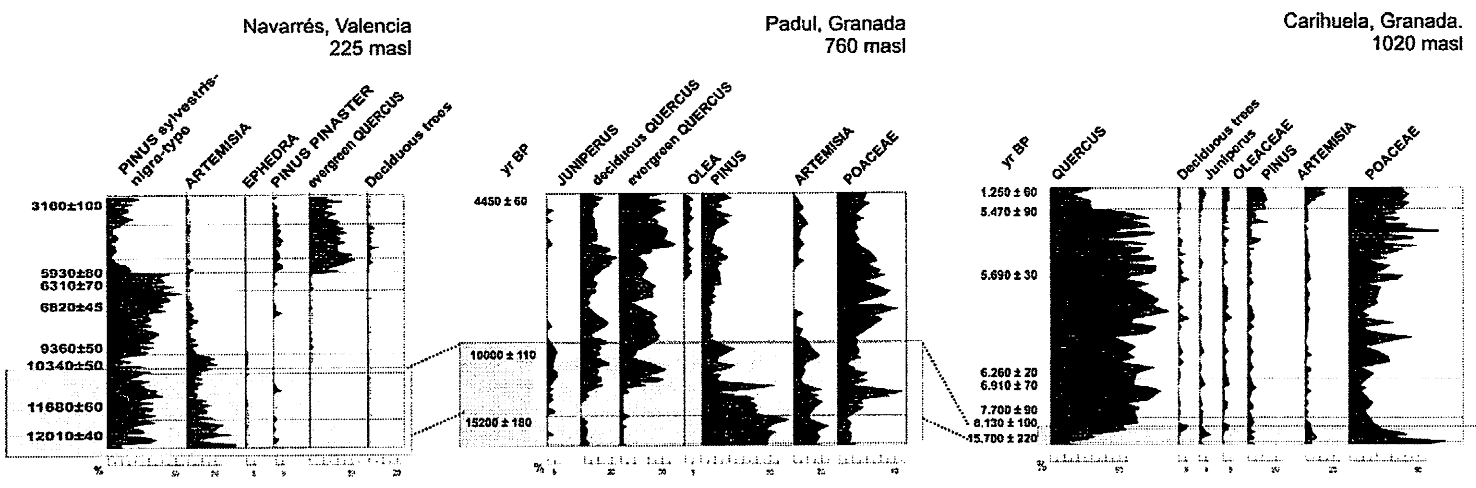

Figure 2. Synthetic pollen diagrams for Padul, Carihuela, and Navarrés (see text for discussion). Gray boxes at the bottom reflect similar time intervals during the Late Glacial.

also demonstrates this phenomenon. Notwithstanding the influence of climate, fire is a prime factor shaping local landscapes from the mid-Holocene onwards. Based on the variation in the macro- and micro-charcoal concentration in the core, the spread of evergreen *Quercus* at about 6,000 BP was related to increasing fire disturbance. Hence, pine forests were only replaced by evergreen-oak scrub after local burning, apparently related to the establishment of a Neolithic settlement in the vicinity of the study site (Carrión and van Geel 1999; Carrión et al. 1999, 2000b). A historically contingent process is responsible, consequently, for the beginning of a new ecological structure.

Although Navarrés shows a clear correlation between ecological change and the Neolithic onset, this pattern is far from generalizable across Iberia. In fact, other pollen diagrams from the southeast suggest that human activities during the Neolithic may not have left traces on the landscape (Carrión et al. 2000a; Dupré 1988). Neolithic people occupied alluvial soils with potential for cultivation—however, hunting and fishing also remained important. They appear to have occupied relatively unspecialized communities and developed exploitation strategies based on a diverse physical environment with relatively close proximity to resources (Sánchez-Quirante et al. 1995). Such strategies would have included the seasonal use of summer mountain pastures and winter fallow lowlands in addition to agriculture, which could be carried out year-round. Without doubt, farming activities would have been combined with the gathering of wild plants, as is shown by paleobotanical data (Buxó 1997).

In the pollen record of Villaverde (Figure 3; Carrión et al. 2001), *Pinus* was dominant from about 8,400 to 5,100 BP, although a moderate spread of deciduous *Quercus*, and other mesothermophilous taxa, is evident in the catchment area (deciduous trees in Figure 3). This expansion could have been shaped, in part, by competitive adjustments made after the arrival of these taxa in the study area, probably as a result of increased moisture. Note, however, that pines remained dominant for more than a millennium even though the climate became more humid and a rich pool of potential free colonists was available. The abrupt shift toward deciduous *Quercus* dominance, estimated to have occurred within ca. 10–33 years, could be a threshold response ultimately mediated by climate. Deciduous oaks, being shade-tolerant species, may have invaded closed stands of pines quite rapidly.

Dominance of evergreen *Quercus* communities (included in the Mediterranean taxa of Figure 3) is observed in Villaverde over a period of 300–400 years within the mid-Holocene. This change can be regarded as the consequence of competitive interactions following a climatic trend of increased aridity, which would have been critically manifested in the pollen record at ca. 3,200, 2,600, 2,300, and 1,700 BP. The arid trend from mid- to late Holocene is also supported by charcoal species identification (Terral and Arnold-Simard 1996) and geomorphological evidence of badlands (Wise et al. 1982). On a broader scale, important changes in the hydrological regimes of North African lakes have also been reported (Gasse 2000).

An additional time lag is detected in the *Pinus* response to climate changes during the late Holocene. Indeed, the last spread of pines (ca. 1,680 BP) and xerophytes does not correlate with the timing of the arid crisis, which is dated ca. 4,500–3,500 BP. Pine peaks were preceded by charcoal increases since about

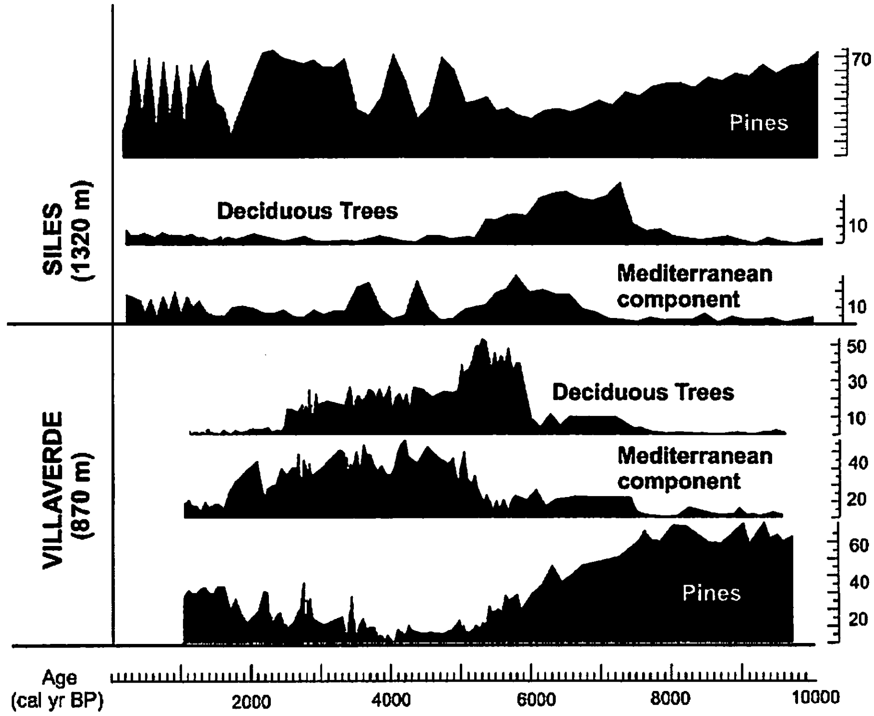

Figure 3. Synthetic pollen diagrams for Holocene records at Siles and Villaverde.

3,200–1,700 BP, reflecting a *Pinus* invasion of mixed and evergreen oak forests mediated by fire disturbance. This agrees with simulations predicting changes in the relative abundance of *Quercus rotundifolia* and *Pinus halepensis* with changes in the prevailing fire regime (Pausas 1999). Frequent fires would have led to *Pinus halepensis*–dominated landscapes, as this taxon is able to germinate after fires (Eugenio and Lloret 2006). Eventually, the Villaverde sequence seems to reflect the autoecology of a Mediterranean mid-mountain system in which the vegetation has changed continually without ever returning to an intermediate or previous state, so every stage in the sequence appears contingent.

The overall picture in Siles (Figure 1, Table 1) during the early Holocene is similar to that at Villaverde (Figure 3)—namely, pine woodland inherited from the Late Glacial. In this case, the main taxon is most probably *Pinus nigra*, followed by a climatically induced dominance of deciduous oaks and other mesophilous trees. The replacement of pine forests by mesophilous species after about 7,400 cal BP is viewed as a response to increased water availability. The expansion of Mediterranean vegetation after 5,900 cal BP coincides with summer drought limnological indicators (Carrión et al. 2001). However, comparison with Villaverde establishes an earlier response of deciduous and Mediterranean trees between ca. 7,500 and 7,000 BP, corresponding to the *Pinus* decline. While it remains clear that the succession from deciduous to Mediterranean forest took place in a context of increased aridity, it is worth wondering why developments of angiosperm trees occurred earlier in Siles than in Villaverde. We attribute the discrepancies to physiographic differences between the two localities. Siles lies within wetter, orographically more complex territory, whereas Villaverde is located on a high plain near the semiarid Murcia-Almería phytoprovince and La Mancha steppic region (Carrión et al. 2001). Consequently, given the existent altitudinal gradient, early Holocene climate conditions improved in Villaverde before they did in Siles.

From the mid-Holocene onward, Siles is characterized by a narrowing of its mesophilous component while pines and the Mediterranean cluster remained dominant, although these spectra followed opposite dynamics. Climatically this phase corresponds with increasing aridity and a very important increase in fire frequency beginning about 2,000 cal BP, which could explain the abrupt changes observed in the *Pinus* spectrum and Mediterranean scrub. As mentioned previously, pines in Siles are mainly *Pinus nigra*, which do not germinate after fire as effectively as *Pinus pinaster* or *Pinus halepensis*.

Human-Conditioned Landscapes and Ecologically Driven Socioeconomic Changes in the Southern Mountains

Anthropogenic disturbances have produced a complex pattern of responses in time and space across southern Iberian landscapes during the Holocene. Within this general scenario, the specific question pursued in this study is to what extent cultural transitions and changes in socioeconomic systems could have been ecologically driven.

The Sierras de Baza and Gádor (Figure 1) represent two case studies of differential landscape exploitation dating from the Neolithic. The Sierra de Baza paleoecological record (Carrión et al. 2007) covers nearly the entire Holocene (from about 8,400 to 160 cal BP) and includes a long history of human occupation, with phases of both settlement and abandonment (Figure 4). During the early Holocene, until ca. 6,000 cal BP, *Pinus sylvestris-nigra* woodlands dominated. Afterwards, mesophilous forests replaced these woodlands, plausibly owing to a regional increase in rainfall. However, xeric pollen types in both localities point toward a trend of progressive desiccation. Indeed, the Gádor pollen record indicates a xerophytization trend from the mid-Holocene to 1,000 years ago. Dynamic interactions between climate, humans, and vegetation appear responsible for this pattern. Supporting this view, we found that the first Neolithic cultural impacts that have been detected are concurrent with mid-Holocene climate improvement. In this environmental context, the snowfall decline would have increased the impact of pastoral activity on deforestation of the original pine woodland. Pine density would be reduced at a time when climatic amelioration increased the competitive potential of oaks, hazels, and other deciduous trees. Therefore, we observe increasing aridity that parallels competitive adjustments made as a consequence of expanding deciduous woodlands.

Chalcolithic settlements, known in southeast Spain as the Los Millares culture, can be dated initially to around the interval between 5,700–5,600 and 4,500 cal BP (Sánchez-Quirante 1998). The Millares culture did not drastically deforestation, and competitive interactions as well as climate-human-vegetation feedbacks. Taking into account that southeastern Iberia has many Paleolithic and Neolithic settlements, and is also one of the zones in western Europe in which metallurgy was first practiced, and where cultural transitions are occasionally manifested as collapses, this approach is of critical importance.

NOTE

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