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Monitoring Regional Fire History Through Size-Specific Analysis of Microscopic Charcoal: The Last 600 Years in South India

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The quantitative analysis of microscopic charcoal from stratified lake, swamp or reservoir deposits can provide a record of fire history at a number of spatial scales. Recent research on charcoal particle production, dispersal and deposition indicates that fires at varying distances from a sediment source and of varying intensities will contribute particles in different size classes differentially to a deposit. Thus, analyses of regional fire history require consideration of charcoal particle sizes as well as ubiquity. Quantitative analysis of microscopic charcoal in a sediment core from a reservoir of the Vijayanagara period (*c*. AD 1300–1600) in northern Karnataka, India, indicates well-defined periods of burning which coincide with periods of open vegetation as defined by pollen analysis, and with periods of high settlement densities and intensive land use as defined by archaeological evidence. Charcoal particles in different size categories do not always co-vary in the core, reflecting differences between more local and more regional fire histories.

Keywords: SOUTH INDIA, CHARCOAL ANALYSIS, FIRE HISTORY, MICROSCOPY, LAND USE.

Introduction

An understanding of the scale and intensity of past burning is an essential prerequisite for the assessment of many reconstructions of past land use and settlement history. Major shifts in agricultural intensity or cultivation practices, for example, might be expected to leave recognizable traces in the palaeoecological as well as the archaeological record, traces which include quantitative (and qualitative) shifts in charcoal patterns. The record of microscopic charcoal, in particular, when used in conjunction with such well-developed techniques as pollen analysis, may provide important information on occupation and land use histories on a subregional and regional scale. This paper presents the results of a preliminary analysis of microscopic charcoal from a late precolonial (*c*. AD 1300) to modern (AD 1990) sediment core from southern India. Because size data were collected on individual charcoal particles, an assessment of the differential patterning of charcoal in different size classes is also possible. Archaeological, historical and pollen analytical data indicate that charcoal maxima in different particle size classes reflect significant changes in regional population density and agricultural production.

Indicators of regional burn patterns provide potentially important information on the management of natural vegetation, forest clearance, field and facility maintenance, crop burning and the scale and intensity of burning associated with craft production and domestic activities. Although such indicators represent composite patterns from a variety of sources subject to complex determinants of dispersal and deposition, regional scale burn patterns provide essential information about fire history on a scale larger than that typically reflected in archaeological charcoal studies. Regional fire histories, when combined with archaeological evidence, can contribute significantly to our understanding of past land use and occupation history.

Archaeologically focused studies of charcoal commonly concentrate on the identification of woody taxa, and on shifts in patterns of species exploitation through time. Such studies have proved to be very important in palaeoenvironmental reconstructions, in that they may contain species-specific information and, further, the larger pieces of charcoal required for taxonomic identification can often also be easily dated by radiometric methods. However, macroscopic charcoal assemblages from site contexts do not provide quantifiable information on regional fire history, reflecting instead more local patterns of site structure and deposition. In depositional contexts such as lakes, reservoirs and mires, airborne and waterborne charcoal particles, both microscopic and macroscopic, constitute a quantifiable part of the sedimentary record, as do other small particles such as pollen that are produced in great abundance and are effectively distributed (cf. Faegri, Kaland & Krzywinski, 1989).

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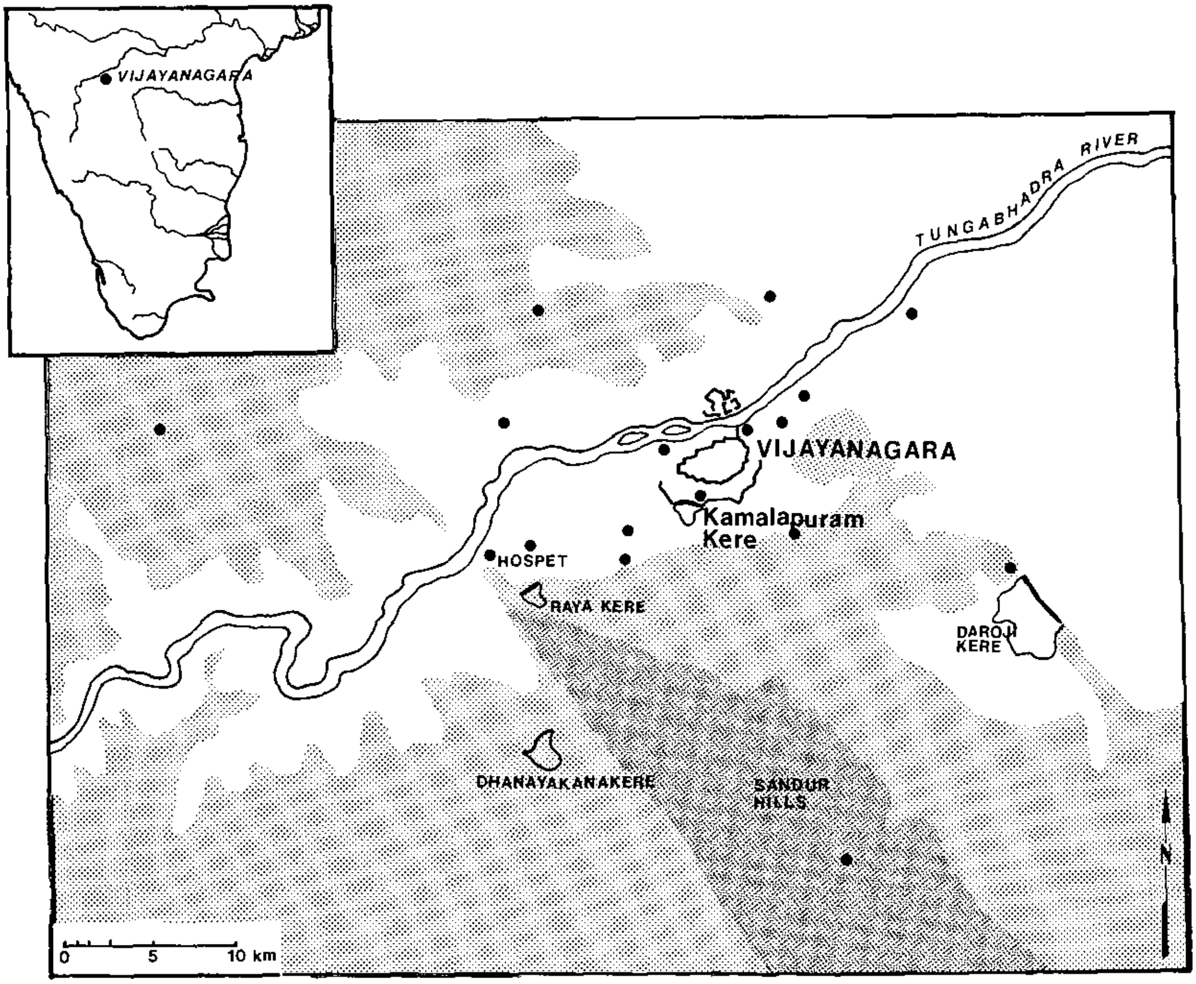

Figure 1. Location of Vijayanagara and the Kamalapuram reservoir in South India. Lighter shading represents land over 500 m, darker shading land over 700 m. Black circles indicate the location of Vijayanagara-period settlements and forts. The Kamalapuram reservoir has been integrated into an outer city wall.

South Indian Agriculture and Land Use: Archaeological and Historical Evidence

The semi-arid interior of South India (Figure 1) has supported agriculturalists practising a wide range of production strategies for several thousands of years. In the southern Deccan, cattle still provide the primary source of traction for plough agriculture, which ranges from commercial production of irrigated sugar cane, paddy rice, vegetables and fruits to subsistence production of rainfed millets, sorghum and oilseeds. Prior to the advent of electric pumps, all irrigation was dependent upon the flow of perennial and seasonal streams and rivers. Water and soil control features are of great importance in the agricultural strategies of this region, where rainfall is strongly seasonal. The low (*c*. 500 mm mean annual rainfall) and temporally variable precipitation is only sufficient for the production of the "dry" grain staples of sorghum and millets. The landscape is now dominated by cultivated fields and by a degraded thorn scrub of the *Albizzia amara-Acacia* series (Gaussen *et al*., 1966).

Archaeological and historical data allow us to trace the settlement history of the area now included in the Bellary and Raichur Districts of the state of Karnataka. The earliest agriculture appears to have been fairly small-scale and was combined with stock raising. However, by about 1000 BC, small reservoirs ("tanks") which may have been used for agriculture are known to have existed (Allchin & Allchin, 1982: 123, 292). Although several settlement concentrations are known, population densities in this area remained fairly low throughout the early 1st millennium AD (Morrison, 1992), but expanded rapidly with the establishment of the city of Vijayanagara in the early 14th century AD (Stein, 1980, 1989; Fritz, Michell & Nagaraja Rao, 1984). The city grew as the result of large scale in-migration, and by its peak, in the early 16th century, it contained a population of 300,000–500,000 people (Stein, 1989). After a military defeat in 1565 and the abandonment of the city shortly afterwards, regional population densities again dropped until the construction of a large dam in the 1940s and 1950s. Thus, in the long settlement history of Bellary

Table 1. Chronological and agricultural periods in the area around the Kamalapuram reservoir

Period	Dates AD (approximate)	Agricultural facilities	Agricultural production	Settlements larger than 20,000
Recent/Post-Independence	1940–present (Independence 1947)	—extensive network of modern canals —expansion of electric pump and well sets —Vijayanagara canals continue in use —a small portion of Vijayanagara reservoirs continue in use —minor use of dry agricultural facilities such as terraces and gravel mulched fields	—large scale commercial production of irrigated sugar cane —other irrigated crops include paddy rice, bananas and vegetables —subsistence production of dry farmed sorghum and millets —small scale commercial production of dry farmed oilseeds	Hospet
Colonial	1700–1940	—Vijayanagara canals continue in use —a small portion of Vijayanagara reservoirs continue in use, some are renovated —moderate use of dry agricultural facilities such as terraces and gravel mulched fields	—medium scale production of commercial irrigated sugar cane, indigo, rice, and vegetables —subsistence production of dry farmed sorghum and millets	Hospet
Post-Vijayanagara	1600–1700	—Vijayanagara canals continue in use —a small portion of Vijayanagara reservoirs continue in use —moderate use of dry agricultural facilities such as terraces and gravel mulched fields	—medium scale production of irrigated rice and vegetables —subsistence production of dry farmed sorghum and millets	None (?)
Vijayanagara	late 1500–1600 middle 1400–1500 early 1300–1400	—canal system constructed —expansion of reservoir irrigation, hundreds of reservoirs constructed —extensive use of dry agricultural facilities such as terraces and gravel mulched fields	—large scale commercial production of irrigated rice, vegetables, tree crops —subsistence and commercial production of dry farmed sorghum and millets	Vijayanagara
Pre-Vijayanagara	1000–1300	—one small 12th century canal —some reservoir irrigation, probably small scale —minimal to moderate use of dry agricultural facilities such as terraces and gravel mulched fields	—subsistence production of irrigated rice, vegetables, tree crops —subsistence production of dry farmed sorghum and millets	None

and Raichur Districts there have been two major periods of settlement and agricultural intensity; the Vijayanagara (*c.* AD 1300–1600) and the recent (post AD 1940) periods.

During the occupation of the city of Vijayanagara, the Tungabhadra river provided a source of water for an extensive canal network serving the city and its hinterland. Reservoirs also continued to be important for agriculture and domestic water supply, and there was a rapid expansion in reservoir construction in the 14th and again in the 16th century (Morrison, 1992). Pollen and charcoal analyses discussed here derive from a sediment core from the Kamalapuram *Kere*, or reservoir. This reservoir was constructed in the early 14th century, and has continued in use until the present (Table 1). Watered by both a river-fed canal and seasonal runoff, the Kamalapuram Kere contains water year-round. The dam of the reservoir is approximately 2 km long and the maximal extent of water in the rainy season is *c.* 120 ha. The small walled settlement of Kamalapuram is located on the north-eastern edge of the reservoir; this Early Vijayanagara settlement was later engulfed by the expanding city. The irrigated produce of the reservoir would have been important to urban dwellers and Kamalapuram residents alike. Kamalapuram survives as a small village, and the area beneath the reservoir is now almost exclusively devoted to the production of sugar cane.

Because the occupational and agricultural history of the region around the Kamalapuram kere is relatively well-known, pollen and charcoal records from this reservoir provide an important opportunity to compare the patterns of fire history and vegetation change derived from palaeoecological studies with the archaeological and historical records.

Fire in Context: Land Use and Burning in South India

Fire plays an important role in the contemporary agricultural practices of South India. The stubble remaining in sugar cane fields after harvesting is regularly burned off, and the ashes are either ploughed back into the soil or carried off to other areas and distributed on the fields. Because of the long maturation period of sugar cane (11 months) and its reliance on irrigation water, planting, weeding, harvesting and burning of cane fields occur more or less simultaneously across large areas in a patchwork fashion. The patches in this mosaic are larger than a single field, however, and generally consist of several neighbouring fields served by a single water source. Although the need to coordinate water flow to fields requires some cooperation, this does not take place on a supra-regional scale. While individual cane fires are usually small, burning less than 10 ha at a time, fires are frequent wherever it is possible to grow sugar cane. Fire is also employed to control weed and shrub growth along field borders, roadways, and near settlements. Fire may have been an important tool for forest clearance, although the contemporary landscape has been almost completely deforested and clearance of vegetation is not a serious problem. At present, no crop other than sugar cane is regularly burned. There is, however, no evidence that the present pattern of commercial sugar cane production also obtained during the Vijayanagara period. Thus, Vijayanagara agricultural burning in the intensively farmed lowlands immediately surrounding the city may relate primarily to field clearance and maintenance.

Undoubtedly, the most well-known role of fire in agricultural production is in "slash and burn" or swidden agriculture (Iverson, 1941; Stewart, 1956; Mellars, 1976; Jacobi, Tallis & Mellars, 1976; Simmons & Tooley, 1981). Swidden agriculture was widely practised in India and is well documented in the literature of the Colonial period from the 17th to early 20th centuries. Chola inscriptions of the 11th century from the southern state of Tamil Nadu refer to swidden plots (*kummari*) of "forest people" (Stein, 1980: 26). Stein (1980: 75–76) discusses the tensions between lowland peasants and the non-peasant inhabitants of the hills and dry forests, a tension well documented into the 16th century. In the Vijayanagara region, swidden cultivation could have been supported on the slopes of the Sandur Hills (Figure 1). There is, at present, no unequivocal archaeological or historical evidence of this agricultural regime during the Vijayanagara period.

Finally, the non-agricultural use of fire was also significant. Both wood and dung would have been burned in domestic contexts. Some forms of craft production also employed fire extensively, either in kilns or open burns. Charcoal, which was produced locally, was often used as the fuel in ceramic, lime and metal production. Thus, one must guard against assuming that the fossil record of fire relates solely to agricultural burning (cf. Patterson, Edwards & Maguire, 1987: 4).

Proxy Measures of Fire

Given that information on fire history may be of interest in reconstructing Vijayanagara land use, how to best investigate the fossil record of that history? Archaeological investigations in the central urban area of elite structures have revealed evidence of fires which destroyed numerous buildings (Devaraj, 1991). Investigators have attributed this evidence to the burning and sacking of the city following the battle of Talikota in AD 1565 (Balasubramanya, pers. comm.). Other, more localized ash levels are evident in excavated sections, but these do not inform on regional scale fire history. As with pollen, the action of lakes (or reservoirs) as regional or even supraregional sediment traps provides the best possibility for reconstructing Vijayanagara fire history.

The most common measures of fire history from lake sediments include microscopic and macroscopic charcoal; pollen assemblages and accumulation rates; chemical digestion of elemental carbon; geochemistry of lake sediments; and sedimentological measures (Waddington, 1969; Swain, 1973; R. L. Clark, 1982; Tolonen, 1986; Patterson, Edwards & Maguire, 1987; J. S. Clark, 1988*a*,*b*; MacDonald *et al.*, 1991). A growing literature, mostly concerned with the reconstruction of boreal forest fire histories, discusses each of these methods in detail. Several recent studies have compared the efficacy of different methods using documentary history and fire scars on trees as controls (e.g. MacDonald *et al.*, 1991; J. S. Clark, 1988*b*). MacDonald and others (1991: 65) found little consistency between proxy measures of fire history and documented fires. Pollen records provide some indication of vegetation succession, but present a limited picture of post fire recovery. The results of carbon digestion-combustion techniques are not consistent with microscopic and macroscopic charcoal patterns and may be affected by very small charcoal particles, which are not counted in visual studies, and by changes in sediment types (Winkler, 1985: 319). Visual studies of charcoal, both microscopic and macroscopic, provide fairly good indicators of fire history in a region up to 120 km from the sediment source (MacDonald *et al.*, 1991: 62, figure 8). The following discussion is limited to visual studies of charcoal from lake sediments.

From Fire to Lake: Production, Dispersal and Deposition

Fires may vary a great deal in the amount of charcoal they produce and in the extent of dispersal of that charcoal. Relevant variables include the type of fuel, the size of the fire, and weather conditions. It is often assumed that larger fragments of charcoal are found nearer the source of the fire and smaller fragments farther away. Patterson, Edwards & Maguire (1987: 5–7) present a simple zonal model of the effect of distance on the quantity and size of charcoal fragments deposited after a fire. They tentatively suggest the deposition of a set of concentric rings of charcoal size classes in the absence of wind, with multiple sources causing overlapping patterns.

In practice, however, the dynamics of charcoal transport are much more complex. In an important study of the physics of charcoal transport, J. S. Clark (1988*a*) has shown that wind has fundamentally different effects on different size classes of charcoal. Clark (1988*a*: 69) identifies three major forms of wind transport: (1) suspension; (2) saltation, in which moving particles strike other particles, lifting them from the surface and moving them downwind; and (3) traction, or movement along the surface. Smaller particles are more subject to suspension, intermediate size classes are moved by saltation, and larger particles are moved by traction. Clark notes:

> mineral particles approximately 100 μm in size are most easily entrained by wind; cohesive forces and aerodynamic properties of smaller particles make them difficult to pick up, and larger particles are too massive. Although difficult to entrain, smaller particles tend to be transported long distances, if they are suspended. Source areas for dust fallout at a given point may be subcontinental or even global, depending on particle size and atmospheric conditions. 'Coarse dust' (5–50 μm) transported by dust storms is generally deposited within 100 km of the source. 'Fine dust' (2–10 μm) is frequently transported hundreds to thousands of kilometres, remaining in suspension until washed out by precipitation. (Clark, 1988*a*: 69)

Charcoal particles have a much lower density than mineral particles, so that charcoal fragments in the 130–150 μm range are the most readily lifted by the wind (Clark, 1988*a*). Most charcoal fragments examined microscopically fall well below this size category and thus must be considered representative of burning over a large spatial scale. Clark (1988*b*) describes a method for examining macroscopic charcoal from lake sediments using thin-sections of sediment cores. This method is, however, appropriate only for annually laminated or varied deposits. Such deposits are rare, especially in the tropics. Macroscopic analysis of charcoal from lakes and reservoirs holds great promise for studies of fire history (cf. Hutchinson & Goulden, 1966; Byrne, Michaelson & Soutar, 1977, 1979), and would be complementary to the broad spatial perspective afforded by microscopic charcoal studies.

The second major contribution made by J. S. Clark's (1988*a*) study is the identification of a finite "skip distance" between the point where most particles of a given size leave the ground and where they settle back down. Indrafts and convection in the rising hot air of a fire create turbulence in which particles are suspended, and the specific skip distance depends on the height of the convection column created by a particular fire. In general, the higher the convection column the larger the skip distance and the larger the particle size, the smaller the skip distance. Clark (1988*a*) fails to stress, however, that this skip is applicable only for airborne particles. Even for easily entrained smaller particles, some proportion is left *in situ* in the burn location. Further, his model is based on wildfires, which may differ significantly from small, controlled burns in several ways, including type of fuel and height of the smoke plume (Komarek, Komarek & Carlysle, 1973; Patterson, Edwards & Maguire, 1987). Komarek *et al.* (1973: 2) point out that particulates from low and moderate temperature fires tend to be larger and more varied in size than those from more intense fires, so variation in both fire type and distance will be significant. Most fire history studies attempt to find fossil evidence for individual large forest fires, events of high intensity, short duration, and variable periodicity (see J. S. Clark, 1988*a*, for a discussion of fire periodicity and sampling intervals). Many of these analyses have failed to isolate individual fires. However, the overall importance of fire during different periods is just the sort of broad pattern likely to be isolated in charcoal studies.

Charcoal size categories must be carefully considered in light of the recent scholarship on the dynamics of charcoal transport. Different size classes do not always co-vary (MacDonald *et al.*, 1991: 61, table 2), and size categories may have to be individually studied and interpreted.

Clark's (1988*a*,*b*) studies focus exclusively on air transport of charcoal, and he asserts that air transport is the most important mechanism of charcoal deposition in lakes, at least for areas with uncompacted forest soils. Swain (1973: 391) suggests that slope wash of charcoal into lakes may be quite important even in forested areas (see also Cwynar, 1978; Patterson, Edwards & Maguire, 1987). Fires themselves may increase surface runoff and erosion (Tsukada & Deevey, 1967; Swain, 1973; Cwynar, 1978). In either case, it is clear that water-assisted movement of soil must be considered in the case of the Kamalapuram Kere, where no forest cover exists, rainfall is highly seasonal, erosion severe, and soils are compacted (cf. Peck, 1973; Bonny, 1976). Thus, fires in the runoff catchment to the south of the reservoir are expected to contribute disproportionately to the Kamalapuram charcoal record, which in any case reflects a regional scale pattern of both pollen and charcoal.

Charcoal from the Vijayanagara Region: Methods of Analysis

Charcoal analysis from the Kamalapuram core was carried out using the same preparations employed for

Table 2. Charcoal in 1KP: level, number of charcoal particles, maximum, mean and S.D. *of particle area and length*

Level (cm)	*N*	Maximum area (μm^2)	Mean area (μm^2)	S.D. (area)	Maximum length (μm)	Mean length (μm)	S.D. (length)
0	19	2361·5	699·4	581·9	401·7	69·3	89·4
8	101	15,372·4	3005·6	2696·5	234·2	80·4	41·6
10	77	14,375·6	2875·1	3226·0	402·1	91·4	77·6
12	69	6853·7	991·0	1374·1	402·1	89·6	76·7
14	47	5058·4	880·4	1013·9	198·2	43·9	29·5
16	443	5952·0	612·2	581·6	144·1	35·1	16·8
18	213	3574·4	536·9	470·6	103·4	32·6	14·5
20	67	3767·7	824·9	880·5	482·9	69·1	93·2
22	30	1132·4	297·9	187·7	46·5	24·7	7·5
24	211	4613·0	473·8	542·7	431·0	38·8	38·6
26	65	8114·9	681·4	1160·3	166·7	38·7	27·3
28	43	5283·8	710·4	889·6	112·8	41·1	21·6
30	43	1800·6	552·2	427·7	229·2	43·3	34·1
32	144	5884·9	521·6	704·6	175·4	36·0	23·6
34	49	2906·2	660·0	596·6	101·6	40·3	16·4
36	38	1084·1	456·5	263·8	58·2	34·5	11·1
38	164	9263·5	731·2	1333·4	531·5	46·4	68·4
40	69	6711·5	638·6	986·3	118·9	38·4	21·3
42	10	3222·9	682·7	919·2	114·2	39·7	27·5
44	24	2756·0	446·3	519·0	132·2	35·3	22·8
46	50	1663·8	466·0	361·9	93·9	33·8	16·4
48	84	5643·4	652·2	855·2	173·4	43·3	29·3
50	253	2699·6	454·7	387·9	107·6	35·2	16·7
52	235	4723·0	592·6	667·7	158·0	38·2	21·7
54	179	9384·2	645·7	992·3	273·0	42·3	35·0
56	41	2954·5	690·4	676·1	143·8	42·8	25·4

pollen analysis. Although charcoal is not normally destroyed in the process of pollen extraction, there is some indication that samples treated with nitric acid contain a significantly smaller proportion of charcoal than untreated samples. Nevertheless, the relative proportions of charcoal in each sample appear to be stable even with nitric treatment (Singh, Kershaw & Clark, 1981; Patterson, Edwards & Maguire, 1987). Nitric acid treatments, necessary for pollen extraction in the Kamalapuram case, do, however, have the benefit of removing opaque spherules (iron oxide particles which can be confused with charcoal from plant tissues: Waddington, 1969; Clark & Patterson, 1984; Renberg & Wilk, 1985; Winkler, 1985; Patterson, Edwards & Maguire, 1987), thus eliminating them as a source of error in this analysis.

Most studies of microscopic charcoal have been made by physical counting of the number of charcoal particles or by measuring their areas by point counts. These methods are well documented (Waddington, 1969; Clark, 1982, Patterson, Edwards & Maguire, 1987). Charcoal counts of the Kamalapuram Kere slides, however, were made using an automated system described in detail by Horn, Horn & Byrne (1992).

Five hundred randomly selected fields of view were analysed for each slide. Views were selected from within a 12 × 12 mm area in the centre of the coverslip (22 × 22 mm). Only particles with a minimum linear dimension of 15 μm and a minimum area of 156 μm^2 were counted. Images on the slides were analysed by the computer as containing grey shade values between 0 and 63, where 0 is black and 63 is white. All pixels in a particle image were analysed individually and mean grey shade value and standard deviations were calculated. Only objects having a mean grey shade value of 3·5 or less and a standard deviation of 5 or less were considered. Thus, particles had to be quite dark and uniformly dark in order to be counted as charcoal. Periodic visual monitoring of the procedure provided a high level of agreement between the occurrence of charcoal and its fit with these criteria. Magnification was set at 160 × . MacDonald and others (1991) also used an automated counting system, but they counted every particle larger than 10 μm long and 10 μm wide. Because of the high frequency of long, thin charcoal particles in the Kamalapuram sample, these parameters would have excluded a great deal of charcoal. As it is, charcoal counts are probably somewhat low due to bleeding of light onto the edges of the particles, which leads to higher mean grey shade values. More problematic, perhaps, is the computer's inability to distinguish between superimposed objects. Where small pieces of charcoal lay atop clumps of cellular material, the resultant form was counted as one object, generally with a high grey value standard deviation. Such charcoal was not counted by the procedure. For this reason, preparations were made as thin as possible. Special scans of the charcoal slides were made in order to count *Lycopodium* spores added as a "spike" to the sample (cf. Stockmarr, 1971). These values were used to calibrate the charcoal counts, which are indicated in Table 2.

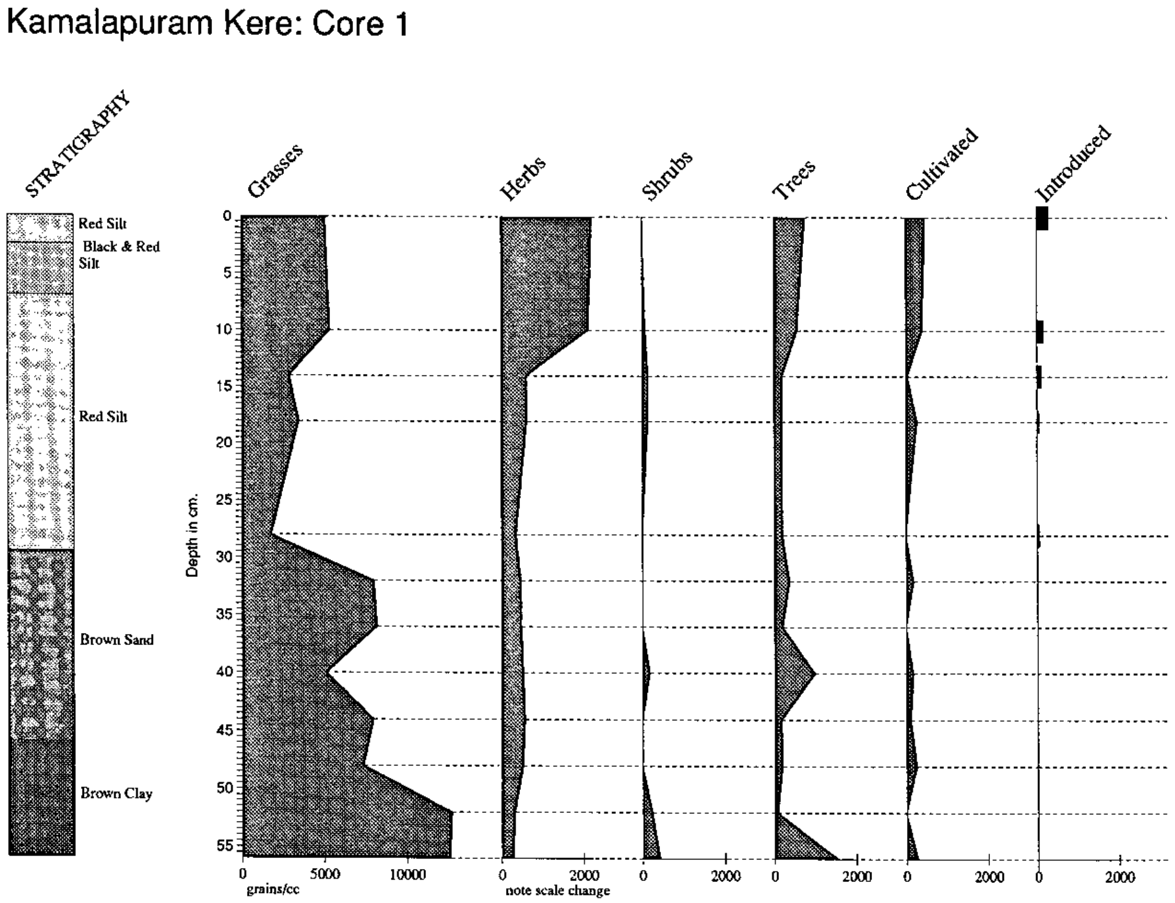

Figure 2. Composite pollen concentration diagram from Kamalapuram reservoir. The base of the core dates to the early 14th century. The first occurrence of introduced species (black bars) is at or after AD 1500, the second occurrence dates to the late 1700s. The category "grasses" includes both cultivated and non-cultivated grasses; "cultivated" includes all known non-grass cultivars.

Analysis Results: Vegetation Patterns

The charcoal record from the Kamalapuram core can be compared with a generalized pollen diagram (Figure 2; for more detail see Morrison, 1992, 1994) in order to place the charcoal patterns in vegetational context. The base of the pollen record dates to the beginning of the 14th century, or the Early Vijayanagara period (Table 1), a time when the city was experiencing rapid population growth. As noted, archaeological and historical data also suggest that this was a period of intensive agriculture and expanding settlement in the region.

Interpretations of the pollen record are hampered by the imprecision of dates from the core and by the lack of detailed studies relating modern vegetation in dry interior South India to the pollen record. Nevertheless, several strong patterns have emerged. These patterns include very high values for grass pollen at the very beginning of the record and a concurrent sharp decrease in the pollen of trees and shrubs. The quantities of tree and shrub pollen were reduced significantly in what is suggested to be the Middle or Late Vijayanagara period, only to undergo a rebound, probably at the end of the Vijayanagara period. This portion of the core reflects a very open landscape, and one which archaeological and historical data also suggest was dominated by cultivated fields (Morrison, 1992). In the post-Vijayanagara period, the reservoir became choked with aquatic vegetation (not shown in Figure 2). About the time the reservoir was cleared of swampy vegetation, the first introduced New World species appear in the record, and the concentrations of pollen also decrease, which may reflect more rapid sedimentation. At 24 cm, the reservoir may have dried out completely for a time (Morrison, 1994).

Toward the top of the record, the later Colonial or the Post-Independence periods, agricultural production seems to be of renewed importance, but this agricultural landscape appears different from the Vijayanagara period landscape in several important respects. First of all, the grass-dominated Vijayanagara record is not duplicated in the record of modern, commercial agriculture. Instead, herbaceous plants appear much more important, and specifically, Compositae (with "low spine" pollen grains) come to constitute

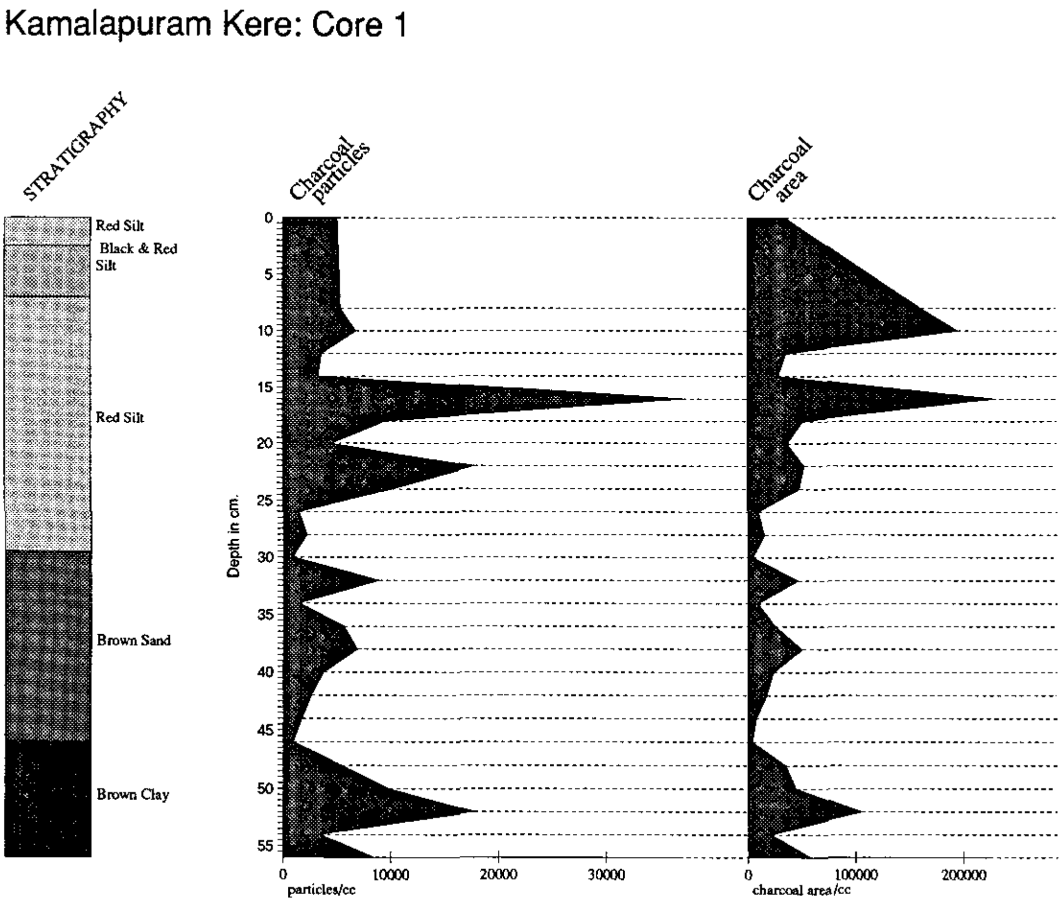

Figure 3. Overall charcoal concentration diagram from Kamalapuram reservoir. The curve on the left shows the total number of charcoal particles (larger than minimum size specifications, see text) per cc of sample. The curve on the right shows the total area (μm^2) of charcoal per cc of sample.

a significant proportion of the pollen flora. Coconut pollen, reflected in the "cultivated" category, also appears in greater quantities. While coconuts did appear in the Vijayanagara period record, their numerical importance in more recent sediments is striking, and is consistent with their current value as commercial crops. Thus, the pollen record of Vijayanagara agriculture shows a pattern of intensive land use and a landscape significantly altered by forest clearance, already established by the mid-14th century. These data accord well with the archaeological evidence.

Analysis Results: Patterns of Burning

Figure 3 shows the results of the charcoal analysis in terms of the number of charcoal particles and the total area of charcoal. The differences between the two representations relate primarily to differences in particle size distributions by depth, as discussed in the following section.

Beginning at the base of the core, a small charcoal peak can be seen in the lowest level, followed by a decline and then a major peak at about 52 cm. At this same level a decline in trees and shrubs and an increase in grasses was also recorded. Thus, although some of this charcoal may be attributable to domestic burning in the Vijayanagara period, it is likely that it also relates, at least in part, to land use practices which led to the creation of a more open, less wooded landscape. Charcoal peaks in this densely settled region undoubtedly relate to periods of intensification of human burning activities, and many of those were probably related to agricultural operations. Following the marked charcoal peak at 52 cm, the amount of charcoal in the sample drops off, and then rises again into two minor peaks between 46 and 26 cm. Above this point, the difference between the count data and the area data become much more pronounced. At 8 and 10 cm the mean area of charcoal in the sample (Table 2) rises sharply in response to an increase in the size of the largest charcoal particles. In general, the pattern that emerges from the charcoal analysis is similar to that of grasses and herbaceous vegetation, with initially high values in the lower portions of the core, followed by generally lower values in the middle part of the core and a resurgence of high values in the

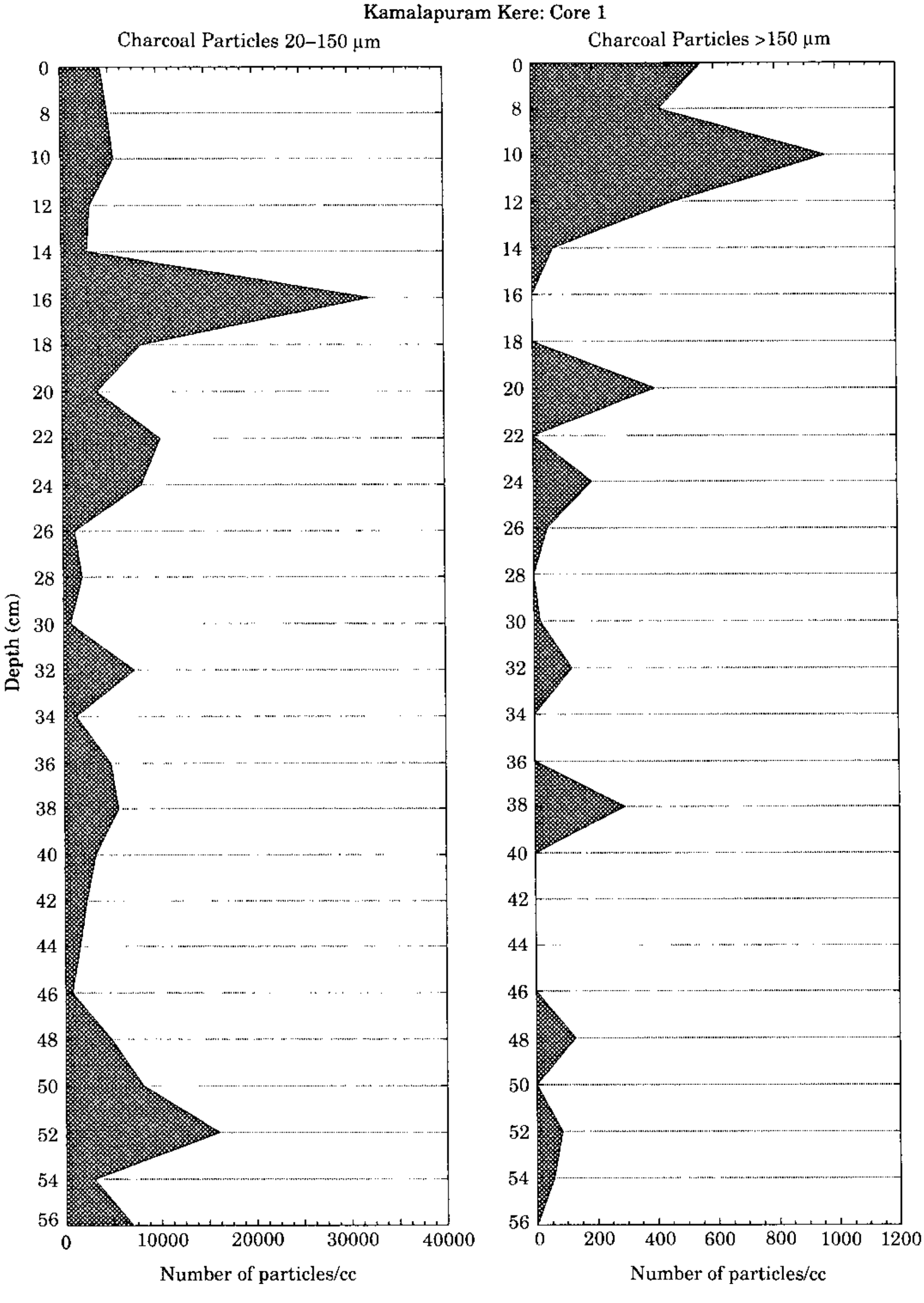

Figure 4. Charcoal particle concentrations by size from the Kamalapuram reservoir. Particles longer than 150 μm are represented on the right. Note scale change between the two diagrams.

upper portion of the core. Thus, charcoal patterns correspond with the patterns of open, transformed vegetation. Both burning and open vegetation are indicated in the Vijayanagara period and again in the Colonial to recent periods, when agricultural production was the most intensive. In the period during which the reservoir sediments contained a large amount of aquatic pollen, the charcoal record reaches its minimum, with both measures suggesting a cessation of maintenance activities in and around the facility.

Following Clark's (1988*a*) analysis of particle movement in different size classes, the Kamalapuram charcoal data may be disaggregated into two size classes. The first, particles 20–150 μm long, are of a size that is easily entrained and subject to suspension and long-distance transport. The second, particles greater than 150 μm long (none are longer than 600 μm), are not easily suspended and move primarily via saltation. The record of each size class (Figure 4) is distinctive, and the patterns do not always co-vary. The record of small particles mirrors that of the overall frequency of particles (Figure 3), because of the numerical predominance of this size class in the sample. This regional-scale record shows a maximum near the base of the core, in the period associated with the intensive settlement and agriculture of the Vijayanagara era. In the middle portion of the core, when settlement in the region was sparse, only minor peaks occur, and the largest concentration of charcoal (16 cm below surface) falls sometime during the Colonial or post-Colonial era. This peak occurs during a period of very low overall pollen concentration but before some of the vegetation changes associated with the uppermost levels of the core, and may be partly derived from slope transport of charcoal. The record of small particles represents a composite view of burning over a very large spatial scale, with burning in the area immediately around the reservoir under-represented (cf. Clark, 1988*a*: 67). On this scale, local variability is minimized, and the overall importance of the Vijayanagara and the Colonial periods in the fire history of South India can be seen. The modern contribution of microscopic charcoal in this size category is, in contrast, rather modest.

More local-scale burning, represented by the larger particles, follows a rather different pattern. Most strikingly, the particle maximum above 12 cm deviates significantly from the pattern of smaller particles. This peak appears to reflect the contemporary focus on sugar cane production in the area, and the practice of cane burning in the region around the reservoir. Sugar cane requires large amounts of water, and the study area is merely a small pocket of irrigated land in a larger semi-arid region devoted to dry crops and containing stunted scrub forests. Thus, the local importance of cane burning is not reflected in the regional-scale diagram. Furthermore, the larger particles appear to be a contemporary phenomenon, suggesting that if they do reflect cane burning, this practice, and the large-scale production of sugar-cane close to the Kamalapuram reservoir, was not part of pre-Colonial agriculture.

Discussion

Archaeological investigations of prehistoric land use typically recognize the importance of fire, both natural and anthropogenic, in forest clearance, field maintenance, agronomic practices, domestic burning, craft production, and the destruction of settlements. However, little systematic effort to quantify the effects of such fires has been made, in spite of the general recognition of the value of charcoal analysis in archaeological research.

The depositional contexts and sizes of charcoal particles are closely related to their potential as indicators of past land use on a regional scale. Macroscopic charcoal from either archaeological sites or lake sediments provides a different range of information than does microscopic charcoal. Very small particles of charcoal (cf. Clark, 1988*a*) may be suspended aloft and transported long distances, so that the fallout of particles in this size class represents a larger/longer-scale spatial and temporal view than that of larger sizes. Such a measure cannot resolve individual fires nor does it necessarily reflect fire history on a "site" level scale. Instead, microscopic charcoal studies may provide us with broad regional patterns of the intensity of burning, patterns which reflect land use, settlement and natural fires on a scale more commensurate with regional archaeological studies. However, in order to approach these regional patterns of fire history, it will be necessary to obtain specific information on charcoal particle sizes as well as ubiquity, and to incorporate the analysis of charcoal from non-site depositional contexts such as lakes and bogs into routine archaeological research. In the preliminary case study presented, charcoal data accorded well with archaeological, historical and pollen analytical patterns, and have provided new data on the disparities between fire histories at a number of scales.

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