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Geoarchaeology of the Danilo Bitinj and Pokrovnik Sites, Dalmatia, Croatia

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GEOARCHAEOLOGY OF THE DANILO BITINJ AND POKROVNIK SITES,

DALMATIA, CROATIA

by

Cynthia M. Fadem

A dissertation presented to the
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ABSTRACT OF THE DISSERTATION

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Associate Professor Jennifer R. Smith, Chairperson

This dissertation examines the paleoecology of earliest European agriculture via geological and geochemical analysis of two Neolithic settlements in central Dalmatia, Croatia. The Early Farming in Dalmatia Project, of which this geoarchaeological study is a part, is a case study in the adoption and environmental impact of agricultural technology. Dalmatia served to transmit agriculture from the domestication centers of the Middle East to mainland Europe. The record of neolithization in this region is incomplete - biased toward caves, upland storage locales. The landscape setting of the foraging-to-farming behavioral evolution is missing, even as Neolithic transition research turns to more complex human behavioral ecological models. The Danilo Bitinj and Pokrovnik sites are open, lowland sites enabling detailed study of the early farming landscape. Pedology and geomorphology combine in the reconstruction of Neolithic paleoenvironments and the investigation of conditions affecting the preservation of archaeological remains. This site-specific geoarchaeology provides a dataset critical to the archaeological interpretation of and behavioral model-building for this momentous cultural change.

The dissertation’s main objectives are characterizing dominant site materials (soils and ceramics) and their variation, and understanding Neolithic site choice in terms of potential differential productivity. Three summers were spent mapping site areas, conducting in-field geomorphology and pedology, and sampling natural and cultural materials. Laboratory analyses describing the chemistry and mineralogy of site soils and ceramics include pH, electric conductivity, organic carbon content, stable isotope chemistry, and X-ray diffraction. Results indicate sodic (high pH, low conductivity) soil conditions in which Neolithic artifacts have resided for over 7000 calendar years. Both Danilo Bitinj and Pokrovnik subsoils contain quartz and potassium feldspar, revealing a non-karst, possibly volcanic origin. The valley-and-range topography of the central Dalmatian polje-karst field coupled with this fertile, fine-grained fill most likely served to enhance the agricultural settlement and productivity of this region. Site subsoil and ceramic mineralogies are similar, revealing a potential common source for these materials. The primary contributions of this dissertation are a differential regional productivity model explaining Neolithic settlement strategy, a comparative characterization demonstrating similarity between site soils and ceramics, and a ceramic typology enabling archaeological analysis of site assemblages.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1. *Introduction*

Researchers have traditionally characterized Southeast Europe as a bridge between Near East domestication and European farming, with technology-transmission methods as their primary focus (Tringham, 2000). Despite a long history of investigation, the process, character, and diversity of Southeastern European 'neolithization' remain largely unknown – perhaps due to the scale at which archaeologists have historically viewed this transition, and to the bias in the record toward sites that would have been unsuitable for farming. Tringham (2000) and Zvelebil and Lillie (2000) suggest this behavioural transformation is evidenced at a smaller scale and in far greater complexity than previously envisioned. Their perspective presages a paradigmatic shift from the currently dominant model of Southeast European neolithization via migration of Near East farmers to one integrating local Mesolithic foragers (Tringham, 2000; Harris, 1996). Such a shift requires re-examination of the archaeological record with an eye to greater complexity and subtlety of behavioural mechanisms.

The Early Farming in Dalmatia Project (EFDP), under the direction of Andrew Moore (Rochester Institute of Technology) and Marko Menđušić (Šibenik Museum & Ministry of Cultural Heritage, Croatia), aims to satisfy this need through site-specific geoarchaeological, paleobotanical, zooarchaeological, and artifactual analysis at the Danilo Bitinj and Pokrovnik sites (Figure 1.1); inter-site comparison of these datasets; and regional paleoclimatology. Drs. Jennifer Smith and Robert Giegengack are leading regional paleoclimatological efforts, for which reconnaissance was conducted at Krka National Park in the summers of 2005 and 2006. My focus is on site-specific geoarchaeology, analysis of the site matrix and artifacts. The excavations at Danilo Bitinj and Pokrovnik provide a unique opportunity for re-examination and comparison of Neolithic expression – and expression of the foraging-to-farming behavioral evolution – at two open lowland sites in central Dalmatia. Korošec (1964, 1958) first excavated at Danilo Bitinj in 1953; and Brusić (in press, 1980), at Pokrovnik in 1979 (Chapman and Müller, 1990).These sites

Figure 1.1. Map of Croatia showing site locations.

have been occupied and farmed for at least the last 7000 calendar years (Moore et al., 2007a, 2007b). Prehistoric cultural deposits contain Neolithic phase ceramic and lithic artifacts, and floral and faunal remains.

Background & Setting

Geology. The Danilo Bitinj site is located in the fertile plain of Danilo Polje, an elongate, flat-bottomed karstic valley whose long axis aligns northwest-southeast with the Dinaric portion of the Alpine orogeny (Figure 1.2). Danilo Polje is part of the Dalmatian polje-karst field (White, 1988), thought to have been morphologically stable since their formation during the Pliocene-Pleistocene transition (~2.6 Ma) (Klär, 1957; Melik, 1954; Roglić, 1940). Despite sharing certain surface characteristics (flat plain, lens shape, and steep sides), these karstic valleys can vary in structure and age (Gams, 2005, 1978; Nicod, 2003; White, 1988; Gospodarič, 1981b; Wenzens, 1977). The fact that polje morphogenesis is not straightforward poses unique problems for establishing archaeological context. While not in a polje proper, the Pokrovnik site is also located in the polje-karst region – ~10 km further inland and in closer proximity to tributaries of the Krka River (Rijeka Krka) than the Danilo Bitinj site (Figure 1.3). Both sites are located directly southeast of the Krka River between the cities of Šibenik and Drniš.

In the area surrounding and between the Danilo Bitinj and Pokrovnik sites, bedrock is composed of carbonates (predominantly shallow water) alternating in NW-SE trending outcrops: Cretaceous limestones and dolomites, Eocene foraminiferous limestones, and Eocene/Oligocene conglomerates and marls (Mikes et al., 2008; Perica et al., 2005; Krizmanić and Prlj-Šimić, 2002). The densities of these rocks and their differential responses to tectonic forces control the region's underlying structural fabric (Dragičević et al., 1999). Dalmatia is part of the Alpine orogen; its Cretaceous and Eocene carbonates form the Outer Dinaric Alps (Mikes et al., 2008). Regional structural history is complex, with the Adriatic micro-plate indenting the European plate to the north and bounding the retroarc (intramontane) Pannonian Basin of Hungary to the east.

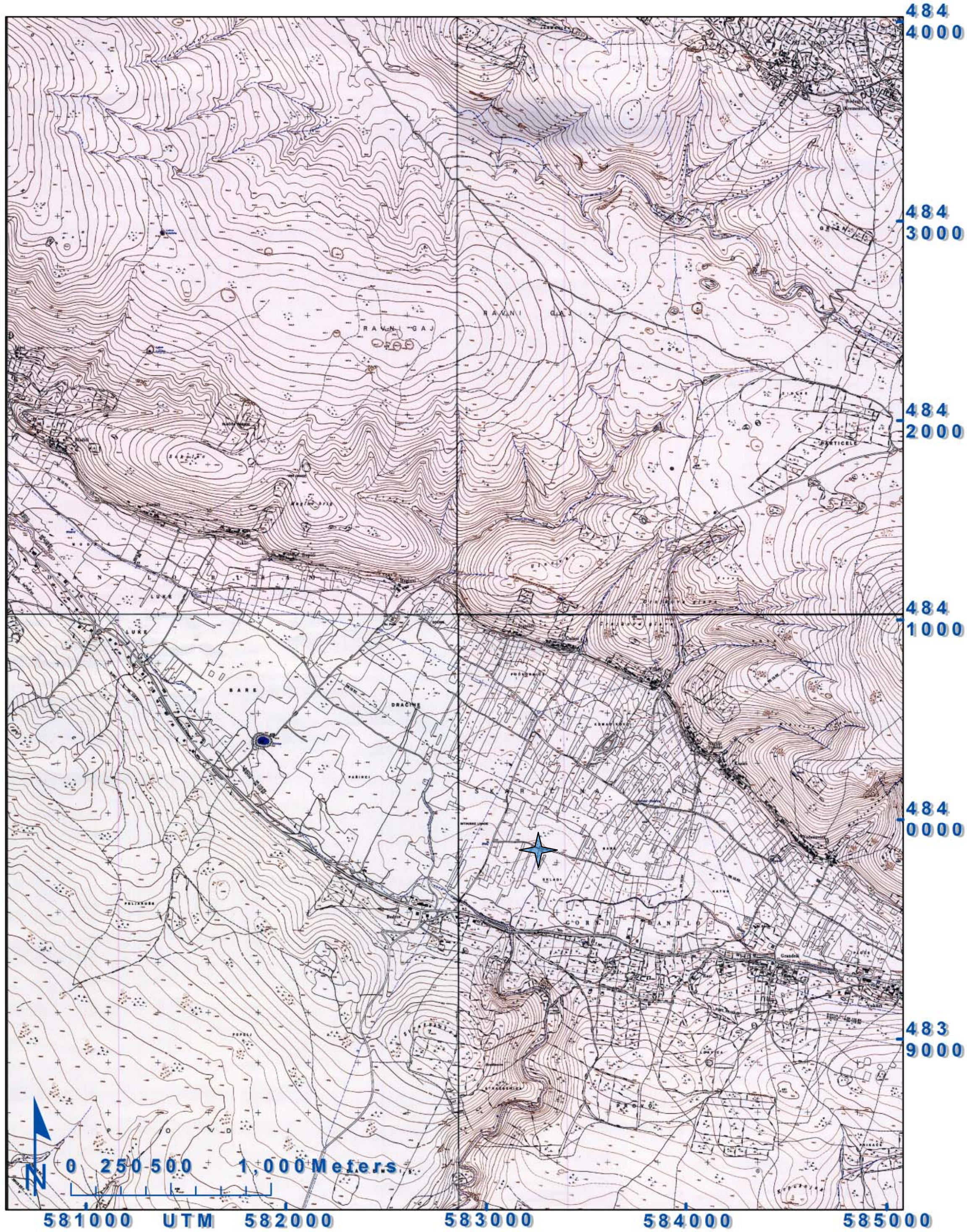

Figure 1.2. Topographic map of the Danilo area. Cross marks the location of the Danilo Bitinj site. Modified from Zavod za izmjeru zemljišta (1996a, 1996b, 1996c, 1996d).

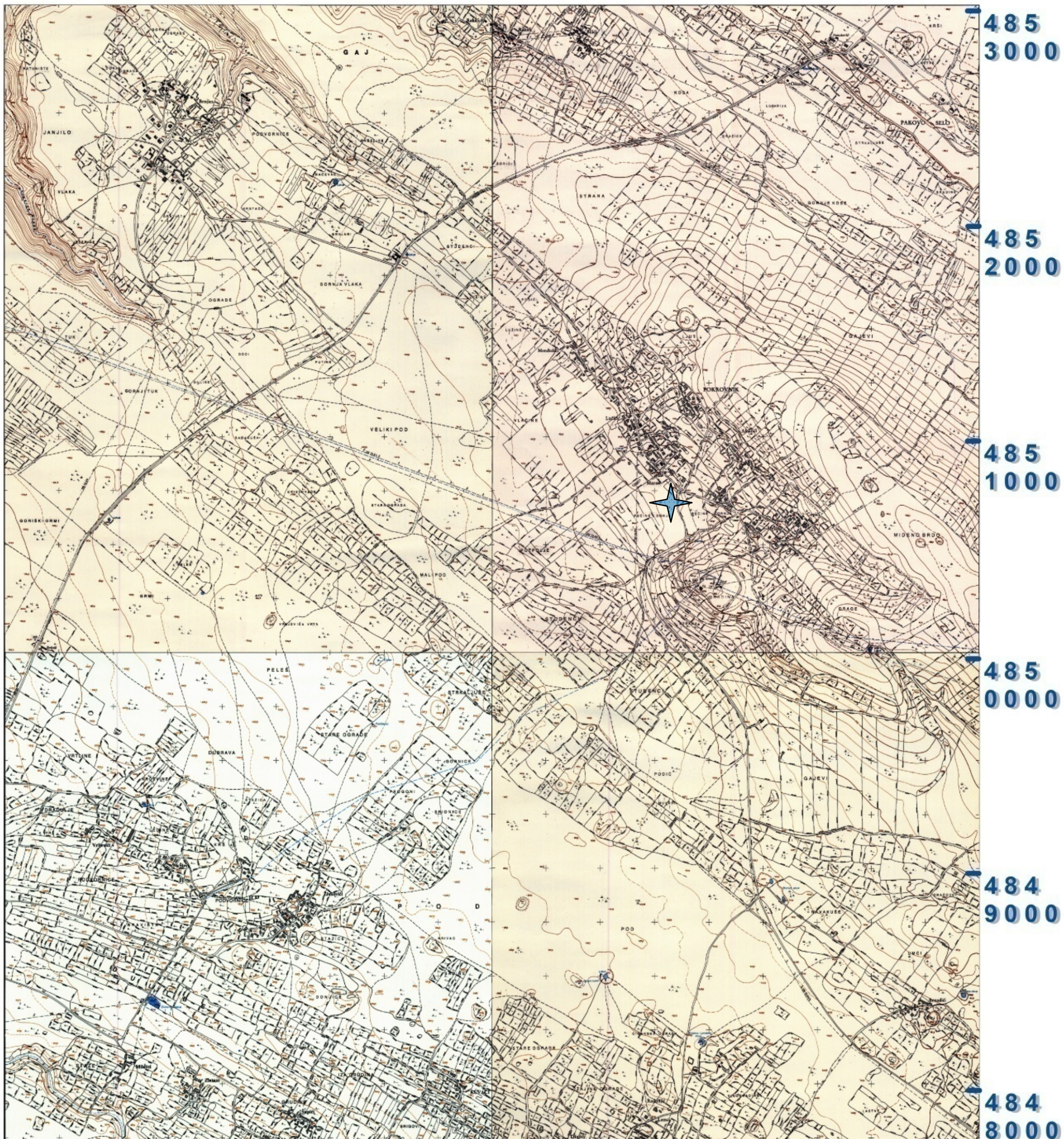

Figure 1.3. Topographic map of the Pokrovnik area. Cross marks the location of the Pokrovnik site. Modified from Geodetski zavod d.d. Osijek (2003) and Zavod za izmjeru zemljišta (1987a, 1987b, 1987c).

Thrusting and faulting of the Dinaride Mountains occurred during the Neogene, with major deformation in the Outer Dinarides ending by ~10 Ma (Einsele, 2000). However, compression and rotation are ongoing processes in the Adriatic micro-plate, further complicating surface and cave morphology in this well-developed karst terrain (Roglić, 2004; Ford, 2002; Dragičević et al., 1999).

Despite the great variety in polje manifestation, two factors appear most influential to their formation: structure and chemistry. Rock masses which differ in density often differ in chemistry. When these fault-bounded masses outcrop at the surface, they are subjected to differential weathering and erosion based on chemistry. Most poljes have a less-permeable rock type (in the Dinaric karst, dolostone) on one side or at their center (Gams, 1978). Lower permeability serves to focus erosive processes at the surface, forming surface depressions; whereas water is slowed and distributed in the more-permeable limestone, forming cave systems (Perica et al., 2002; Gospodarič, 1981a). Once initiated, this pattern reinforces itself as dissolution-aggressive meteoric water enters the limestone at the edges of the less-permeable rock, widening and deepening the feature through time (Perica et al., 2002; Gams, 1978). Regional structure and polje morphology continue to co-evolve today as the plate moves and karstification continues (Dragičević et al., 1999). These processes were likely more intense at wetter times in the past, like the Pliocene-Pleistocene transition during which most of the 130 Dinaric karst poljes are thought to have formed, as well as during periods of elevated Holocene sea-level (Surić et al., 2005; Gambolati et al., 1998; Filipčić, 1992; Melik, 1954; Roglić, 1940).

Continuous paleoclimate records in closest proximity to central Dalmatia are lake and sea-bottom sediments. Sediment cores from the central Adriatic indicate the Bölling/Alleröd oscillation (Greenland ice-core episode GI-1) took place from 14.6-12.6 ka, the Younger Dryas (GS-1) from 12.6-11.5 ka, and the Early Holocene from 11.5-9.2 ka (Asioli et al., 2001). A multi-proxy lake core study from the Isle of Mljet, Croatia indicates a wet (pluvial) phase from 8.4-4.5 ka, with tephra deposition occurring at 7.3 ka, a dry period at 7.1 ka, and the transition to the current xeric moisture regime (most of annual precipitation falling in winter) between 6.3 and 5.5 ka (Wunsam et al., 1999; Jahns and van den Bogaard, 1998). This evidence places the onset of Neolithic occupations at Danilo Bitinj and Pokrovnik following a volcanic event (most likely in Campania, Italy) and roughly at the time of a short-lived but profound dry phase, the effects of which are recorded in lake cores as far away as Spain (Wunsam et al., 1999).

Archaeology. Current explanatory models for universal agricultural diffusion are human migration (the influx of farmers equipped with the necessary cultigens, livestock, and tools) (Ammerman and Cavalli-Sforza, 1971) and technology migration (the movement of cultigens and tools through natural and cultural process) (Dennell, 1985). Fort and Méndez (1999a, 1999b) presented reaction-diffusion equations for population dynamics to describe the human migration model. Davison et al. (2006) adapted these equations to include ecological variables, and Dolukhanov et al. (2005) suggest modification to account for interaction with local foraging populations. General origins of agriculture and Southeast Europe-specific research are both shifting toward more complex models of neolithization, in which human behavioral ecology is coming to the fore (Winterhalder and Kennett, 2006). This evolutionary paradigm is founded on the understanding that environmental attributes and their variance are as large a part of human adaptation as selection itself (Broughton and O'Connell, 1999; Winterhalder and Smith, 1992). Incorporating ideas of energy budget and subsistence strategy into origins-of-agriculture research means considering the costs and benefits of changes in technology and subsistence strategy (Bettinger et al., 2006; Ugan et al., 2003; Boone, 2002).

Although environmental variables are being considered in current research on the spread of the Neolithic (e.g., Davison et al., 2006), general discussion and speculation of environmental conditions does not constitute a cost-benefit analysis (Winterhalder and Goland, 1997). This is not to say that climate is the only selective force that acted on Neolithic foragers and farmers, but that it is a vital force, and one of great prominence in current Neolithic explanatory models for Southeast Europe and worldwide (Turney and Brown, 2007; Mohen, 2006; Winterhalder and

Kennett, 2006; Richerson et al., 2001; Chapman et al., 1996; Watson, 1995). Increasingly, researchers in behavioral ecology are realizing the need for better measures of environment (Gremillion, 2002), the need to consider not only environmental attribute averages, as traditionally applied in evolutionary models (productivity, heterogeneity, etc.) (Bettinger, 1991; Winterhalder 1981), but the scale and predictability of these attributes' variability (Allen, 2004; Madsen et al., 1999; Winterhalder and Goland, 1997). If researchers seek to explain the persistence of agricultural subsistence technologies and behaviours, they must observe them at appropriate scales and in selective context, asking:

- Can we deduce the ecological context of the transition from foraging to farming in this place and time? *and*
- Can we isolate the environmental attributes that would have selected for agricultural subsistence choices?

Towards a Geoarchaeological Theory

This geoarchaeological study characterizes the relationships between Neolithic Dalmatian culture and its matrices (*sensu* Schiffer, 1995) in an effort to understand subsistence strategy changes. These relationships take three forms: (1) conditional – paleoenvironment and landscape, (2) interactive – natural resource acquisition and manipulation, and (3) subsequent – site formation processes and taphonomy. Geoarchaeology is uniquely suited to address these relationships, as their treatment involves intimate knowledge of one or more Earth Sciences. In this case, these include Geomorphology (mapping, GIS modeling), Pedology (pH; electrical conductivity; stable isotope chemistry; calcium carbonate, and organic carbon content), Mineralogy (X-ray diffraction), and Geochemistry (neutron activation analysis). This approach enables analysis on multiple levels from landform to soil.

A soil is essentially a palimpsest of its own life-history (Targulian and Goryachkin, 2004), so archaeological sites in living soils are geoarchaeological palimpsests. The conditions of human behavior are evidenced in soils and sediments. The conditions and mitigations of the archaeological site (however long its life) are recorded in the same soil. Reconstructing this life-history and deciphering condition from mitigation are also the particular province of Geoarchaeology, but in what frame of reference? The culture-matrix construct employed here is essentially a geoarchaeological theory capable of addressing both Earth Science-based archaeological inquiries and general descriptive needs. Here this theoretical framework is used to evaluate and characterize (1) the conditions of Neolithic occupation at Danilo Bitinj and Pokrovnik, (2) the interaction of Neolithic culture (as manifested at these two sites) with geologic raw materials, and (3) the subsequent development of the Danilo Bitinj and Pokrovnik sites from the Neolithic to the present.

Fieldwork & Sampling

I spent the summers of 2005 and 2006 conducting on-site pedology and sampling natural and cultural materials. These experiences, along with early laboratory analyses, made clear the complicated nature of the site materials. The source and nature of the subsoils at Danilo Bitinj and Pokrovnik were unclear. The soil parent materials at both sites are homogenous lowland deposits with no apparent relation to the bedrock, and no upland or lateral colluvial or alluvial source. Aside from Potok Dabar (an ephemeral stream at the center of Danilo Polje), there are no apparent surficial processes at work in either site plain. Danilo Polje soil survey revealed topsoil throughout the polje to be gravelly and cobbly (Figure 1.4, Table 1.1). Outside of these coarser clasts, soil textures are fine, with no hand-detectable constituent coarser than very fine sand. Soil colors are yellows and yellow-reds, with 87% of samples of Munsell[1] hue 2.5Y. Almost the entire polje is under grape or hay cultivation, so topsoils are loose and well-aerated due to frequent hand-tillage. The few sampling locales not under cultivation were found to have hard, well-structured blocky soils – including the site soils, which haven't been under cultivation for the last ~30 years. Farming practices in this area involve light to no machinery, indicating compaction is not an important process in these soils. Though I did not conduct a similar formal survey at

[1] All Munsell colors in the dissertation are dry, taken from the inside of the peds.

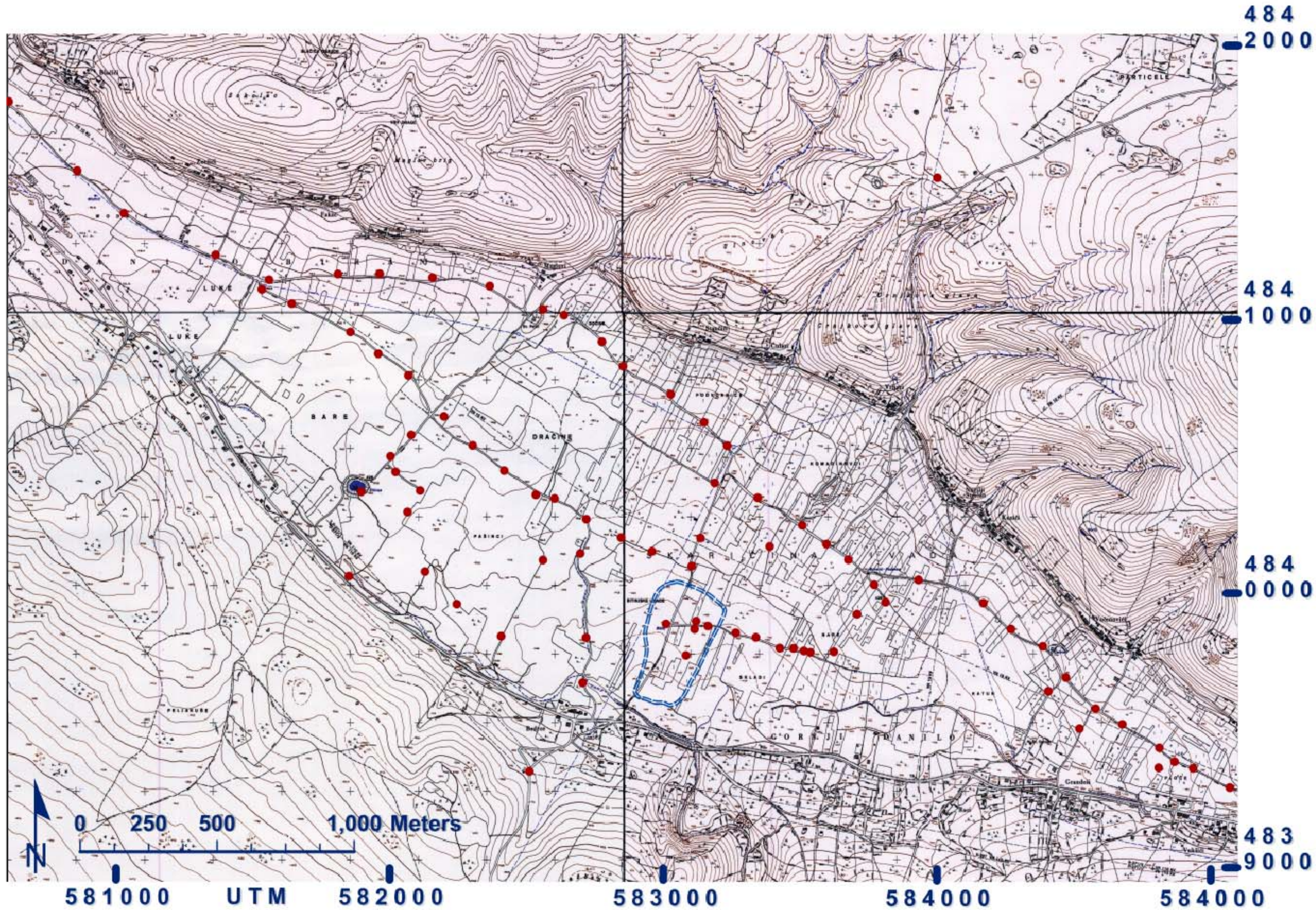

Figure1.4. Danilo Polje soil survey points.

Table 1.1. Soil survey data.

Survey Point	Easting	Northing	Texture	Coarse Fraction /Structure	Color	Context
1	582512	4839355	very fine sand, silt	cobbly	10YR3/3	
2	584002	4841520	very fine sand, silt	cobbly	10YR3/4	
3	583164	4839885	very fine sand, silt	rocky	10YR4/4	vineyard
4	583266	4839860	very fine sand, silt		2.5Y4/3	hay
5	583339	4839844	very fine sand, silt	cobbly	2.5Y4/2	hay
6	583426	4839805	silt	rocky	2.5Y5/3	
7	583477	4839804	silt	rocky	2.5Y4/3	vineyard
8	583515	4839794	silt	rocky	2.5Y4/3	vineyard
9	583538	4839789	silt	rocky	2.5Y4/3	hay
10	583121	4839903	silt, clay	very well structured	2.5Y3/2	hay
11	583115	4839874	silt, clay	very well structured	2.5Y3/2	hay
12	583084	4839778	silt, clay	very well structured	2.5Y3/2	hay
13	583011	4839893	silt, clay	very well structured	2.5Y3/3	hay
14	584936	4839366	silt	cobbly	2.5Y4/4	
15	584869	4839390	silt	very rocky	2.5Y3/3	
16	584813	4839441	silt, clay	rocky	2.5Y4/3	vineyard
17	584678	4839527	silt, clay	rocky	2.5Y3/3	
18	584580	4839584	silt	very rocky	2.5Y4/3	vineyard
19	584471	4839697	silt, clay	very rocky	2.5Y4/4	vineyard
20	584387	4839811	silt	very rocky	2.5Y4/3	vineyard
21	584271	4839874	silt	rocky	2.5Y5/3	
22	584170	4839969	silt	rocky	2.5Y4/3	vineyard

Table 1.1. Soil survey data.

Survey Point	Easting	Northing	Texture	Coarse Fraction /Structure	Color	Context
23	583933	4840053	silt, clay	very rocky	10YR3/3	vineyard
24	583677	4840127	silt		2.5Y4/3	vineyard
25	583597	4840184	silt	rocky	2.5Y4/3	vineyard
26	583509	4840252	silt		2.5Y4/3	vineyard
27	583346	4840353	silt	rocky	2.5Y3/3	vineyard
28	582562	4841040	silt, clay		5Y6/2	sinkhole
29	582638	4841019	silt	rocky	2.5Y4/3	vineyard
30	582777	4840922	silt, clay	rocky	2.5Y4/4	vineyard
31	582854	4840833	silt, clay	rocky	2.5Y4/4	hay
32	583028	4840730	silt, clay	rocky	2.5Y4/3	
33	583150	4840628	fine sand, silt	rocky	2.5Y4/3	vineyard
34	583235	4840543	very fine sand, silt	rocky	2.5Y4/4	vineyard
35	583105	4840104	silt, clay	cobbly	2.5YR2.5/3	
36	582367	4841125	fine sand, silt	rocky	2.5Y5/3	vineyard
37	582158	4841156	silt	rocky	2.5Y5/3	vineyard
38	581965	4841170	silt	rocky	2.5Y4/2	
39	581813	4841169	silt	rocky	2.5Y4/3	
40	581561	4841148	silt	rocky	2.5Y4/3	vineyard
41	581366	4841239	fine sand, silt	rocky	2.5Y5/3	
42	581031	4841391	sand, silt		2.5Y4/3	
43	580860	4841546	fine sand, silt	rocky	2.5Y4/2	
44	580610	4841798	fine sand, silt	rocky	2.5Y4/3	vineyard

Table 1.1. Soil survey data.

Survey Point	Easting	Northing	Texture	Coarse Fraction /Structure	Color	Context
45	580524	4841863	silt	rocky	2.5Y4/4	
46	580283	4842060	silt, clay		2.5Y4/4	
47	580064	4842227	silt, clay	rocky	2.5Y4/3	vineyard
48	582200	4840650	silt		2.5Y5/3	hay
49	582305	4840544	silt	rocky	2.5Y4/3	vineyard
50	582420	4840452	clay	very rocky	5YR3/2	hay
51	582536	4840364	sand, silt		10YR3/3	hay
52	582604	4840350	loam	rocky	2.5Y3/3	hay
53	582720	4840275	silt, clay	very well structured	2.5Y3/2	hay
54	582698	4840150	silt, clay	very well structured	2.5Y3/2	hay
55	582719	4839843	sand, silt		2.5Y4/3	hay
56	582706	4839678	very fine sand, silt		2.5Y4/3	
57	583624	4839791	silt, clay	rocky	2.5Y4/2	vineyard
58	583709	4839928	silt	rocky	2.5Y4/3	hay
59	585213	4839251	silt, clay	cobbly	2.5Y3/2	hay
60	585070	4839296	fine sand, silt	rocky	2.5Y4/2	vineyard
61	584810	4839368	silt, clay	very rocky	10YR3/3	
62	584521	4839511	fine sand, silt	rocky	2.5Y4/2	hay
63	584407	4839647	loam	rocky	2.5Y5/3	hay
64	583813	4839972	silt	rocky	2.5Y5/3	hay
65	583771	4840036	fine sand, silt	very rocky	10YR3/3	vineyard
66	583390	4840175	silt		2.5Y6/3	hay

Table 1.1. Soil survey data.

Survey Point	Easting	Northing	Texture	Coarse Fraction /Structure	Color	Context
67	583189	4840407	silt	rocky	2.5Y4/3	vineyard
68	583137	4840206	fine sand, silt	very well structured	2.5Y3/3	hay
69	581535	4841113	fine sand, silt		2.5Y4/2	
70	581644	4841061	sand, silt	rocky	2.5Y4/3	hay
71	581858	4840958	silt		2.5Y4/2	hay
72	581960	4840878	fine sand, silt		2.5Y4/4	
73	582070	4840799	sand, silt	rocky	2.5Y6/2	
74	582080	4840582	silt	very rocky	2.5Y5/2	
75	582005	4840504	fine sand, silt	rocky	2.5Y4/2	hay
76	582023	4840447	fine sand, silt	rocky	2.5Y3.5/5	vineyard
77	582113	4840379	silt	structured	2.5Y5/3	hay
78	582067	4840301	very fine sand, silt	rocky	2.5Y5/3	vineyard
79	581898	4840375	silt		5Y5/2	doline
80	581853	4840067	sand, silt		2.5Y5/3	bedrock
81	582131	4840084	silt, clay	fluffy	2.5Y5/3	hay
82	582247	4839965	silt		2.5Y4/3	vineyard
83	582409	4839848	silt, clay	rocky	2.5Y6/3	hay
84	582562	4840126	silt		2.5Y5/3	hay
85	582847	4840208	silt		2.5Y3/3	hay
86	582960	4840157	silt, clay		2.5Y4/3	hay

Pokrovnik, land-use practices are the same at both locales. Soils are fine and contain gravels, but are redder (7.5YR) and less structured than at Danilo.

Excavations at Danilo Bitinj and Pokrovnik took place in the summers of 2005 and 2006, respectively (Moore et al., 2007a, 2007b). Archaeological sites were not fully recovered – Andrew Moore (EFDP director, Rochester Institute of Technology) chose excavation locales within each site based on ground-penetrating radar profiles taken by Lawrence Brown (Cornell University). Archaeologists excavated five trenches at Danilo Bitinj and four at Pokrovnik, each designated with a letter. The Early Farming in Dalmatia Project soil sample inventory includes samples[2] taken from the surface downward in each archaeological trench, and in ~50 cm^2 test pits in culturally sterile material surrounding each site: fourteen in Danilo Polje and nine in Pokrovnik, each designated with a number (Figures 1.5 and 1.6, Appendices 1 and 2). I photographed and described each profile and test pit that I sampled for horizonation, color (Munsell soil color scheme), texture, and structure (Figures 1.7 and 1.8, Tables 1.2 and 1.3). The systematic profile sampling strategy (Pansu et al., 2001; Tan, 1996) I used will enable in-depth inter- and intra-site analysis and comparison of soils and their biophysical data, by enabling acquisition of comparable data from on- and off-site at both Neolithic sites. Soil hardness and brittleness limited sampling ability. Greatest sampling resolution was achieved by dividing the profile into 10-cm vertical intervals and extracting every other one. Soil samples represent 10 cm of depth (10-20 cm, 30-40 cm, etc.), with average depth for each sample occurring in 20-cm intervals (15 cm, 35 cm, etc.). I also attempted to take soil micromorphology samples from profile walls. Soil brittleness limited these sampling efforts as well. In the summer of 2008 on an excursion to Grofova Jama (Count's Cave), Slovenia I sampled a clay deposit (Appendices 1 and 2). This yellow and white clay resembled the Danilo Bitinj subsoil, which I hoped would illuminate the nature of the subsoil material.

[2] All samples were air-dried prior to laboratory treatment.

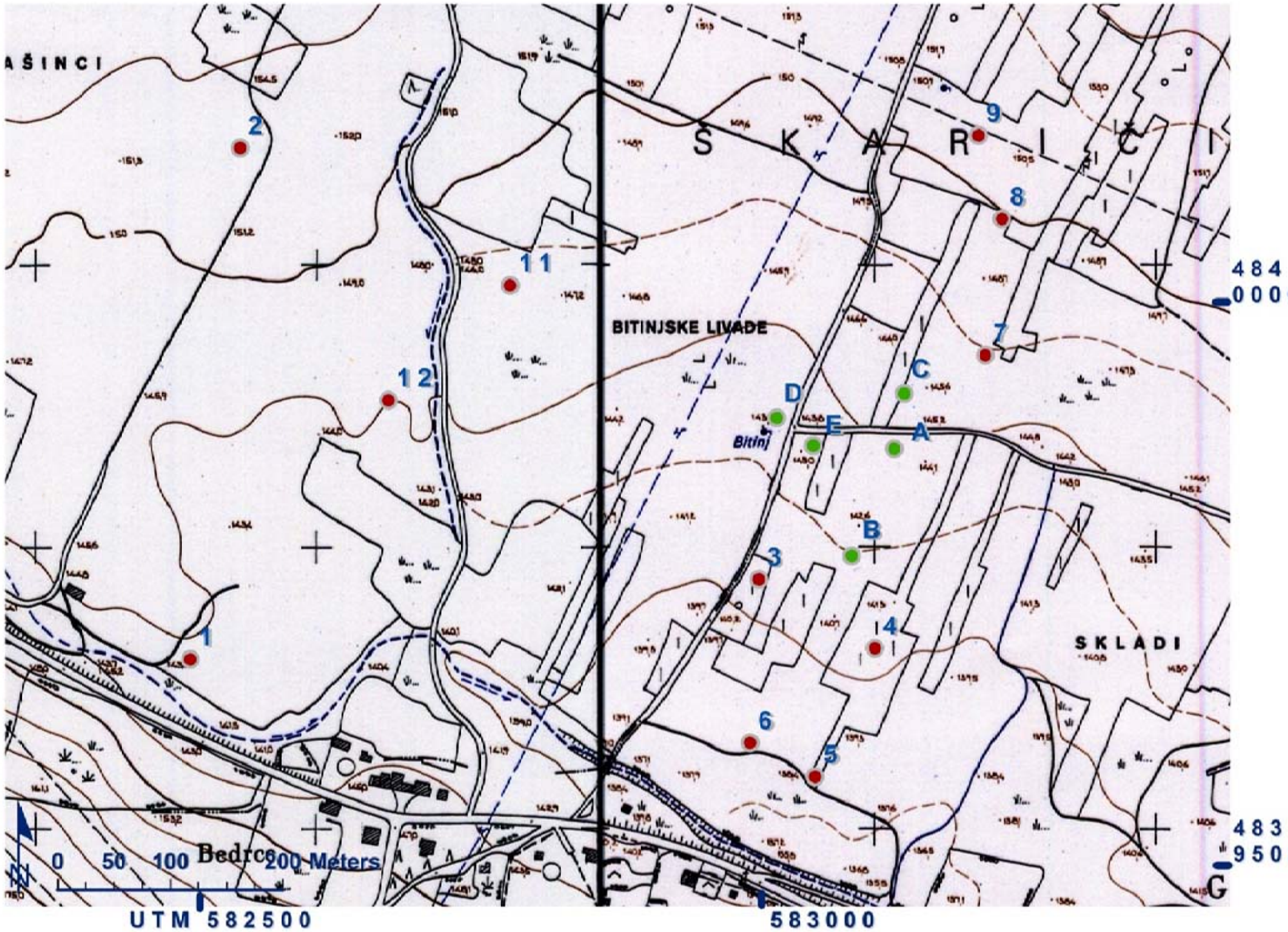

Figure1.5. Danilo Bitinj site soil sample locales. Letters designate profiles taken from the wall of corresponding archaeological trenches. Numbers designate those from independent test pits. Modified from Zavod za izmjeru zemljišta (1996c, 1996d).

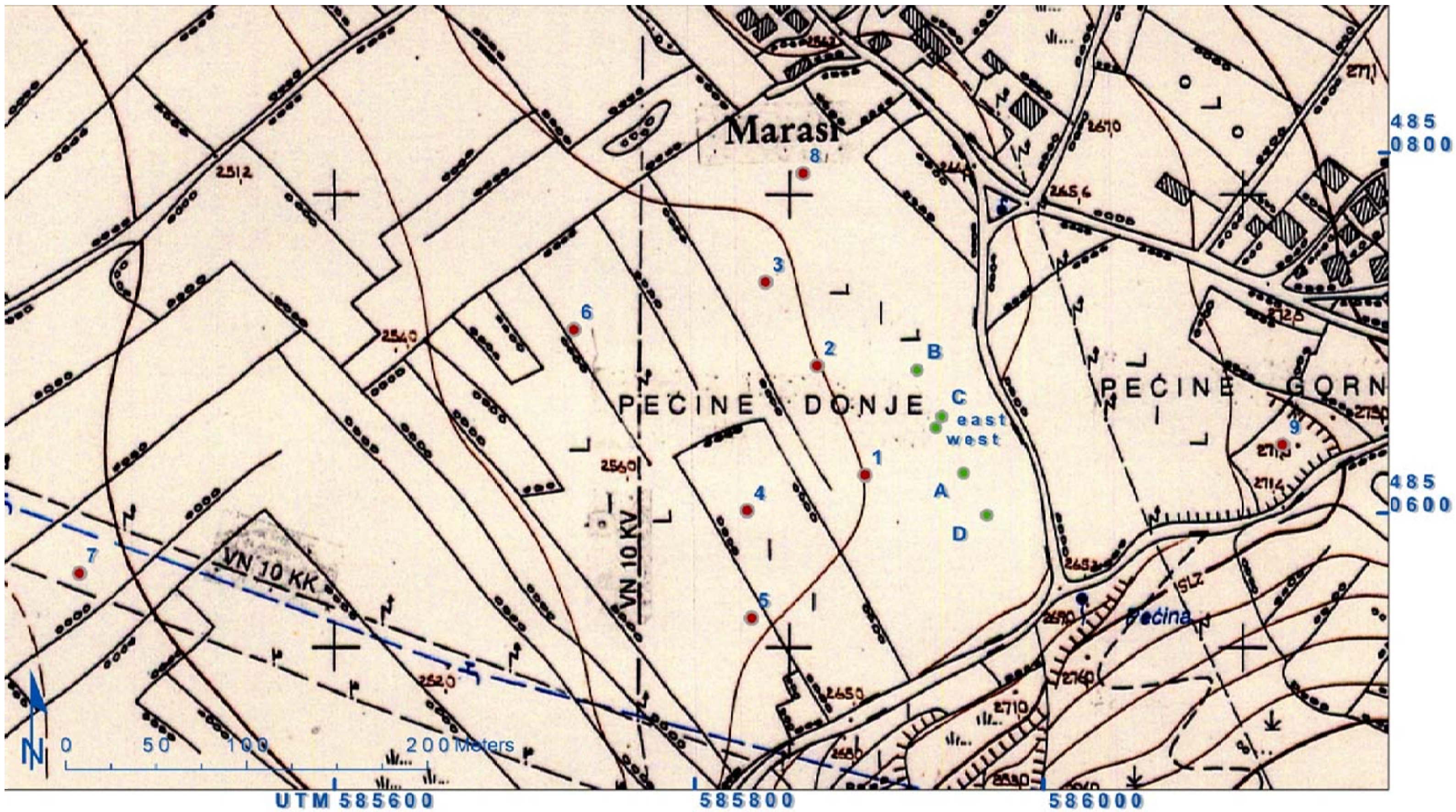

Figure 1.6. Pokrovnik site soil sample locales. Letters designate profiles taken from the wall of corresponding archaeological trenches. Modified from Zavod za izmjeru zemljišta (1987b).

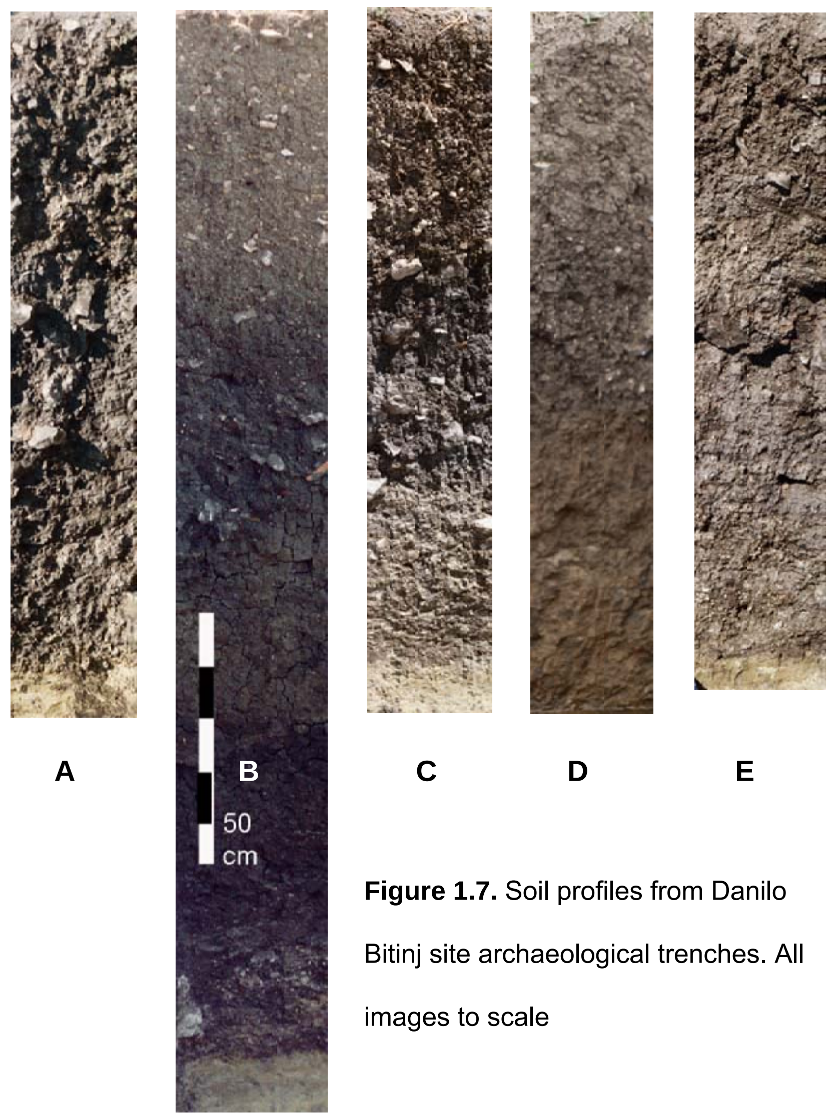

Figure 1.7. Soil profiles from Danilo Bitinj site archaeological trenches. All images to scale

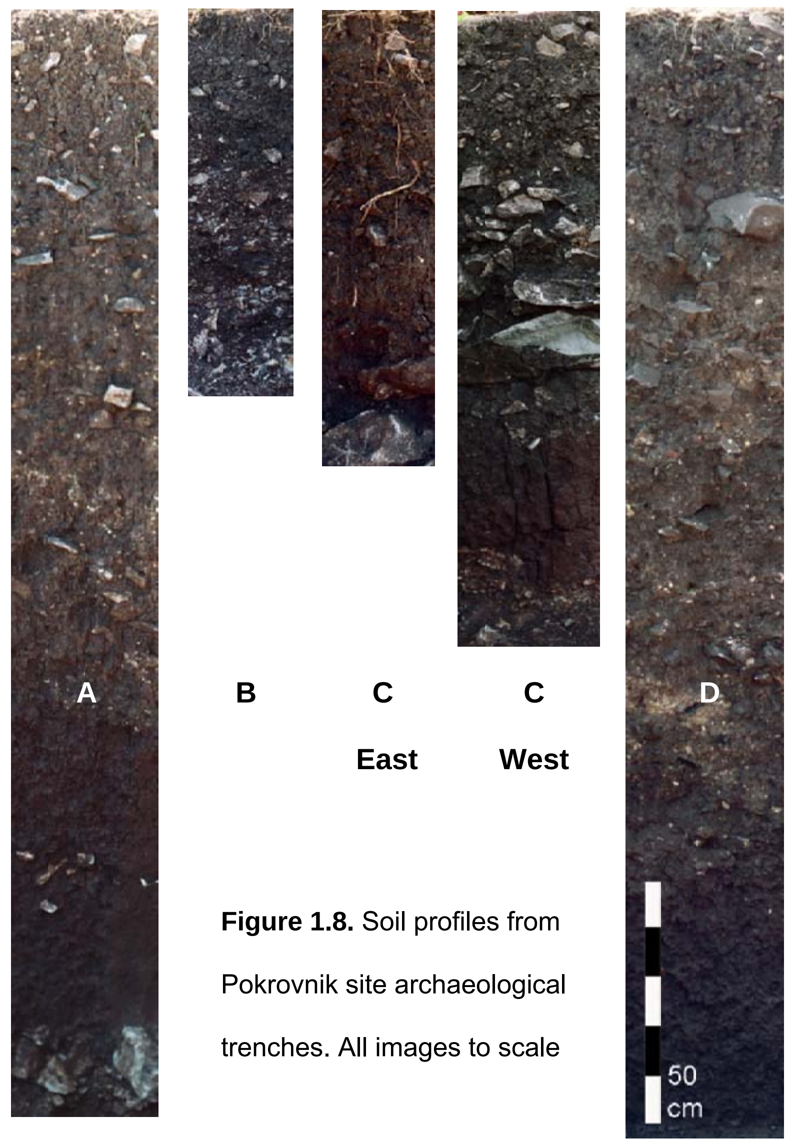

Figure 1.8. Soil profiles from Pokrovnik site archaeological trenches. All images to scale

Table 1.2. Soil descriptions from archaeological trenches.

Site	Trench	Depth (cm)	Horizon	Color	Texture	≥Gravel Fraction %	≥Gravel Size (cm)
Danilo Bitinj	A	0-40	A p	2.5Y 3/2	Silty-clay loam	5	4
		40-95	A	2.5Y 3/1	Silty-clay loam	20	2-10
		95-123	B	2.5Y 5/4, 3/1	Silty-clay loam	5	0.25
		123-140	C	5Y 5/6, 3/2, 5/2	Silt & clay	0	None
Danilo Bitinj	B	0-55	A	2.5Y 4/1	silty-clay loam	10	1-5
		55-72	A p	2.5Y 3/1	clay loam	10	5-8
		72-105	A	2.5Y 2.5/1	clay loam	35	5-10
		105-122	B	2.5Y 3.5/1	clay loam	10	0.25-1
		122-141	B	2.5Y 4/2	silty-clay loam	5	0.25-1
		141-187	A2	2.5Y 4.5/2	clay loam	5	0.25-1
		187-211	B2	2.5Y 5/2, 4/1, 5Y 6/3	silty-clay loam	50	0.25-1
		211-220	C	5Y 6/4, 7/2	fine silt	0	None

Table 1.2. Soil descriptions from archaeological trenches.

Site	Trench	Depth (cm)	Horizon	Color	Texture	≥Gravel Fraction %	≥Gravel Size (cm)
Danilo	C	0-45	A p	5Y 3/2	silty-clay loam	25	1-2
Bitinj		45-67	A	5Y 2.5/2	silty-clay loam	5	2-5
		67-87	A	5Y 2.5/2	clay loam	25	1-2
		87-130	B	5Y 4/2, 3/1, 6/6	silty clay	50	0.25-1
		130-133	Bk	5Y 6/1, 5/6, 2.5Y 5/3	f silt w/25% conc	10	.5
		133-140	C	5Y 6/1, 5/6, 2.5Y 5/3	f silt w/5% conc	0	None
Danilo	D	0-40	A p	2.5Y 4/2	Silt loam	10	1-4
Bitinj		40-73	A	2.5Y 4/2	Silty-clay loam	5	1-2
		73-132	B	2.5Y 4/3, 4/1	Silty-clay loam	10-20	0.25-1
		132-140	C	2.5Y 5/4	Clay & silt	80	0.25-2

Table 1.2. Soil descriptions from archaeological trenches.

Site	Trench	Depth (cm)	Horizon	Color	Texture	≥Gravel Fraction %	≥Gravel Size (cm)
Danilo	E	0-34	A	2.5Y 4/2	Silt loam	7	1-5
Bitinj		34-52	A	2.5Y 3.5/2	Silty-clay loam	7	1-5
		52-90	A	2.5Y 3/2	Silty-clay loam	10	0.5-1, 10
		90-127	B	2.5Y 3.5/2	Clay loam	40	0.25-2
		127-135	C	2.5Y 6/6, 6/4, 8/1, 5/4	Clay loam	0	None
Pokrovnik	A	0-30	A p	7.5YR 3/2	Silty-clay loam	10	0.25-5
		30-50	A	7.5YR 2.5/2	Silty-clay loam	30	0.25-10
		50-80	B	7.5YR 3/2	Silt loam	20	0.25-10
		80-125	B	7.5YR 2.5/1	Silt loam	30	0.25-10
		125-165	C-Fines	7.5YR 2.5/2	Silty-clay loam	0	None
		165-170	Gravel	7.5YR 2.5/3	Clay loam	30	0.25-10
		170-205	Fines	7.5YR 2.5/3, 3/2	Silt loam	0	None
		205-225	Gravel	7.5YR 3/2	Clay loam	80	0.25-50

Table 1.2. Soil descriptions from archaeological trenches.

Site	Trench	Depth (cm)	Horizon	Color	Texture	≥Gravel Fraction %	≥Gravel Size (cm)
Pokrovnik	B	0-30	A	10YR 3/2	Silty-clay loam	5-10	1-5
		30-60	A/B	7.5YR 3/3	Clay loam	80	.25-5
		60-80	B/C	7.5YR 2.5/2	Clay loam	80	1-10
Pokrovnik	C	0-15	A p	7.5YR 3/1	Clay loam	20	0.25-10
	West	15-70	A	7.5YR 3/2	Clay loam	50	0.25-50
		70-85	A2	7.5YR 3/4	Clay loam	10	0.25-10
		85-110	B	5YR 3/4	Clay loam	0	None
		110-123	B/C	5Y 3/4	Clay loam	60	0.25-5
		>123	C(R)	Ls Bedrock	Degraded bedrock	None	None

Table 1.2. Soil descriptions from archaeological trenches.

Site	Trench	Depth (cm)	Horizon	Color	Texture	≥Gravel Fraction %	≥Gravel Size (cm)
Pokrovnik	C	0-15	A p	7.5YR 3/2	Silty-clay loam	10	0.25-5
	East	15-35	A	7.5YR 3/2	Silty-clay loam	30	0.25-40
		35-85	A/B	7.5YR 3/2	Silty-clay loam	10	0.25-20
		>85	C(R)	Bedrock	Bedrock slabs	100	20-70
Pokrovnik	D	0-30	A	7.5YR 3/2	Silty-clay loam	30	0.25-10
		35-70	B	10YR 4/3, 3/1	Silt loam	20	0.25-40
		70-150	B/C	10YR 4/3, 3/1	Silt loam	20	0.25-20
		150-175	A2	10YR 3/3	Silt loam	10	0.25-10
		175-230	C	7.5YR/10YR 2.5/2, 2/2	S-c loam/clay	1	5

Table 1.3. Soil descriptions from geologic test pits.

Site	Test Pit	Depth (cm)	Horizon	Color	Texture	≥Gravel Fraction %	≥Gravel Size (cm)
Danilo Bitinj	1	0-15	A p	2.5Y 4/3	Silty-clay loam	2	0.25-5
		15-68	A	5Y 3/2	Silty-clay loam	2-40, 1	0.25-5, 10
		68-82	B	5Y 5/3	Silt loam	0	None
		82-94	C	5Y 5/4	Silt	0	None
	2	0-58	A	7.5YR 3/2	Silty-clay loam	60	0.25-10
		58-65	B?	10YR 4/4	Clay loam	0	None
	3	0-10	A p	2.5Y 5/3	Silt loam	30	0.25-5
		10-46	A	2.5Y 4/4	Silty-clay loam	50	0.25-10
	4	0-10	A p	2.5Y 4/2	Silty-clay loam	20	0.25-5
		10-30	A	2.5Y 3/2	Silty-clay loam	20	0.25-5
		30-48	B	2.5Y 3/2, 5/4	Silty-clay loam	15	0.25-5
		48-80	C	5Y 6/4	Silt	0	

Table 1.3. Soil descriptions from geologic test pits.

Site	Test Pit	Depth (cm)	Horizon	Color	Texture	≥Gravel Fraction %	≥Gravel Size (cm)
Danilo	5	0-30	A	2.5Y 3/2	Silty-clay loam	10	0.25-3
Bitinj	6	0-30	A	2.5Y 3/2	Silty-clay loam	10	0.25-3
	7	0-10	A p	2.5Y 3/2	Silt loam	10	0.25-5
		10-25	A	2.5Y 4/4	Silty-clay loam	20	0.25-5
		25-60	A/B	2.5Y 5/4	Silty-clay loam	10	0.25-5
	8r	0-10	A p	5Y 4/3	Silt loam	0-2	0.25-1
		10-30	A	5Y 4/3	Silt loam	2	0.25-2
		30-50	B	5Y 5/3	Silty-clay loam	2	0.25-2
		50-75	C	5Y 6/4	Silty-clay loam	0	None
	9	0-10	A p	5Y 1/2	Silt loam	0-2	0.25-1
		10-47	A	5Y 4/2	Silt loam	2	0.25-5

Table 1.3. Soil descriptions from geologic test pits.

Site	Test Pit	Depth (cm)	Horizon	Color	Texture	≥Gravel Fraction %	≥Gravel Size (cm)
Danilo	10	0-10	A p	5Y 4/2	Silt loam	0-2	0.25-1
Bitinj		10-25	A	5Y 4/2	gravelly	0	None
		25-30	A	5Y 4/2	silt loam	5	0.25-5
		30-37	A	5Y 4/2	Silty-clay loam	0	None
		37-54	A/B	5Y 4/3	Silty-clay loam	50	0.25-10
	11	0-10	A p	5Y 4/2	silt loam	0	None
		10-48	A	5Y 4/3	s/sc loam	0	None
		48-57	B	2.5Y 3/2	Silty-clay loam	0	None
		57-62	B	2.5Y 3/2	Silty-clay loam	10	0.25-1
	12	0-30	A	10YR 2/1	Silty-clay loam	20	0.25-5
		30-50	B	10YR 2/1, 3/3	Silty-clay loam	20	0.25-5
		50-62	B	7.5YR 3/3	Silty-clay loam	0	None
		62-70	C	7.5YR 3/3	Silty-clay loam	70	1-5

Table 1.3. Soil descriptions from geologic test pits.

Site	Test Pit	Depth (cm)	Horizon	Color	Texture	≥Gravel Fraction %	≥Gravel Size (cm)
Danilo	13	0-40	A	7.5YR 3/3	Loam	40	0.25-2
Bitinj		40-75	B	7.5YR 3/4	Loam	50	0.25-5
		75-100	C	7.5YR 4/6	Silty-clay loam	60	0.25-5
	14	0-10	A	2.5Y 4/3	Silt loam	1	0.25-1
		10-75	B	2.5Y 4/3	Silty-clay loam	10	0.25-5
Pokrovnik	1	0-30	A	10YR 2/2	Clay loam	20	0.25-10
		30-55	B	10YR 2/1	Clay loam	5	0.25-10
		55-67	B	10YR 2/1	Clay loam	5	0.25-10
	2	0-43	A	10YR 2/2	Silty-clay loam	20	0.25-10
		43-60	B	10YR 3/3	Clay loam	50-100	0.25-10
		60-75	C	10YR 5/6, 2.5Y 8/2, 6/4	Degraded bedrock		

Table 1.3. Soil descriptions from geologic test pits.

Site	Test Pit	Depth (cm)	Horizon	Color	Texture	≥Gravel Fraction %	≥Gravel Size (cm)
Pokrovnik	3	0-10	A	10YR 2/1	Silty-clay loam	10	1-5
		10-40	A	10YR 3/3	Silty-clay loam	5	1-5
		40-65	B	7.5YR 2.5/2	Clay loam	30	1-5
		65-75	C	10YR 3/4, 8/2	Silt loam	50-100	1-5
	4	0-20	A	10YR 2/2	Silty-clay loam	20	1-10
		20-35	A	10YR 2/2	Silty-clay loam	70	1-10
		35-70	B	10YR 2/1	Silty-clay loam	30	1-10
	5	0-10	A	10YR 2/1	Silty-clay loam	10	0.25-5
		>10	C	Bedrock	Bedrock		

Table 1.3. Soil descriptions from geologic test pits.

Site	Test Pit	Depth (cm)	Horizon	Color	Texture	≥Gravel Fraction %	≥Gravel Size (cm)
Pokrovnik	6	0-20	A p	10YR 2/2	Clay loam	10	1-10
		20-45	A	7.5YR 3/3	Clay loam	0	1-10
		45-60	B	7.5YR 3/4	Silty-clay loam	50-80	1-10
		>60	C	7.5YR 7/6, 10YR 8/1	Silt	90	1-10
	7	0-22	A	10YR 3/3	Clay loam	0-70	1-10
		>22	C	Bedrock	Bedrock		
	8	0-50	A	10YR 2/2	Silty-clay loam	10	0.25-5
		50-62	B		Silty-clay loam	50	0.25-10
		>62	C	Reddish, crumbly	Wthrd bdrk	90	0.25-10
	9	0-52	A	2.5Y 5/3	silty	30	0.25-10

A separate project question concerned the time-depth of the current practice of transhumance. I believe the best way to address this question is by comparison of modern and ancient soils and caprhine remains from the archaeological sites and Mt. Dinara. This strategy will allow quantification of any soil isotope gradient between central Dalmatian lowlands and uplands, as well as comparison of ancient animals with those we know to have single or mixed (lowland/upland) dietary inputs. To enable such a study I collected surface soils from Mt. Dinara (Appendices 1 and 2) and teeth from sheep slaughtered in the summer of 2006. Anthony Legge (project zooarchaeologist, University College London) provided archaeological sheep teeth for comparison.

Methods

I used the following procedures to analyze EFDP soil samples in the laboratory. I conducted all laboratory work reported in the dissertation at Washington University between the summers of 2005 and 2009, except soil organic matter radiocarbon graphitization, which I performed at the University of Arizona in the spring of 2009. In accordance with USDA foreign soil regulations, all samples were heated at 100°C prior to handling and analysis.

Wet chemistry. The following investigations represent methods I used and hypotheses I have toward the acquisition of standard biophysical data for EFDP soils. I performed soil wet chemical analyses in the Washington University Terrestrial Paleoecology Laboratory. I mixed all necessary reagents from chemical concentrates and powders.

pH is the negative log of H^+ ions in solution, a measure of soil acidity. Some consider pH the single most diagnostic soil chemical measurement, as it controls ion exchange, dissolution, precipitation, redox, adsorption, and complexation reactions (Thomas, 1996; McBride, 1994). Electrical conductivity (EC) is proportional to the ionic charge of a solution, a measure of soil salinity. Conductivity may be measured by electrodes in solution or by electrode array *in situ*; pH, by colorimetric and electrode potential methods. Field methods require soils to be moist, either naturally or by the addition of water, and result in apparent pH and EC values due to uncontrolled moisture and soil mass conditions (Brady and Weil, 2000). As EC and pH are measurements of activity in aqueous solution, results are partially dependent on the solid to liquid ratio. For pH this effect is most pronounced in acidic soils, as the addition of neutral (or distilled/deionized) water can raise the pH to 7 (neutral conditions). Experimentally I have found differences in pH in acidic and basic soils to be much greater between a 1:1 and 1:2 soil:water[3] paste (0.0-0.4 pH units) than between a 1:2 and 1:10 paste (0.0-0.2 pH units) (c.f. Thomas, 1996:480). A seasonal effect may also be observed in soils with variable salt content (whether natural or due to fertilization), in which case pH is lowest during humid summer growing months and highest at spring planting (Thomas, 1996). Soils in the area around each site are irrigated but not fertilized, while soil at Danilo Bitinj has been fallow for ~30 years. As the local moisture regime is xeric, soils at both sites have low salt content (inferred from EC), and Danilo Bitinj soil is alkaline and Pokrovnik soil neutral-to-alkaline, this effect does not seem applicable (at least not according to the scenario described above). If there are times of the year when salt content is higher, it would be difficult to assess without collecting soil seasonally. Because the primary crop in both site areas is grapes, and soil salts are known to be highest after planting and harvest (Thomas, 1996), I hypothesize that salt content is not substantially higher at other times of the year. (Soils were sampled in the summer.) Land use can also affect general soil pH – in most cases agricultural practices like fertilization decrease pH and increase toxicity through associated aluminum solubility (e.g., Fenton and Helyar, 2000; Mulvey and Elliott, 2000), such that pH remediation usually focuses on raising soil pH (Brady and Weil, 2008). However, the effect of land use practices on pH must be evaluated individually for each soil; for example, although slash-and-burn or field-burning practices are known to raise pH by the addition of ash, they can also lower pH by the addition of organic matter and attendant organic acids (Tinoco et al., 2006; Troeh and Thompson, 2005; Fenton and Helyar, 2000).

[3] All water used in laboratory procedures is deionized water (6 MΩ).

I normally measure the EC and pH of a stirred 1:2 soil:water paste (EC_w and pH_{H2O}), but this method proved inadequate here, due to the inability of water to infiltrate the peds. Therefore, for both pH and EC I mixed a 1:5 soil:water paste mechanically for one hour (Rayment and Higginson, 1992). I measured EC_w immediately and pH_{H2O} after settling. I also experimented with measuring pH in a 0.01 M $CaCl_2$ solution, normally used to stabilize the measurement and counteract the effect of salt in the soil (Brady and Weil, 2000). Outside of having a more stable meter reading, pH_{CaCl2} is usually only 0.2-0.5 lower than pH_{H2O}; however, in this case addition of salt changed the pH of the soil paste more drastically (up to 1.1 pH units), and made measurement more erratic than that of water alone. As salt may be used to remediate sodic soils by changing their physical make-up and chemistry (Brady and Weil, 2008), I could not in good conscience view this change as a 'pH correction'. This experiment also confirmed the sodic nature of the soil, as addition of salt caused the sample to flocculate and settle out of solution extremely quickly (within 30 min) (c.f. Brady and Weil, 2008:421). EC and pH meters are accurate to 0.1 μS/cm and pH unit. I calibrated each measurement with solutions of known activity and concentration.

I measure organic carbon and carbonate content to understand the physical make-up of the soil and the proportional effects these constituents may exert on its chemistry. Soil organic matter in particular is integral to soil physics and chemistry due to its abilities to maintain pore structure, retain water, retain nutrients, adsorb potentially toxic organic compounds, and release nutrients via its decomposition (McBride, 1994). Organic carbon content may be measured by thermal gravimetry or wet combustion. Carbonate content may be measured by thermal gravimetry, dissolution gravimetry, or gas volumetry. I have personal experience with all of these methods. Gravimetric, or 'loss' analysis determines the weight percent of a soil constituent by exposing the bulk sample to conditions which remove the targeted constituent. Thermal gravimetric methods vary considerably in their selectiveness for the target; accuracy is dependent on (1) whether weight measurements are made within the closed combustion device or after removal from the furnace, and (2) the ratio of number of weight measurements to temperature increases. In the first case, weight of the powdered sample inside the combustion device (LECO or other furnace) is the true remnant powder weight. Immediately upon removal from the furnace, the powder and the hot surfaces of the ceramic crucible or boat absorb atmospheric water, which increases their weight. In the second case, the number and proportion of variably combustible materials in the soil sample are increasingly discernible with increasing number of combustion steps (or decreasing change in temperature per weight measurement). For a simple soil make-up (e.g., quartz sand and calcium carbonate) number of combustion steps would be less important than for a soil with high colloid content, varying mineral crystallinity, or simply higher or unknown diversity of combustible constituents. Combustion temperatures are generally lower (300-500°C) for organic and higher for mineral (800-1000°C) constituents.

Dissolution gravimetry is used to target carbonate content by exposure of the bulk sample to acid solution. A variety of acids and concentrations may be used; I usually use 2N hydrochloric, which proved inadequate here. Carbonate dissolution of both bedrock and soil samples required 5N hydrochloric acid in larger acid volume to sample weight ratios than any sediment or soil I have studied. Aggressive dissolution of bedrock samples (with up to 120 mL of 5N HCl) was not problematic, probably because of their relatively simple crystalline carbonate nature. The soils under study, however, proved complex and unaccountable in two ways: improbable results and the apparent dissolution of non-carbonate constituents. Analysis of samples from Danilo Bitinj trench A resulted in carbonate contents of 81-106%. If no material remained, I could accept that 6% were within error, but such was not the case. These results seemed especially improbable in light of the fact that isotopic analysis (see below) required at least twice as much bulk sample as for analysis of pure carbonates. The supernatant was various shades of dark yellow-brown and black, leading me to conclude that organic, oxide, or other non-carbonate soil constituents were forced into solution. It is possible that immersion of a high colloid content, highly alkaline soil in a strong acid solution caused a chemical change drastic enough to alter overall soil make-up, leading to both curious mass change and dissolution of non-carbonate high-pH-stable substances.

Carbonate content may also be measured by gas volumetry using a Chittick apparatus. This device measures the amount of gas evolved from carbonate dissolution via displacement, similar to a manometer. This method or an automated multi-step combustion would be most efficient for resolving carbonate content. I believe combustion over the entire range 25-1000°C in many increments may be one of the only ways to resolve the overall physical make-up of these soils. I was able to measure organic carbon content using the Walkley-Black wet combustion method. This technique measures only the decomposed, or humus, fraction of soil organic matter. Results do not include un-decomposed material like roots. I immersed fine-grained bulk sample in sulfuric acid and potassium dichromate, which broke apart and oxidized humus compounds respectively. Using an ortho-phenanthroline indicator and titration of ferrous sulfate, I measured the amount of oxidized material. This measurement represented soil organic carbon content, from which I calculated the soil organic matter (SOM) content (known to relate to organic carbon by a factor of 1.724) (Tan, 1996).

Soil granulometry is useful for defining both soil texture and the character of the material from which the soil formed (Birkeland, 1999). A soil's texture is one of its basic properties and can help elucidate its behavior (Brady and Weil, 2000). In the past I have analyzed grain size distributions for soil and sedimentary materials using wet sieve, dry sieve, and hydrometer methods. For the soils under study here, dry sieving was impossible, as the peds do not break up into grains. Wet sieving took multiple days per sample and did not provide very much information, as soils are extremely fine and smaller grains are indistinguishable by this method (for example, of Danilo Bitinj sample E1, 87% is smaller than very fine silt). Because of the high carbonate content, I had originally assumed hydrometer method would not be useful, as the procedure requires dissolution of carbonates to prevent flocculation. However, having confirmed the sodic nature of the soil, I now believe its natural dispersive properties may allow for hydrometer granulometry, even without a sodium hexametaphosphate additive.

Isotope chemistry. The stable isotope ratios examined in this study are $\delta^{13}C$ of soil organic matter ($\delta^{13}C_{om}$) and $\delta^{13}C$ and $\delta^{18}O$ of pedogenic carbonate ($\delta^{13}C_{cc}$, $\delta^{18}O_{cc}$). Isotopic measurements are ratios between heavy and light isotopes of an element ($^{13}C/^{12}C$ or $^{18}O/^{16}O$) in parts per million (‰). The standard for reporting the $^{13}C/^{12}C$ composition of organic matter and the $^{13}C/^{12}C$ and $^{18}O/^{16}O$ composition of carbonates is PDB. Stable isotope measurements are reported in reference to the standard as a difference between the sample's ratio and the standard's ratio:

$$\delta^{13}C = [\ (\ (^{13}C/^{12}C)_{sample} - (^{13}C/^{12}C)_{PDB}\ )\ /\ (^{13}C/^{12}C)_{PDB}\ ] \times 10^3 ‰$$

$$\delta^{18}O = [\ (\ (^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{PDB}\ )\ /\ (^{18}O/^{16}O)_{PDB}\ ] \times 10^3 ‰$$

In general carbon fractionation favors the light isotope (^{12}C) during photosynthesis (leading to lower $\delta^{13}C_{om}$ values) and the heavy isotope (^{13}C) in inorganic reactions (leading to higher $\delta^{13}C_{cc}$ values) (Hoefs, 2009). Oxygen fractionation generally favors the light isotope (^{16}O) more during evaporation than during evapotranspiration, leading to higher $\delta^{18}O_{cc}$ values in areas with little vegetative ground cover and lower $\delta^{18}O_{cc}$ values in areas with denser vegetation (Hoefs 2009, Quade et al. 1989).

Beyond these generalizations, plant metabolisms and soil processes have varying effects on $\delta^{13}C_{om}$, $\delta^{13}C_{cc}$, and $\delta^{18}O_{cc}$. The two dominant plant metabolic pathways are named for both the researchers that discovered them and the first intermediate molecule formed by the cycle's carbon fixation: Calvin-Benson (C_3) and Hatch-Slack (C_4). Common C_3 plants are trees, rice, wheat, oats, barley, rye, potato, sweet potato, sugar beet, most shrubs, and cool season grasses; common C_4 plants are corn, sorghum, sugarcane, saltbush, saltgrass, crabgrass, savanna grass, and prairie grass (Sakamoto et al., 2003; Quade et al., 1998; Starr and Taggart, 1995; Cerling, 1992; Quade et al., 1989). A third pathway fixes carbon through Crassulacean Acid Metabolism

(CAM), which involves chemical reactions of the C_4 pathway. Rather than fixing carbon in different cells – as C_4 plants do – CAM plants fix carbon at different times of the day. The $\delta^{13}C$ ranges for the three types of plants are as follows: C_3, -34 to -23‰; C_4, -23 to -6‰; CAM, -33 to -11‰ (Figure 8) (Hoefs, 2009). The average isotopic composition of C_3 plants is -26‰; of C_4 plants, -12‰ (Cerling, and Quade, 1993; Cerling, 1992). Due to fractionation effects, the values of soil carbonates are enriched relative to organic matter by ~14‰; thus, the mean value of carbonates formed in C_3 plant community soils is about -11‰, while the mean in C_4 community soils is about +2‰ (Nordt, 2001; Cerling, 1992).

In terms of climatic adaptation, C_3 plants are less sensitive to cold and take advantage of cool temperature growing seasons, while C_4 plants are found in warmer climates and flourish in areas with hot growing seasons (Starr and Taggart, 1995). Because the C_4 metabolic pathway is more efficient than the Calvin cycle alone, C_4 plants have much smaller stomata and lose less water during glucose manufacture, making them more tolerant to drier climates (Starr and Taggart, 1995; Cerling, 1992). CAM plants generally are adapted to climate extremes and flourish only in climates unsupportive of large C_3 or C_4 populations, because (1) C_3 and C_4 plants generally lose too much water during photosynthesis to survive in dry climate extremes, and (2) CAM plants grow far too slowly to compete with C_3 and/or C_4 plants in environments that support them (Starr and Taggart, 1995). The above generalizations coupled with isotopic data from throughout the United States allow the following assumptions: (1) as temperature decreases (depleting the $\delta^{18}O$ of meteoric water) and the C_3 pathway is favored over the C_4 pathway, $\delta^{13}C$ and $\delta^{18}O$ should become depleted at the same rate as long as the primary water source to the plant community is meteoric (Davis et al. 2002; Cerling and Quade, 1993; Cerling, 1992), (2) because so many meteorological factors can affect $\delta^{18}O$, this relationship applies in areas with consistent rainfall sources (Davis et al., 2002; Amundson et al., 1996; Grootes, 1993); and (3) $\delta^{13}C$ applies to local variation and $\delta^{18}O$ to regional variation, allowing for the discrimination of local plant communities (and by proxy temperature and moisture variation) from regional moisture variation (Huckleberry and Fadem, 2007; Davis and Schweger, 2004; Davis et al., 2002). Currently in the area around the Danilo Bitinj and Pokrovnik sites there are presumably very few C_4 plants and no known CAM plants. Site areas are arid, receiving only 8-10 cm of rainfall per year on average; and xeric, with the majority of rain coming in winter months and highest average rainfall occurring in November (Milković and Trninić, 2005). A cool growing season limits the plant population to a predominance of C_3 plants. Meteoric water source is slightly more difficult to assess; however, winds have come predominantly from the north to north-northeast for at least the last 40 years (Zaninović, 2005).

The complexity of soils and of pedogenic processes cannot be overstated; however, it is possible to make some generalizations on the sources of, and processes involved in, the genesis of soil organic matter and carbonates. Soil organic matter begins with plant and animal material. The sugars, starches, and amino acids of these tissues are most easily decomposed, followed by cellulose. Early decomposition releases carbon dioxide, water, energy, nitrogen, phosphorous, and sulfur back into the soil for re-consumption by organisms. The lignin in plant materials is resistant to decay. Even when the molecules are broken apart, it is theorized that their subunits remain intact and are chemically protected in soil humus (Brady and Weil, 2000). Humus contains this modified lignin along with other organic compounds from decomposition and is strongly resistant to further decay (Brady and Weil, 2000; Birkeland, 1999). This resistance may be the reason diagenetic alteration (the breakdown of compounds in older sediments and paleosols due to burial, compaction, microbial activity, groundwater composition and fluctuation, etc.) is known to have only a negligible effect on $\delta^{13}C_{om}$ (Kelly et al., 1998). Additionally $\delta^{13}C_{om}$ has been shown to reflect the $\delta^{13}C$ of plant tissues themselves, as long as the soils have not been agriculturally enriched with exotic lime or fertilizer (Nordt, 2001; Amundson et al., 1998).

Calcium carbonate ($CaCO_3$) precipitates in soil via the following reactions (Birkeland, 1999):

$$(CO_2)_{gas} + (H_2O)_{liquid}$$

$$\updownarrow$$

$$(CaCO_3)_{crystal} + (H_2CO_3)_{solution} \leftrightarrow (Ca^{2+} + 2HCO_3^-)_{solution}$$

$CaCO_3$ can move in and out of solution due to fluctuations in soil H_2O and CO_2 pressure. For example, high CO_2 pressure at the soil surface can inhibit $CaCO_3$ crystallization. Water leaching through the soil carries Ca^{2+} and HCO_3^- with it. When Ca^{2+} and HCO_3^- accumulate and CO_2 pressure decreases, $CaCO_3$ precipitates, forming pedogenic carbonate (carbonate formed via soil genesis) (Birkeland, 1999). Because in some soils this accumulation only occurs via illuviation, concurrently produced $CaCO_3$ and organic matter may be vertically offset in the solum. In areas with carbonate bedrock, bulk soil carbonate stable isotope values may represent a mixture of bedrock and pedogenic signatures, as some carbonates may be detrital rather than pedogenic. In the case of pedogenic carbonates, $\delta^{13}C_{cc}$ is in equilibrium with soil CO_2 and, therefore, relates systematically to the proportion of varying photosynthetic pathways in the local ecosystem (Nordt, 2001). $\delta^{18}O_{cc}$ is known to be in equilibrium with local meteoric water at the time of precipitation (Amundson et al., 1998; Cerling and Quade, 1993). Soil diagenesis can affect $\delta^{13}C_{cc}$, but the use and comparison of multiple stable isotope measures can serve as a check on alteration.

The utilization of stable isotope geochemistry as one of a suite of multiproxy data is a powerful paleoclimatic indicator that provides a record of environmental changes at the actual locus of human occupation. By deriving the fluctuation in percentages of C_3 and C_4 plants through time, Nordt et al. (1994) were able to distinguish periods with warmer and drier conditions from those that were cooler and wetter. Nordt (2001) suggests using the following equation for estimating relative percentages of C_3 and C_4 populations from $\delta^{13}C_{om}$ via

$$\delta^{13}C_{om} = (\delta^{13}C_4)_{avg}(x) + (\delta^{13}C_3)_{avg}(1 - x)$$

where $\delta^{13}C_{om}$ is the value obtained for a given soil sample, $\delta^{13}C_{avg}$ is the average known value for C_3 and C_4 plants, and x is the percentage of C_4 plants contributing to soil organic matter. Expected values for pedogenic carbonate can also be calculated using

$$\delta^{13}C_{cc} = \alpha_{CaCO3\text{-}CO2} (\delta^{13}C_{om} + 1004.4) - 10^3$$

where $\delta^{13}C_{cc}$ is the value obtained for a given sample and α is the fractionation factor between soil CO_2 and pedogenic carbonate, usually 1.0103. In practice carbonates yielding valid paleoclimate signatures can range from mathematically expected values (due to temperature and other variables), so validity judgements must be made on a case-by-case basis. Though the average is 14‰, valid enrichments usually range between 11 and 16‰ (Nordt, 2001). For example, Wang et al. (1993) determined that neither organic matter nor carbonate values were suspect since all coeval pairs of $\delta^{13}C_{om}$ and $\delta^{13}C_{cc}$ were consistently different from one another with an average enrichment value of 15.3‰. Budd et al. (2002) determined that isotope values were paleoenvironmentally invalid when most samples showed a >18‰ difference in $\delta^{13}C_{om}$ and $\delta^{13}C_{cc}$ values.

I measured carbonate isotope ratios using a Finnigan MAT 252 gas-source mass spectrometer with a Finnigan GasBench II peripheral device. I prepared soil samples for analysis by grinding them to a powder. I loaded tubes with sample powder, evacuated them, and injected them with 100% ortho-phosphoric acid. The acid dissolved the carbonate in the sample, producing CO_2 gas. This automated on-line method uses the continuous flow mode, programmed to deliver sample CO_2 to the mass spectrometer in a stream of helium, measuring $\delta^{13}C_{cc}$ and $\delta^{18}O_{cc}$. I measured $\delta^{13}C_{om}$ using off-line sample preparation and the dual-inlet mode for delivering CO_2 to the mass spectrometer. Off-line organic matter preparation involves manual conversion of each sample from organic solid to CO_2 gas, a procedure I personally implemented in the Washington University Stable Isotope Research Laboratory under the direction of Dr. Robert Criss. The method I implemented was originally described by Sofer (1980) and later evaluated by Tao et al. (2001), Vandeputte et al. (1996), Engel and Maynard (1989), McGaw et al. (1988), and Boutton et al. (1983). Soil organic matter is measurable by gas-source mass spectrometers via organic carbon combustion, oxidation to form CO_2 gas, and CO_2 gas purification. I powdered, measured, and combined samples with CuO powder, an oxidation substrate. I evacuated and sealed tubes on a vacuum chemical extraction line. I combusted tubes and transferred the sample gas to the extraction line for purification. I then resealed the purified CO_2 in tubes and transferred it to the dual-inlet ports on the Finnigan MAT 252 for measurement of $\delta^{13}C_{om}$. Although fully-automated, on-line methods for organic matter combustion and sample gas introduction exist, the necessary equipment is costly, limits sample size (effectively increasing the minimum organic carbon content requirement), and can introduce 'memory effects' (retention and imprint of one measurement on subsequent measurements) (Ertl and Spitzy, 2004).

SOM radiocarbon dates are considered minimum ages for the onset of soil organic carbon accumulation (Driese et al., 2005; Scharpenseel and Schiffmann, 1977). These dates, although not instantaneous like those of wood or bone, provide a rough chronology of soil development. I prepared SOM samples for radiocarbon analysis the same way as for stable isotopic analysis. I took purified CO_2 in breakseal tubes to the accelerator mass spectrometry (AMS) laboratory at the University of Arizona, where I measured CO_2 volume and converted it the carbon within to graphite under the direction of Dr. Tim Jull. The graphite was then packed into targets on the AMS and measured for ^{14}C by technician Richard Cruz.

Thin section preparation. Soils, like other unconsolidated materials, require epoxy impregnation before they may be sliced, ground, and mounted. I prepared soils for thin sectioning in order to control impregnation and the orientation of the samples within the block. I mixed Buehler EpoThin high viscosity epoxy and impregnated soil samples under vacuum. Vacuum impregnation insures infiltration of pore spaces with epoxy. I cut and ground the blocks using rock saws and a grinding wheel and notated the blocks for orientation and slide position. As Washington University no longer maintains a thin section machine, I sent the samples to commercial facilities for slide manufacture. Because soil micromorphology examines both the structure and nature of the soil, samples were only impregnated and thin sectioned if some amount of material remained intact inside the sample container. Due to the difficulties of sampling the dry, hard, brittle soils, some samples were lost due to crumbling/disaggregation during sampling and/or shipment. I took 14 micromorphology samples from archaeological trench profiles at the Danilo Bitinj site, of which 12 survived shipment and preparation. Of the 12 impregnated samples, I was only able to recover enough material to fill 4 of the large slides standard in soil micromorphology (5 x 7.5 cm). I processed the other 8 samples regardless, hoping to recover some information; however, these samples may prove less useful for micromorphological study.

X-ray powder diffraction. I ground soil and ceramic samples with an agate mortar and pestle in preparation for X-ray diffraction (XRD). I placed sample powders in an aluminum slide, which I then placed inside the diffractometer. The Rigaku Geigerflex D-MAX/A Diffractometer directs CuK_α radiation at the powdered sample. Automated rotation of the goniometer changes the angle of bombardment. Minerals within a sample diffract the X-rays, producing a spectrum of changes in diffraction intensity with 2θ angle (2 * goniometer angle). As mineral lattices diffract X-rays in a characteristic manner, I was able to analyze the resultant spectra to obtain sample mineralogy using MDI Jade software.

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Chapter 2. *Pedologic Analysis of the Danilo Bitinj Site, Central Dalmatia, Croatia*[*]

Abstract

As part of the Early Farming in Dalmatia Project, an interdisciplinary effort toward understanding the origins of European agriculture, we are performing a site-specific geoarchaeological study of the Middle Neolithic Danilo Bitinj site and the Early and Middle Neolithic Pokrovnik site. Here we present the soil description and analysis for Danilo Bitinj. The site, farmed for at least 7000 years, is located at the center of Danilo Polje, a valley in Dalmatia's well-developed karst terrain. Soils both on- and off-site are fine-grained and carbonate-rich. Other measured pedologic properties indicate a stable valley-bottom environment throughout the life of the analyzed solum. The longevity of agriculture corresponds with the high measured calcite content, while electric conductivity and pH measurements indicate a sodic, plant-toxic chemical environment. Soil organic matter stable carbon isotope data indicate a local environment heavily dominated by C_3 plants. Soil carbonate stable carbon and oxygen ratios were also measured, but appear to be out-of-equilibrium with those for organic carbon, and therefore invalid for paleoclimatic interpretation. According to regional paleoclimatic studies, the earliest agricultural occupation at Danilo coincided with a significant drought. This evidence for regional drought is at odds with the on-site isotope data indicating relatively cool, moist conditions. These findings present an interesting scenario in terms of human behavioral ecology: that despite the soil's sodicity, Danilo may have represented a moist and productive resource refuge.

Introduction

The Early Farming in Dalmatia Project (EFDP) aims to elucidate the origins of European agriculture through site-specific geoarchaeological, paleobotanical, zooarchaeological, and artifactual analysis; and regional paleoclimatology. Despite nearly 100 years of investigation, the process, character, and diversity of Southeastern European 'neolithization' remain largely

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unknown – perhaps due to the bias in the record toward sites that would have been unsuitable for farming (Tringham, 2000). The sites under investigation are Danilo Bitinj (Middle Neolithic) and Pokrovnik (Early and Middle Neolithic) (Figure 2.1). These EFDP excavations provide a unique opportunity for re-examination and comparison of Neolithic expression at two open lowland sites in central Dalmatia, the bridge between Near East domestication and European farming. The geoarchaeological and paleoclimatological components of this project aim to construct the first multi-scale (local and regional) climate records for Central Dalmatia, and to elucidate site taphonomy. We focus here on description and analysis of the Danilo Bitinj soils.

The Danilo Bitinj site is located at the center of Danilo Polje, an elongate, flat-bottomed karstic valley (Figure 2.2). This valley is part of the Dalmatian polje-karst field, whose structure originated in the northwest-southeast structural trend of the Dinaric section of the Alpine orogeny (White, 1988). This region is subject to the Mediterranean, or xeric, moisture regime, in which the majority of annual precipitation falls in winter months. Danilo Bitinj, the type-site for the Dalmatian Middle Neolithic, has been occupied and farmed for at least 7000 years (cal BP) (Moore et al., 2007). Prehistoric cultural deposits contain lithic, ceramic, faunal, and botanical artifacts. Field observation reveals fine soils (clay and silty-clay), and lime- and dolostone bedrock. The reason for the site's long agricultural use-life may be its soils – their texture, parent material, and landscape-setting promote fertility, making the valley-bottom ideal for agriculture, even in times of drought or resource-stress.

Methods and materials

Samples are from a single 150-cm profile in Danilo Bitinj archaeological trench 'A' (Figure 2.2), taken every 20 cm from the surface to the parent material (sample A1 – 10-20 cm depth to sample A7 – 130-140 cm) (Table 2.1). Soils throughout the site are locally-termed 'brown soils' (smeđe zemlište or terra fusca), typically having variable depth, poor drainage, and hard structure (Antić et al., 1982). Site soils are dark brown (2.5Y 3/2 and 3/1), developed from a silty yellow (5Y 5/6) parent material. A and B horizons have blocky structures; the B horizon is distinguished by

Figure 2.1. Modified LANDSAT image of central Dalmatia.

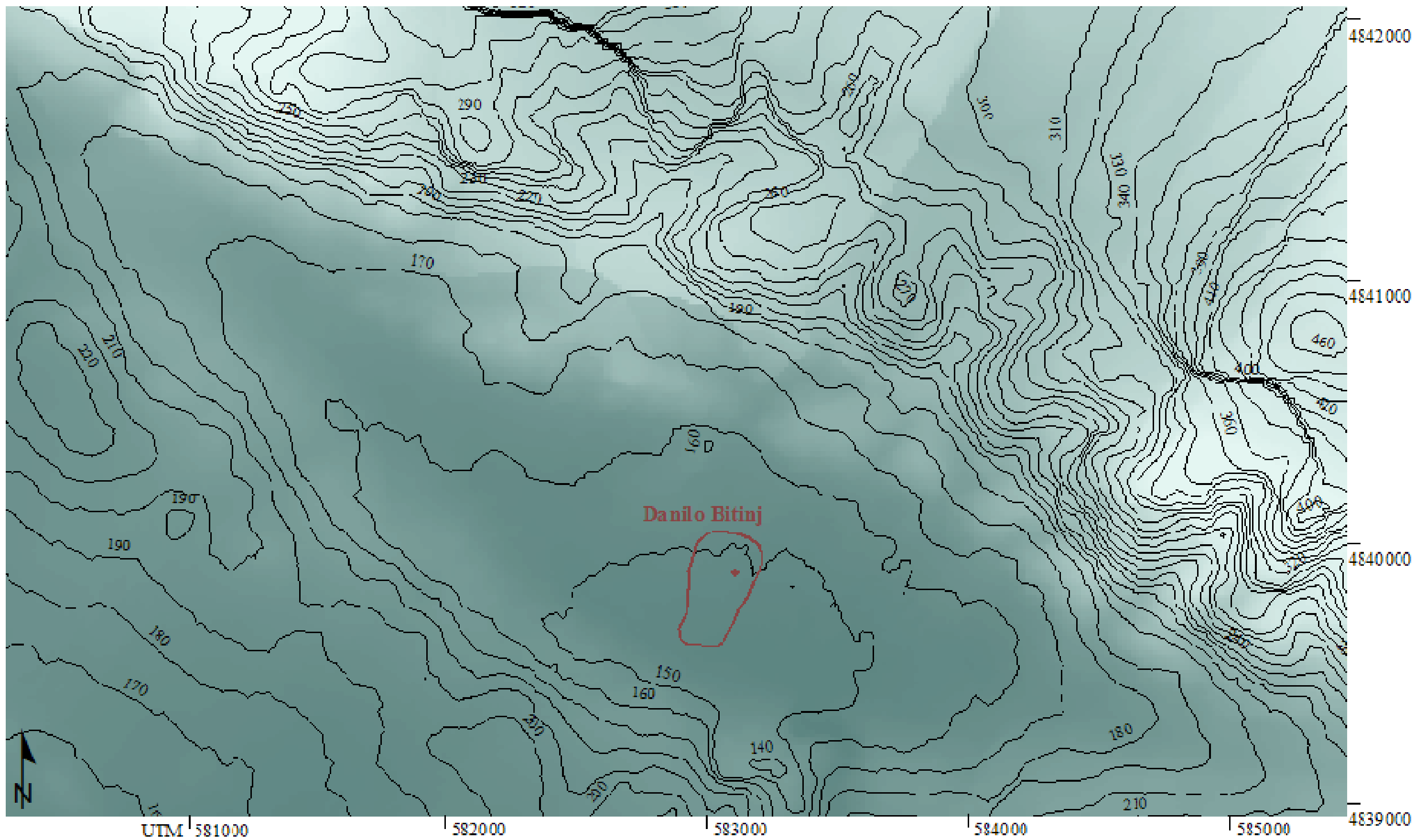

Figure 2.2. Topographic contour map of Danilo Polje showing site boundary outline and on-site soil sample collection point.

Table 2.1. Danilo Bitinj soil data.

Depth (cm)	pH	Conductivity (mS/m)	Organic carbon %	Organic matter %	$\delta^{13}C_{om}$ (‰ PDB)	$\delta^{13}C_{cc}$ (‰ PDB)	$\delta^{18}O_{cc}$ (‰ PDB)	Enrichment (om-cc)(‰)	C_3 %
10-20	9.2	11.99	1.738	2.997	-24.2 ± 0.7	-6.6 ± 0.2	-5.2 ± 0.2	17.6	87
30-40	9.0	13.53	1.906	3.286	-24.4 ± 0.3	-6.2 ± 0.4	-5.4 ± 0.1	18.2	89
50-60	9.2	12.31	1.758	3.031	-24.0 ± 0.6	-9.0 ± 0.2	-7.2 ± 0.1	15.0	86
70-80	9.2	11.54	1.619	2.791	-23.5 ± 0.2	-7.9 ± 0.1	-6.8 ± 0.2	15.6	82
90-100	9.3	10.69	1.167	2.011	-24.2 ± 0.5	-7.7 ± 0.1	-6.6 ± 0.4	16.5	87
110-120	9.5	10.31	0.758	1.307	-23.7 ± 0.2	-5.1 ± 0.3	-5.3 ± 0.0	18.6	84
130-140	9.5	10.39	0.361	0.623	-24.0 ± 0.0	-5.6 ± 0.2	-4.9 ± 0.0	18.4	86

larger, harder peds. We analyzed all seven samples for pH, electrical conductivity, organic carbon content, and pedogenic carbonate and soil organic matter (SOM) $\delta^{13}C$. We evaluated soil mineralogy through x-ray diffraction (XRD) of two soil samples (70-80 cm, B horizon; and 130-140 cm, C horizon). We prepared samples for electrical conductivity and pH measurement by mixing a 1:5 soil:water paste with an electronic mixer for 1 h (Rayment and Higginson, 1992). We used the Walkley-Black digestion-oxidation method to measure organic carbon content. XRD lets us identify soil minerals based on the characteristic way a mineral's crystal lattice diffracts x-rays. We analyzed the resultant spectra using MDI Jade software.

SOM (carbon) and pedogenic carbonate (carbon and oxygen) stable isotope measurements are valuable sources of paleoclimatic information, in terms of vegetation regime and relative local moisture variations (Nordt, 2001; Boutton, 1996; Cerling and Quade, 1993). Vegetation populations contain varying proportions of plant metabolic pathways – in this region both C_3 and C_4 plants, with the former favored by cooler, wetter conditions; the latter by warmer, more arid conditions. These pathways fractionate carbon differently, leaving a direct record of average plant population – and therefore environmental conditions – in SOM stable carbon. $\delta^{13}C$ averages -26‰ for C_3 populations and -14‰ for C_4 (Nordt, 2001). Stable isotope chemistry is particularly valuable for geoarchaeology, as it provides paleoclimatic data from the actual locus of human use or occupation (Huckleberry and Fadem, 2007; Davis and Schweger, 2004). This site-specific data allows inquiry at the level of human-landscape interaction, something not necessarily afforded by regional climate proxies.

The following processes make the SOM sample utilizable in the gas-source mass spectrometer: combustion of organic carbon, oxidation to form CO_2 gas, and isolation of the CO_2. We implemented the organic carbon off-line preparation method for $\delta^{13}C$-determination described by Sofer (1980) and evaluated by Tao et al. (2001), Vandeputte et al. (1996), Engel and Maynard (1989), McGaw et al. (1988), and Boutton et al. (1983). For soil carbonate analysis, samples must be powdered and acidified with ortho-phosphoric acid to produce CO_2 gas. We prepared carbonates by powdering soil samples, and used an on-line Gas Bench II device to liberate the carbon and oxygen. For both SOM and carbonate analyses, we analyzed two to four replicates of each sample using a MAT-252 mass spectrometer.

Results and analyses

Results of the Danilo Bitinj soil analyses are shown in Figure 2.3 and reported in Table 2.1. Results show general stability throughout the soil column. Organic carbon ranges from 1.9 to 0.4%, decreasing down the soil profile. Soils are basic, with pH ranging 9.0-9.5. Electrical conductivity (EC) is very low (10.30-13.53 mS/m), essentially non-conductive, for the entire profile. XRD spectra of samples A4 and A7 reveal a consistent mineralogy dominated by calcite (~90%) with quartz, clay mineral, and amorphous components. High pH and low conductivity indicate sodic conditions, which normally cause plant-toxicity and soil infertility (Brady and Weil, 2000). Because the soil contains such a large amount of calcite and has supported agriculture for 7000 years, we reason that high Ca/Mg-content must mitigate the sodicity. This high buffering capacity leads us to classify the soils as eutric in addition to sodic and xeric.

Soil carbonate isotope ratio measurements are known to incorporate carbon and oxygen from sources other than prehistoric climate, like detrital inputs or modern precipitates (Nordt, 2001; Boutton, 1996). SOM serves as an assessment of carbonate stable isotope data validity via (1) the greater chemical stability and resistance of soil humates (McCarthy, 2001; Brady and Weil, 2000; Birkeland, 1999; Kelly et al., 1998), and (2) the known fractionation between concurrently produced pedogenic carbonate and organic matter (Nordt, 2001; Cerling and Quade, 1993). If carbonate precipitation is concurrent with organic matter production, the enrichment in carbonate $\delta^{13}C$ relative to that of SOM is 11-16‰ (Nordt, 2001; Cerling and Quade, 1993). Enrichment values here range from 15-22‰ with an average of 17‰ (Table 2.1). Stable isotopic analysis of the SOM ($\delta^{13}C$ of 23.5-24.4‰) shows the plant community to be C_3-dominant (82-89% according to Nordt, 2001) and reveals a maximum variation of <1‰ for the life of the solum, indicating great stability in average plant metabolism.

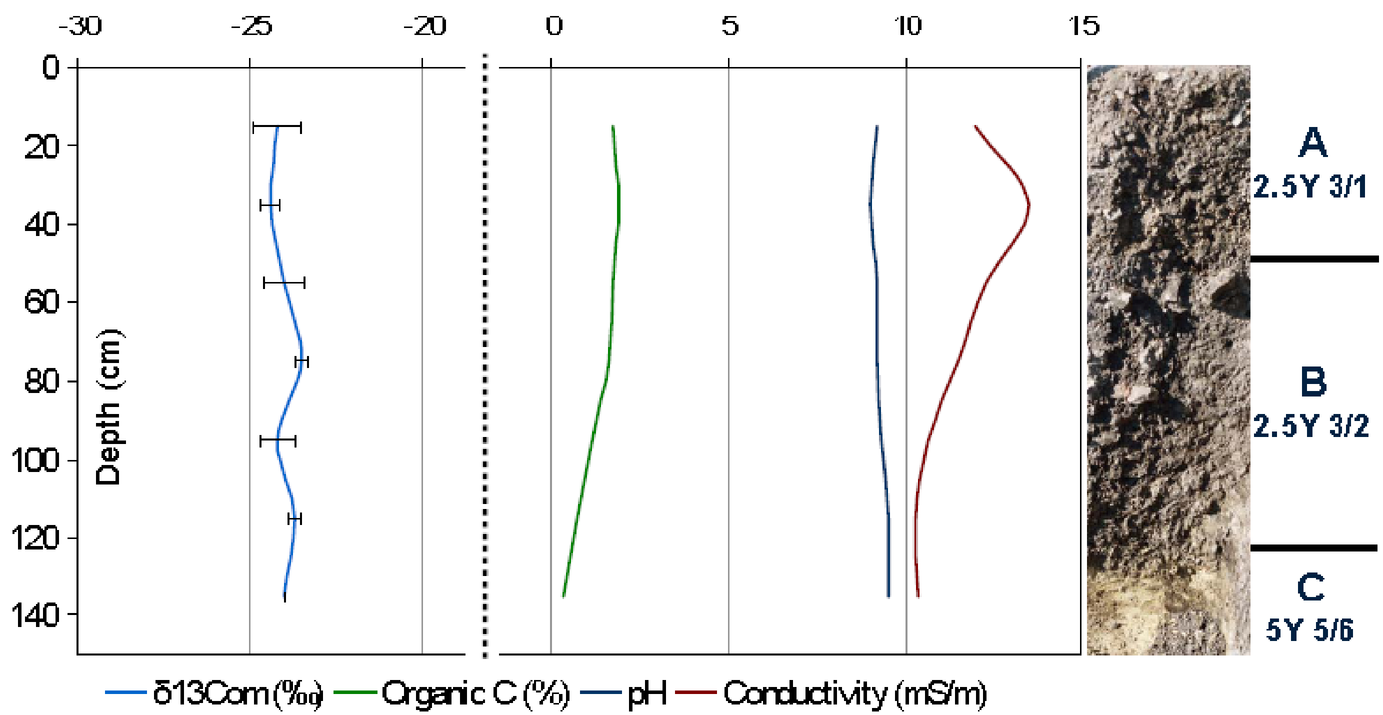

Figure 2.3. Danilo Bitinj soil data with simplified soil profile showing horizonation and Munsell colours. Isotopic data for organic matter (om) and calcium carbonate (cc) is relative to PDB.

The soil isotope data from Danilo Bitinj reveal that (1) soil carbonate isotope chemistry is an unfeasible climate proxy in this case, and (2) the site supported a heavily C_3-dominated plant community throughout the life of the solum. While further field or laboratory investigation may reveal a valid pedogenic carbonate isotopic signal, we will not interpret the carbonate data here, as equilibrium with SOM data should be demonstrated. The superior chemical stability of SOM allows us a view of paleovegetation irrespective of carbonate utility (McCarthy, 2001; Brady and Weil, 2000; Birkeland, 1999; Kelly et al., 1998).

Discussion and conclusions

The $\delta^{13}C$-stability and C_3-dominance of the plant community through the solum indicate a stable, relatively cool and moist valley-bottom environment (Huckleberry and Fadem, 2007; Krull et al., 2005; Davis et al., 2002; Nordt, 2001; Boutton, 1996; Cerling and Quade, 1993). Multi-proxy lake core studies on the Isle of Mljet, Croatia indicate a substantial dry period beginning ~7000 BP (Wunsam et al., 1999; Jahns and van den Bogaard, 1998). The importance of the rough coincidence of Danilo's occupation and a prolonged Early Holocene dry period is clear. What remains to be uncovered is how this climate change translated into resource productivity and availability. Geoarchaeological investigation in the Columbia Plateau of North America has revealed a climate-stress buffering mechanism specific to xeric valley-bottoms (Huckleberry and Fadem, 2007; Davis and Schweger, 2004; Davis et al., 2002). This research shows that the coupling of fine-grained lowland soils with a xeric moisture regime (wet winters and dry summers) produces plant communities essentially unaffected by resource stress. It is likely that this scenario holds true for our valley-bottom site as well, leading us to classify Danilo Polje as an insulated resource patch, or refugium, retaining productivity and biological diversity in the face of regional limiting climate conditions (Weiss and Ferrand, 2007). These data lead us closer to understanding site-choice, one of the Early Farming in Dalmatia Project's primary inquiries: during times of resource-stress in central Dalmatia, productive locales like Danilo Bitinj would certainly have been targeted for exploitation.

The Danilo Bitinj soils are sodic (alkaline, nonconductive, and high in Na^{+}), eutric (high in mobile cations relative to cation exchange capacity), and xeric (subject to dry summers and wet winters). They are composed primarily of calcite, with quartz and clay mineral components. The general pedologic picture is one of a living, moderately developed, fertile Mediterranean soil containing Middle Neolithic cultural remains. Questions remain as to the longevity and chronology of soil development: whether these artefacts and their soil matrix are a true paleosol recently revealed by erosive processes, or a living, stable, 7000-year-old surface. While the chemical data presented here reflect stability, further investigation of the polje's sedimentary history and dating of artefacts and soil humates may reveal greater complexity. Additionally, comparable data from the Early-Middle Neolithic Pokrovnik site will enhance our understanding of the conditions of early agriculture.

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Chapter 3. *Ceramic typology & material characterization for the Neolithic Danilo Bitinj and Pokrovnik sites, central Dalmatia.*[*]

Introduction & Setting

As a case study in the spread of agriculture from western Asia to Mediterranean Europe, the Early Farming in Dalmatia Project (EFDP) is an international, interdisciplinary effort toward understanding the transition to agriculture and its environmental impacts (Moore et al., 2007a, 2007b). Currently under investigation are two open, lowland sites: Danilo Bitinj and Pokrovnik, excavated by EFDP researchers in 2005 and 2006, respectively. Cretaceous limestones and dolomites, Eocene foraminiferous limestones, and Eocene/Oligocene calcareous conglomerates and marls make up the bedrock in the area surrounding the two sites (Perica et al., 2005). Sites are located in the central Dalmatian polje-karst (White, 1988). Poljes, which dominate local geomorphology, are karstic valleys with a lens shape, steep sides, and flat bottom. Danilo Bitinj, the type-site for the Danilo phase of the Middle Neolithic, is located near the coastal city of Šibenik in the bottom of Danilo Polje (Figure 3.1). Pokrovnik is located further inland near the town of Drniš in flat-lying fields – though not in a polje proper. Site assemblages are dominated by ceramics, but also contain faunal, paleobotanical, and lithic artifacts. Initial radiocarbon dates of charred wheat grains from Danilo Bitinj fall between 6737 and 7253 calendar years BP (Moore, 2007a). This study is part of the EFDP geoarchaeological effort to understand the conditions and raw materials of earliest European agriculture via the characterization of ceramics and soil parent materials.

Central Dalmatian Early and Middle Neolithic ceramics are identified by exterior designs – hatches, zig-zigs, and/or spirals pressed into the outside of the vessel prior to firing (e.g., Moore, 2007a; Miracle and Forenbaher, 2005; Brusić, 1980, 1976). While many EFDP ceramics have clearly impressed patterns, often sherd exteriors are worn or absent entirely, making the

[*] Prepared for submission to the journal Archaeometry with co-authors Jennifer R. Smith, Andrew Moore, and Marko Menđušić.

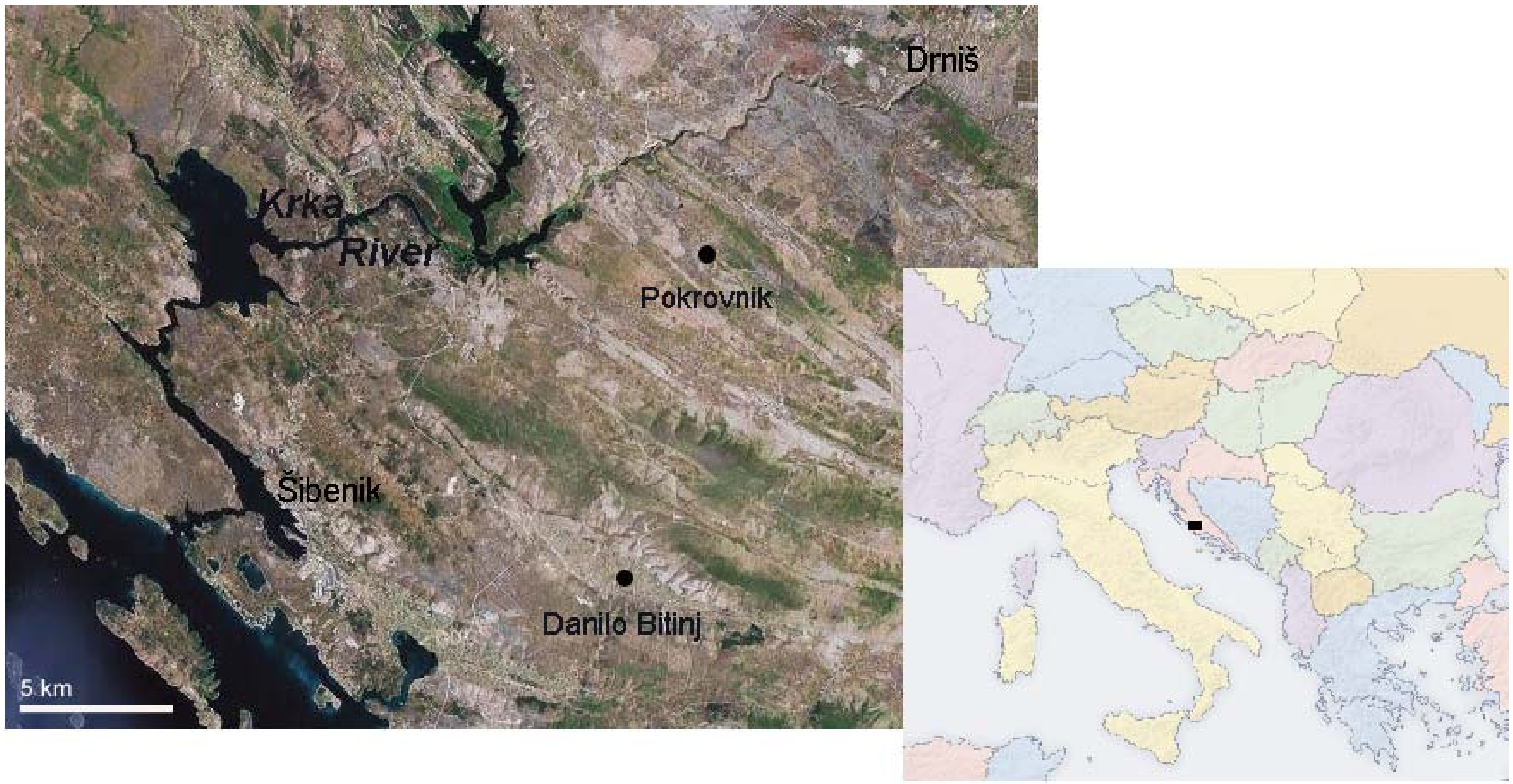

Figure 3.1. Site locations.

artifacts impossible to classify based on exterior decoration (Figure 3.2). Additionally potsherd assemblages are large, containing many thousands of artifacts lacking diagnostic features; thus, systematic analysis of a large portion of the assemblage is currently impossible. Understanding the ceramics, the largest single artifact category of both Danilo Bitinj and Pokrovnik site assemblages (Moore, 2007a, 2007b), is thus essential to understanding the archaeology of earliest European agriculture, as pottery is a technology in which investment entails costs as well as benefits. Ceramic technology is so strongly associated with the European Neolithic that the presence of ceramic artifacts is viewed as evidence for neolithization and cultural phases are named for their pottery design elements (e.g., Linearbandkeramik culture) (Rice, 1999; Dennell, 1983). Neolithic ceramic artifact materials in neighboring areas are described simply as coarse or fine ware, sometimes with description of internal or slip color (Srejović, 1988; Marković, 1985; Mellaart, 1975).

Outside of decorative elements, the assemblages display a wide range of variation in color and some variation in fabric (Figure 3.2). Color differences are quite dramatic – with some sherds featuring sharply differentiated bands or regions. We used petrography to describe ceramic fabrics and to determine whether color variation could be attributed to physical differences not visible in hand sample. Our resulting fabric typology provides a basis for the classification and subsequent archaeological analysis of Danilo Bitinj and Pokrovnik assemblages. This study also establishes the feasibility of a systematic ceramic provenance investigation (*sensu* Neff, 1998). Assigning provenance to artifacts requires comparison with a large database of chemical data (Goren et al., 2002). We know of no Dalmatian or Balkan ceramic sourcing studies; so we have no chemical database of natural or artifactual materials with which to compare EFDP ceramics. The material characterization closest to our study area is of a single illite and smectite clay source in western Serbia (Simić et al., 1997). To begin to understand their composition and variability, we characterized a small set of sherds and possible ceramic source materials using X-ray diffraction. Neolithic Dalmatia is one of the farthest reaches

Figure 3.2. Ceramic sherds typical of the Danilo Bitinj assemblage.

of culturally displaced Italian obsidian and flint (Robb and Farr, 2005), but the assemblages at Danilo Bitinj and Pokrovnik are predominantly ceramic and contain few stone artifacts (Moore et al., 2007a, 2007b). In light of assertions concerning connections between Dalmatia and northern Italy made on the presence or absence of Danilo Culture influence in ceramic assemblages (Biagi, 2004), the potential for Dalmatian ceramics to be traced to their source(s) opens new avenues of research concerning the travel and/or trade of Neolithic cultural materials.

Fabric Typology

After excavations were complete at each site, Barbara Moore (EFDP Curator) selected a subset of sherds representing maximum visual diversity (Appendix 2). Danilo ceramic samples 47 and 48 are relatively unconsolidated and thought to be daub rather than potsherds. The forty-nine Danilo Bitinj sherds were thin-sectioned by Quality Thin Sections (Tucson, Arizona); the twenty Pokrovnik sherds, by Applied Petrographic Services (Greensburg, Pennsylvania). We examined each of the sixty-nine sherds in hand sample, and under stereoscope and petrographic microscope, as analytical types – in order to be useful in studying thousands of sherds – would have to be distinguishable with the naked eye or hand lens. In describing the sherds there are two primary constituents: temper and clay matrix. The clay matrix may either be clay mineral or any other material of the requisite texture and chemistry to partially reorganize molecularly and harden at firing temperature. The temper is used to increase the structural integrity of the ceramic ware and may be any material distinctly coarser than the clay matrix (roughly sand-size). If this coarser material does not combust at firing temperatures or dissolve in the soil environment, it remains within the ware and may be identified as pieces of shell, grit (mineral or rock), or grog (preexisting ceramic ware).

We observed three mutually exclusive fabrics distinct at all levels of analysis (Figure 3.3). These divisions are non-automatic groupings based on observation alone, rather than statistical analysis of codified attributes (Cau et al., 2004). All three types are variable in color, with type one varying more than two and three; we observed no physical variation correlating to color, although

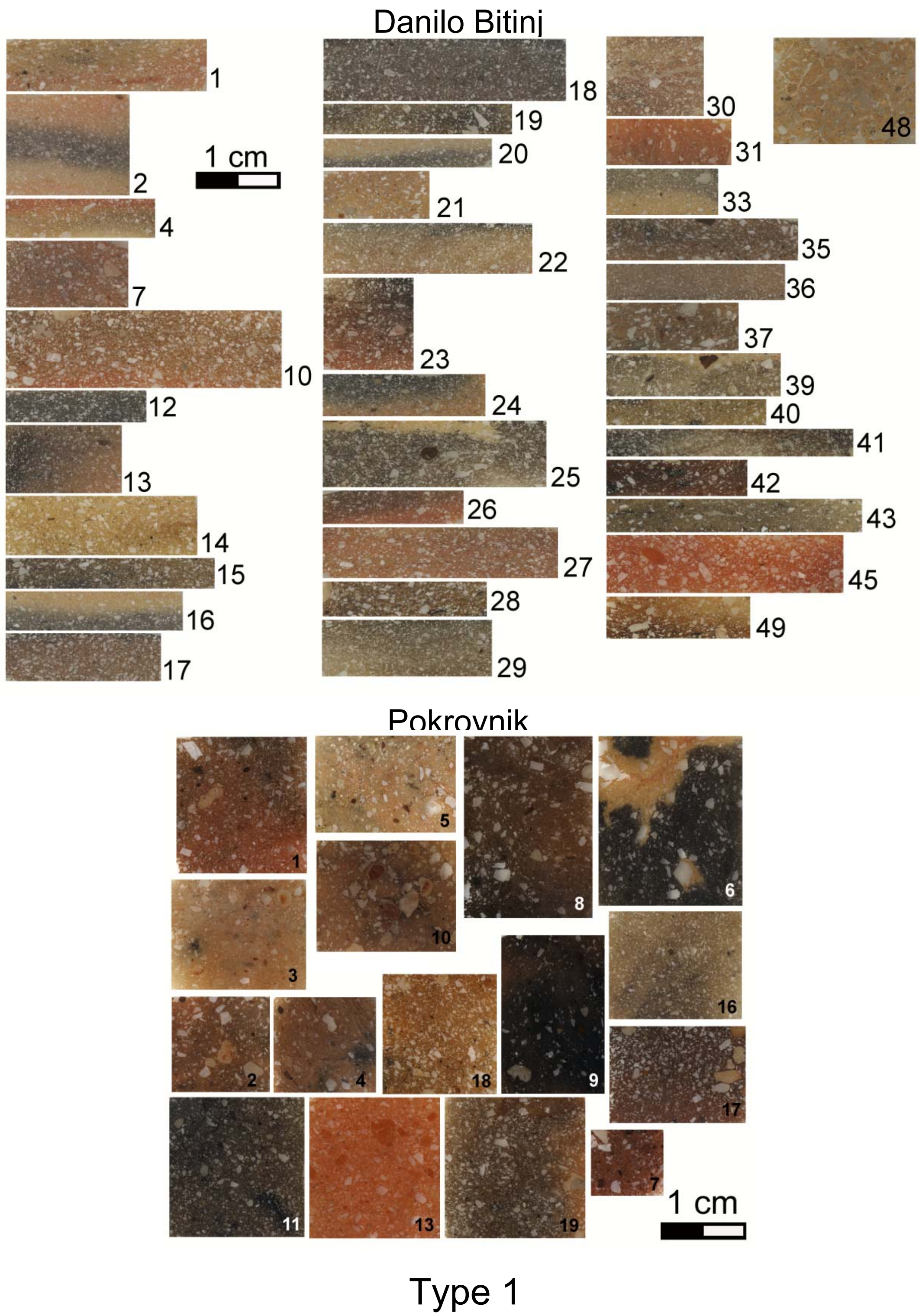

Figure 3.3. Thin sectioned ceramics sorted by site and type.

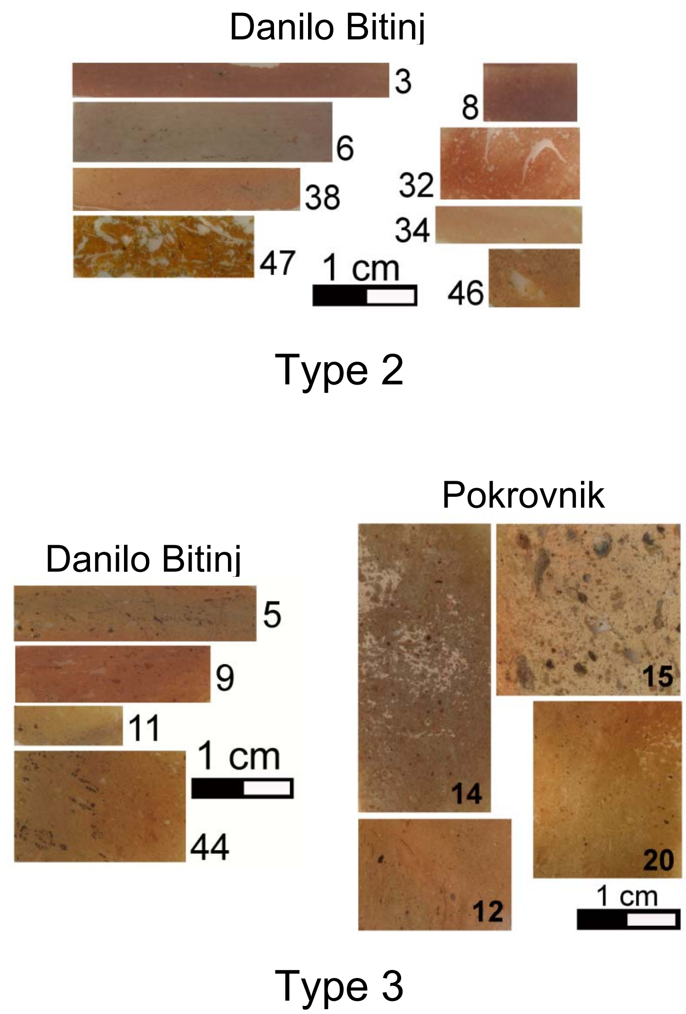

Figure 3.3. Thin sectioned ceramics sorted by site and type.

in some cases it did vary from inner to outer sherd. Excluding color, ceramic matrices are homogenous and amorphous, with no distinguishing features even at high magnification. Types are therefore based on inclusions or lack thereof. Type one is characterized by white mineral inclusions. Grit consists of poorly sorted carbonate and quartz up to 1 mm in size. Carbonate inclusions are of two varieties: (1) translucent in hand sample, and exclusively angular and often rhombohedral in thin section; and (2) opaque and angular in hand sample, with undulose extinction of aggregate, interlocking grains in thin section. Opaque carbonate grains are more common, and are mixed with translucent inclusions when the latter are present. Quartz grains are rounded and far rarer than carbonate grains. Type two appears completely homogenous with no inclusions. Type three has fine non-crystalline black and dark red inclusions, which are in many cases not dispersed evenly through the sherd. Black inclusions are round, wavy, and/or dendritic; red inclusions are round or rectangular.

The nature of these various inclusions is in most cases debatable. While one could refer to them as temper, it is uncertain whether any of the noted inclusions were purposely added to, simply present in, or formed during the firing of the original ceramic source material. The interlocking carbonates are clearly lime- and dolostone fragments, probably non-fossiliferous. Individual crystalline carbonate grains could be cleavage rhombohedra (broken fragments of a coarser material like marble or speleothem) or dolomite crystals precipitated *in situ* during firing (c.f., Adams and MacKenzie, 1998:133). Type three's black inclusions may be carbonized organic residues or manganese accretions; red inclusions may be grog temper or iron oxide accumulations. Overall the inclusions in type three appear much more natural (i.e., native to the source material) than those in type two, due to their lack of crystallinity, wavy and dendritic shapes, and lack of even dispersal. While a directed material-analysis approach like laser ablation or microprobe could address the identity of the inclusions (bulk analyses like X-ray fluorescence would not work for this purpose), they could not address their source – one would still be faced with the question of whether they were present as aggregates in the source material or aggregated during firing. These issues would probably be best addressed by experimental ceramics work attempting to replicate artifact features through manipulation of various local materials and additives.

Of the forty-nine Danilo sherds, thirty-four are type one, eight are type two, and four are type three. Sixteen type one and four type three sherds make up the Pokrovnik sample set. (Though it is classified as type three, Pokrovnik sherd 15 may be a type one sherd with the carbonate inclusions dissolved out of the matrix, as evidenced by its many voids and resemblance to Pokrovnik sherds 3 and 5.) Type proportions are not culturally meaningful; due to population sampling for visual diversity rather than assemblage representation, type one may be overrepresented due to its extensive color variation. As there is no apparent material source for color differences, we surmise these are oxidation features. The earthy brown, black, yellow, and red colors could have developed in firing or during soil residence. As polje floors are wet in the winter and dry in the summer, soils undergo thorough wetting and drying each year. If these burial conditions did variably alter sherd chemistry, such overprinting may complicate sourcing efforts, especially for type one ceramics.

X-ray Diffraction (XRD) Analysis

We chose geologic materials from three locales: the Danilo Bitinj and Pokrovnik sites, and Grofova Jama. In Slovenia in 2008 we were able to sample a deposit at Grofova Jama (Counts Cave) (Figure 3.4). This clay cave deposit resembled the Danilo Bitinj subsoil in texture and color. We had yet to identify or understand this parent material, which could be the source of the soil's seemingly plant-toxic chemistry (Fadem et al., 2009). Hypothesized to be a montmorillonite clay altered from Italian volcanic ash, the yellow clay at Grofova Jama is a common regional cave deposit (Hajna, pers. comm. 2008; Osborne, pers. comm. 2007). Though we are not specifically testing the possibility of archaeological travel and/or trade between this locale and our archaeological sites, analyzing the Grofova Jama material helps us affirm the nature of the cave deposit and whether the Danilo subsoil may have a similar genetic history.

Figure 3.4. Sampling locations.

The Danilo Bitinj sample is subsoil from the deepest part of the site (211-220 cm). The Danilo subsoil is a yellow and white (Munsell 5Y 6/4 and 7/2) fine silt. It has no structure and contains no gravel. The Pokrovnik sample is also subsoil (170-205 cm), a very dark red-brown (Munsell 7.5YR 2.5/3 and 3/2) silt loam with a blocky structure and no gravel. Site subsoils are the only gravel-free portions of either profile. They feel silty in hand test and appear homogenous. We tested these soil parent materials to explore both genetic history (by comparison with the Grofova Jama sample and each other) and sourcing potential (by comparison with two ceramic sherds). All three geologic samples were heated at 100^{0}C (per United States Department of Agriculture foreign soil regulations) and ground with an agate mortar and pestle for analysis.

We chose ceramic sherds for analysis from the Danilo Bitinj assemblage that were relatively homogenous, yet as distinct from one another as possible. As we were only testing two ceramic samples, difference between them increased the likelihood they would be analytically distinct. Homogeneity within the sherd insured analyses would represent contributions from as few components as possible. Inclusions in pottery can be native to the source or added by potters. If a temper is added from a different source, bulk chemistry and mineralogy represent a mixing of the different source materials (Harbottle, 1982). The two tested Danilo sherds – 9 and 34 – are of fabric types three and two, respectively (Figure 3.3). Ceramic samples were ground with an agate mortar and pestle in preparation for analysis.

We performed powder diffraction analyses on a Rigaku Geigerflex D-MAX/A Diffractometer using CuK_{α} radiation. Spectra record diffraction intensity from 2-$70^{0}2\theta$ (Figure 3.5). We analyzed the spectra using MDI Jade software. Due to the relatively high amount of amorphous, colloidal, and organic material in soils versus other materials (Bish, 1994), we used splining for background curve interpolation. In each case we looked for the simplest and most parsimonious match – the smallest number of likely minerals to account for the modeled peaks. Though the Grofova Jama spectrum may look atypical, after a replicate test with the same

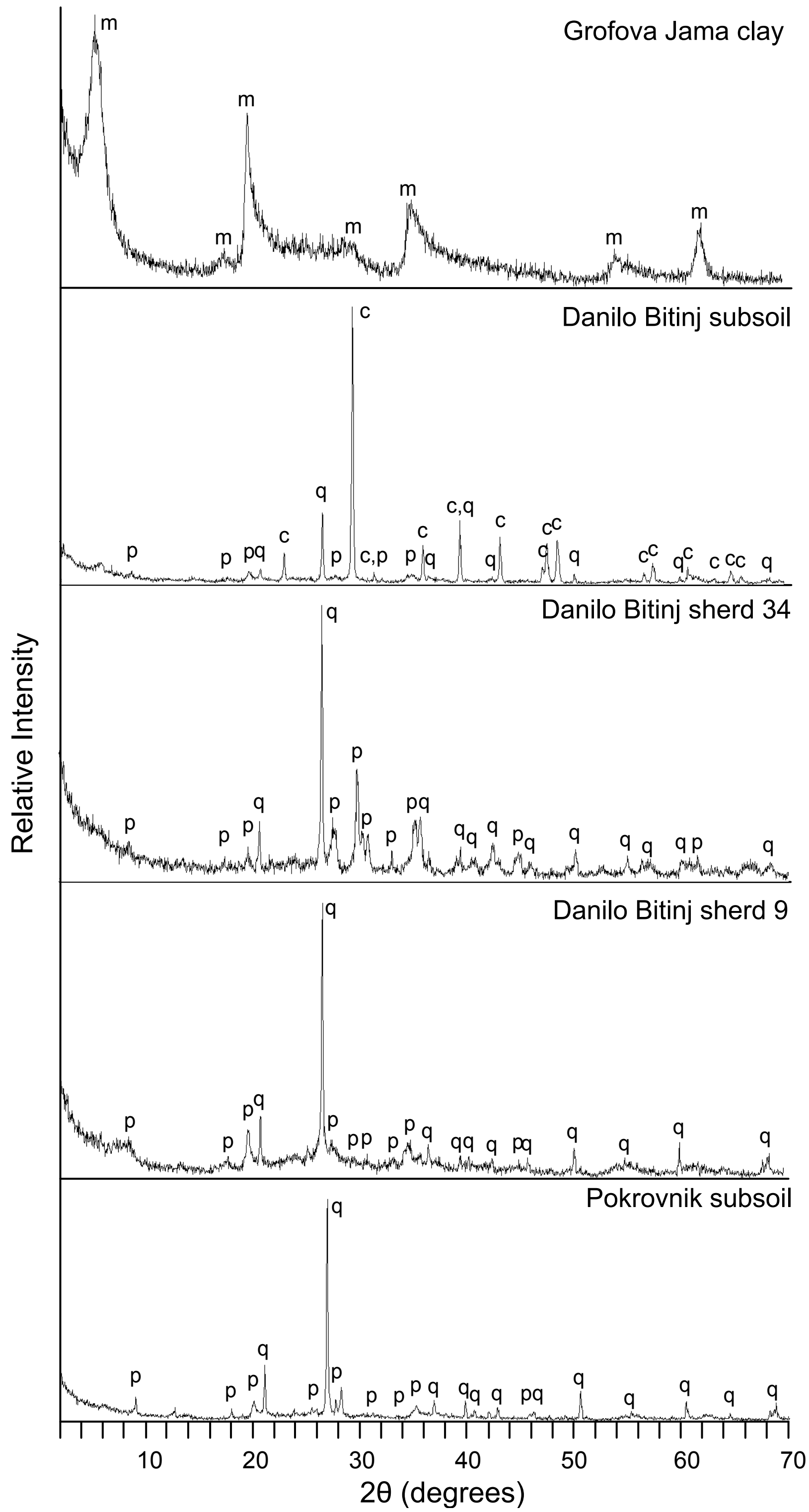

Figure 3.5. X-ray diffraction spectra with the following mineral diffraction peaks identified: m-montmorillonite, p-potassium feldspar, q-quartz, c-calcite.

results, we postulate the sample is actually a purer clay than we normally see, with the asymmetrical peaks characteristic of clays (Figure 3.6). Full intensity montmorillonite spectra account for all peaks and provide a good visual match. Due to the hydrous nature of clays, it is likely the true sample spectrum was somewhat altered by heating during pretreatment; however, the peak seen here at 62°2θ corresponds to the diagnostic *d*(060) montmorillonite peak, confirming this identification (Moore and Reynolds, 1997).

The soil and ceramic samples are more typical, with high-intensity phases distinct from the background. Calcite and quartz resolve the majority of the Danilo Bitinj subsoil spectrum peaks, with remaining peaks resolved by potassium feldspar. With the relatively large amount of quartz in the soil, it is difficult to determine which feldspar(s) is(are) present (Moore and Reynolds, 1997). Work directed at determining the K-spar polymorphs and their proportions, possibly ion microprobe or chemical separation studies, would inform hypotheses presented here and future work by providing formation temperature limitations. The Pokrovnik fines layer contains quartz and potassium feldspar, and – curiously for a karst soil – no calcite. The two ceramic samples share quartz and potassium feldspar as their primary components. If sherds are sourced in site soils, the differences between sherd and soil spectra are most likely a result of atomic reorganization during firing (Goffer, 2007).

Discussion

The hypothesis that the Grofova Jama sample is a montmorillonite is confirmed by XRD analysis. While montmorillonite could be an ash weathering product, the mineralogy alone cannot confirm whether or which volcanic eruption was the source for the original deposit. A comparison would have to be made between elemental data from Grofova Jama clay and known volcanic materials to confirm its identity. The quartz and potassium feldspar of the archaeological site soil parent materials and sherds are more consistent with an alkaline felsic outfall than the Slovenian clay mineral deposit or typical karst residuum. The large quartz-rich deposits feeding the soils at both sites are incongruent with sediments and soils developing solely from local limestones and dolostones, known as terra rossa. Terra rossa is well documented as being high in heavy metals and containing predominantly clay minerals and iron oxides (Durn, 2003; Yaalon, 1997).

It is hematite (α-Fe_2O_3) that gives the soils their red colors. In the Mediterranean (xeric) moisture regime, precipitation comes predominantly in winter months. During the cool, wet months, clays (along with their oxide skins) translocate downward in the soil column. During the dry summer months, ferrihydrite ($Fe_2O_3{\cdot}9H_2O$) 'dries out' to form hematite, thus spreading its red color throughout the soil, often accompanied by argillic (clay-rich) B horizon formation (Yaalon 1997). This pervasive iron-clay association is what gives these soils their name: fersiallitic. (Siallization is the formation of clay minerals.) Terra rossa is often called polygenetic, because it invariably has more than one parent material. The carbonate rock over which terra rossa develops does not form a regolith (parent material that 'feeds' a soil through its weathering), but rather dissolves, leaving small amounts of residual material. This residuum provides a chemical input to the soil, especially through saturated groundwater flow, but the solid parent material input comes from three other sources: Saharan dust, colluvium (sediments transported by gravity), and alluvium (sediments transported by rivers). Pedogenesis then alters these sediments, forming terra rossa (Yaalon, 1997; Durn, 2003). Due to the variation in terra rossa parent material input, establishing background values, or geochemical baselines for the area is difficult. Early studies focused on heavy metal concentration, and determination of 'pollutedness'. Later when construction of a geochemical map for Croatia became the goal of the government and UNESCO, researchers turned to development of surface-sampling methods and baseline determination. In general there is disagreement not over the presence of heavy metals, but over their source (anthropogenic vs. geogenic) and the health threat they pose. Establishing background values is critical for the determination of anthropogenic or geogenic input to the soil system, but in terms of soil contamination the source is inconsequential. Either the soil is contaminated (i.e., unsafe for agricultural use) or it is not. What is certain is that heavy metals do exist in the area and that they are present in terra rossa.

Prohic and Juracic (1989) analyzed Ni, Zn, Pb, Cu, Mn, and Cr content in sediments from the Krka River estuary and possible sources for these elements – cultural versus natural. They group these metals into three groups based on source and behavior in the estuary: (1) Ni and Zn are present in relatively high amounts in flysch, the source rock for the estuary, and behave irregularly in the sediment column. (2) Pb and Cu have low concentrations in both limestone and flysch, but are abundant in the upper sediment column, indicating an anthropogenic source. (3) Redox potential dictates the behavior of Mn and Cr, which are naturally abundant in limestone and flysch, respectively. Mn is more enriched near the surface due to oxidation and precipitation. Cr is depleted near the surface, but precipitates with increasingly reducing conditions lower in the sediment column. Surija and Branica (1995) analyzed the varying roles of exchangeable cations, carbonates, iron oxides, silicates, and organic matter in trace metal fractionation within sediments from the Krka River estuary. Concentrations in exchangeable cations were very low. Pb and Zn were bound predominantly in Fe oxides and carbonates; Cd was bound predominantly in carbonates and organic matter; and Cu was bound in carbonates, Fe oxides, and silicates. These authors note the strange affinity of trace metals for carbonate and raise the possibility of Dinaric carbonates as trace metal collectors. Cr, Ni, V, Mn, Cu, Cd, and Mo have been found in high concentrations in Croatia's relatively unpolluted karstic landscapes (Miko et al., 2003).

Durn et al. (1993) analyzed the heavy metal content of Croatian dolomite and limestone bedrock to gauge the danger posed in using these materials as a potential source rock for agricultural liming material. They analyzed heavy metal concentration in both the whole rock and in the insoluble residue. The bedrock contains Hg, Cd, Cu, Pb, Co, Zn, Mn, and Fe. The authors found concentrations high enough for concern only of Cd, an especially important heavy metal, being both mobile and bio-available in limed arable soils (Durn et al., 1993:153). Prohic et al. (1997) determined that for Istrian soils Pb, V, Cu, and Cr are mostly anthropogenic; radionuclides and Zn are of mixed origin; and Ba, Sr, Ti, Al, Na, Ca, Mg, Fe, Mn, Ni, and Co are geogenic. As part of the initial studies for a Croatian geochemical map, Miko et al. (1999) analyzed soils from

Sinjsko Polje in Dalmatia and Navigrad in Istria. They stated that the only promising sampling medium for a countrywide geochemical survey is the weathered bedrock in the form of soils – more specifically, terra rossa. Their findings show terra rossa to be highly chemically variable, thus attempts to apply normalizing factors or to use regression analysis on the data were mostly unsatisfactory. Miko et al. (2001:53) continued this work, using factor analysis to analyze the variability inherent in the soil data. Element associations derived from this analysis show that Al, As, Co, Cu, Fe, La, Mn, Pb, Ni, Mn, Th, V, Cr, Zn, Zr, and Nb are more abundant in carbonate terrains, while K, Na, Mg, and Ba are less abundant. Sr, P, and Ti are present in equal amounts in carbonate and non-carbonate Croatia (Miko et al., 2001:71). Miko et al. (2003) assessed the mobility and bioavailability of heavy metals in Croatian soils, finding that mobility is high in the topsoil and decreases down the soil column for every heavy metal except Cu, which stays high throughout the column. The authors suggest that this decrease in mobility with depth is due to the high sorption capacity of Fe oxides and oxyhydroxides (Miko et el., 2003:265). The authors also attribute inflated levels of Pb and Zn in topsoil to anthropogenic input, since natural soil processes should be easily removing these elements from the active horizons.

The soils at Danilo Bitinj and Pokrovnik are not red fersiallitic soils – neither are they alfisols or mollisols (Fadem et al., 2009; chapters 4 and 5). We analyzed 15-20 g of five bedrock samples from each site for carbonate content (Table 3.1). Of carbonate bedrock at Danilo Polje, 0.3-1.4% is insoluble; at Pokrovnik, 0.0-4.9%. The residues are fine dark brown, black, and red films. Aside from its lack of similarity to the well-documented carbonate residuum-based soils of the region, the 10-30 cm-thick yellow-white quartz-feldspar deposit at the base of Danilo Polje seems an unlikely carbonate residue. However, the Danilo Polje bedrock samples are from the sides of the polje (Appendix 1) rather than the plain in which the soils are located. (Bedrock was never reached, though excavations in some cases exceeded 2 m depth). The sides and plains of poljes are theorized to host different lithologies (Perica et al., 2002; Gams, 1978), lowering the certainty of genetic difference. For Pokrovnik, though it is possible dissolution of material with

Table 3.1. Bedrock carbonate content

Site Area	Sample #	Sample weight (g)	Insoluble weight (g)	Insoluble weight (%)
Danilo Bitinj	5	15.931	0.227	1.42%
	7	20.824	0.112	0.54%
	8	20.484	0.155	0.76%
	10	19.417	0.109	0.56%
	19	20.255	0.064	0.32%
Pokrovnik	1	20.252	0.003	0.01%
	4	15.360	0.011	0.07%
	5	15.674	0.000	0.00%
	9	16.537	0.748	4.52%
	10	18.132	0.891	4.91%

~5% insoluble residue could have left sizeable deposits, the likelihood of such a scenario is currently impossible to determine: the extent and distribution of the formations from which the bedrock samples come (whether lower or higher in insoluble residue) are unknown (Appendix 1). As Pokrovnik is not located inside a closed depression, it is also difficult to estimate the amount of material which would have potentially overlain the plain and dissolved. XRD analysis of the residues would assist in characterizing the differences in soils and bedrock, but dissolution of much larger samples (particularly from the site plains beneath the soils) would be necessary. To characterize local bedrock and explicitly rule it out as a source for the soil parent material at each locale, detailed geologic rather than soil surveys would have to be undertaken, as well as landform-scale carbonate rock geochemistry studies.

Given the current ubiquity of carbonate bedrock and lack of inter-regional surface material transport, if the quartz and potassium feldspar of the soil parent material is not sourced in the bedrock, it is certainly foreign. The fact that both subsoils and sherds are characterized by quartz and feldspar rather than iron oxide and clay minerals suggests a non-local, possibly volcanic source for all four materials. While many years of pedogenesis may have altered the materials beyond eruption sourcing capability, it is possible for Italian volcanic material to have blanketed Dalmatia in the past. The largest known trachytic eruption is from the Campania volcanic region near Naples, dated to 14.9 ka ago with an estimated volume of 40 km^3 (Deino et al., 2004). Ash deposits as young as 7.1 ka are found in Dalmatian coastal lagoon cores (Jahns and van den Bogaard, 1998). Should eruption identification be possible, it would provide limiting ages for soil inception. Such a scenario raises further questions as to the deposition and preservation of volcanic outfall in Dalmatia. Deposits like that at Grofova Jama are known from cave contexts (Hajna, pers. comm. 2008; Osborne, pers. comm. 2007), indicating that surface processes collected local outfall and redeposited it in cave-systems where it was preserved. Surficial volcanic ash deposits are not currently known near the sites – Danilo Polje is mapped as Cretaceous limestone and dolomite, and Eocene foraminiferous limestone and flysch (calcareous), overlain by Quaternary alluvium; the Pokrovnik site area as Eocene/Oligocene conglomerates and marls, and Eocene foraminiferous limestone (Mikes et al., 2008; Perica et al., 2005). If volcanic material were only preserved in subterranean contexts, quartz-rich soils like those at our Neolithic sites would indicate cave features which collapsed post-deposition. Alternatively if the current polje-karst morphology had already developed, volcanic material may have been preserved or redeposited as basin fill, though a volcanic input to these deposits has not been previously recognized.

Due to the similarity in XRD results for site subsoils and sherds, it is impossible to distinguish them in terms of source. Additionally, montmorillonite clays like the Grofova Jama deposit are known to be impractical for ceramics manufacture without heavy tempering due to a high degree of shrinking during firing (Goffer, 2007; Stimmell et al., 1982). If type one sherds prove a closer match to Grofova Jama or other montmorillonite deposits than type two or three sherds, this mineralogy would suggest that type one carbonate inclusions are a deliberately added temper. For a comprehensive archaeological sourcing analysis, a very large dataset (of both ceramics and potential source materials) characterized using neutron activation analysis would be necessary. The samples tested here do show a marked difference in mineralogy from the most proximal known ceramic clay source (illite-smectite) in western Serbia (Simić et al., 1997). If there were movement of ceramic material throughout the Neolithic Balkans, we might expect differences of similar magnitude to be represented in Danilo Bitinj and Pokrovnik assemblages.

The typology presented here will allow analysis at three levels of ceramic diversity: the Danilo Bitinj and Pokrovnik assemblages, between them, and with sites throughout the region (Rice, 1989). As with any classification, use may initiate change: analysis of large portions of the assemblage may reveal new types, or it may become apparent further division of these three types is beneficial. While we see no physical distinction between clay matrices of different colors in thin section, it is possible some of the variation relates to source materials (e.g., Simić et al., 1997). If such relationships exist, future classification and sourcing studies will inform one another. We have confirmed that Danilo Bitinj ceramics could have been sourced on-site, given both chemistry and mineralogy. If further materials analysis confirms a genetic relationship between site soils and ceramics, these central Dalmatian Neolithic sites would have been loci for both early farming and ceramics raw material acquisition.

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Chapter 4. *Central Dalmatian Soil Dynamics & Earliest European Agriculture.*[*]

Introduction

The Early Farming in Dalmatia Project (EFDP) is an international interdisciplinary effort towards understanding the transmission of agriculture from western Asia to Mediterranean Europe. The Neolithic sites under investigation (Figure 4.1) are uniquely suited to illuminate this transition, as Dalmatia was the path of neolithization into Europe (Moore et al., 2007a, 2007b; Tringham, 2000). The work presented here is part of the geoarchaeological investigations of the EFDP, aimed ultimately at answering the question, 'Why here?' For if we view the transition to agriculture not as a natural progression, but as a conscious change in subsistence strategy, we must assume that farming technologies in this temporal and spatial situation presented a higher perceived benefit-to-cost ratio than precursor Mesolithic hunting-gathering technologies (e.g., Ugan et al., 2003). Our initial geomorphological and pedological investigations led to more questions than answers about the setting of earliest European agriculture (Fadem et al., 2009; Moore et al., 2007a). As we've begun to understand the site matrices more fully, it has become clear that the unanticipated combination of valley-bottom soils and geomorphology supports agriculture to the exclusion of the surrounding terrain. Seemingly incongruous soil attributes are most likely related to a volcanic parent material. Sizeable deposits of this material occurring in lowlands of the dramatic central Dalmatian polje-karst would cause localized karst cessation by blanketing permeable local material and serve as a rich agricultural substrate.

Poljes are karst landforms, valleys with steep-sides and flat-bottoms. Though they occur in many well-developed karst terrains, the central Dalmatian polje-karst hosts the largest concentration of poljes of any region in the world (White, 1988). Various karst researchers, in defining the polje landform, cite the fact that the word 'polje' means 'field' (e.g., Gracia et al., 2003; Biondić et al., 1998; Prohić et al., 1998; White, 1988). While 'field' is an English translation

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Figure 4.1. Site locations.

of ‘polje’, it does not fully express the cultural conflation of landform and land-use (c.f., Gams, 1978). In this region arable land is often found only inside polje landforms, as the surrounding karst is incapable of supporting larger-scale plant productivity due to the lack of productive soil cover of sufficient depth (Durn, 2003; Prohić et al., 1998; Božičević, 1992:16). In the Croatian language, many words dealing with agriculture carry the prefix ‘polje’ (e.g., agriculture/poljoprivreda, literally ‘economy of the polje’; and farmer/poljodjelac, lit. ‘polje worker’). We propose that in this region Neolithic subsistence choices evolved coincident with geomorphology, granting the central Dalmatian polje-karst preference in Neolithic occupation, and its fields subsequent predominance in archaeological site location. Here we present new pedologic data for the Danilo Bitinj and Pokrovnik sites and review our previously published data in light of these assertions.

The Danilo Bitinj Site

Located in the fertile plain at the base of Danilo Polje, Danilo Bitinj is the type-site for the Danilo Phase of the Middle Neolithic (Figure 4.2). Seemingly as important to its Neolithic occupants as it is to archaeologists, Danilo Bitinj represents a sizeable and relatively complex locus of early farming (Moore, 2007a). Yet the site’s long history of agricultural productivity seems at odds with its soil chemistry: initial investigation revealed Danilo soil to have high pH (9.0-9.5), low electric conductivity (0.103-0.120 dS/m), and low organic carbon content (0.36-1.89%) (Fadem et al., 2009). The soil’s severe sodicity (inferred from high pH and very low conductivity rather than direct Na-measurement) and low organic carbon content seem inconsistent with both its apparent fertility (cultivation from the Neolithic to the present) and the local lime- and dolostone bedrock (Brady and Weil, 2008; Moore et al., 2007a; Perica et al., 2005; Sposito, 1989). SOM accumulation is critical to agricultural yield, with a minimum recommended organic carbon content of 1.75% for arability (Hodges, 1991; Johnston, 1991). With a lime-and dolostone parent, one would expect Ca^{2+} and Mg^{2+} to be the dominant cations in the soil solution and exchange complex, and pH to be limited, with a maximum of 8.5 (Brady and Weil, 2008; Birkeland, 1999).

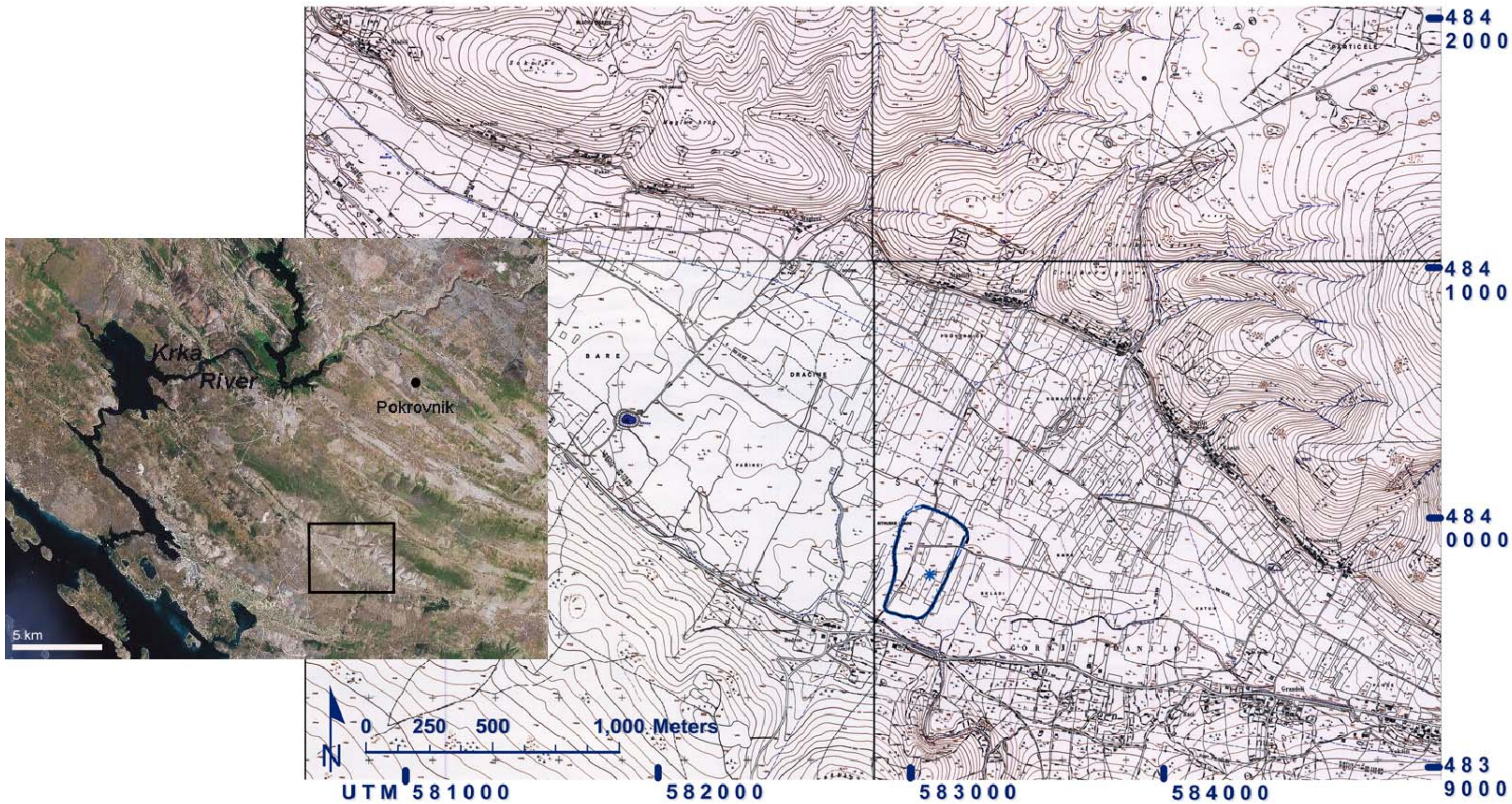

Figure 4.2. Topographic map of Danilo Polje with site boundary outlined and soil sampling locale marked. Inset is a modified LANDSAT image of the surrounding region. Rectangle shows the topographic map location.

Soil chemistry directly contradicted these expectations. There is no evidence in these soils for the long-term agricultural degradation (overgrazing, salinization, erosion, waterlogging) which would directly inhibit or preclude plant growth; however, soil organic carbon content is near the recommended minimum. Though there is always a decrease in soil organic matter at the onset of cultivation (especially tillage) (Riffaldi et al., 2002), the soil eventually reaches a steady-state (experimentally shown to occur after 10-30 years), which it maintains unless agronomic practices change (Janzen et al., 1997). Steady-state is achieved due to the addition and removal of organic matter by the plants under cultivation (Hodges, 1991). While in the past there may have been a different steady-state organic carbon level for Danilo soils, the fact remains that this value is unexpected for a soil known to support crops. Even if organic matter levels were higher in the past and agronomic practices were degradative, it is unlikely that they were high enough to continuously decrease for 7000 years and still support plant life.

Alkalinity may also be contributing to low organic carbon content, as soil organic matter can dissolve at high pH (Brady and Weil, 2008). Though exchangeable sodium percentage was not directly measured, high soil pH alone indicates the dominance of OH^- and HCO_3^- over H^+, as well as Na^+ over Ca^{2+} in the soil solution, despite ubiquitous carbonate bedrock (Brady and Weil, 2008; Birkeland, 1999; McBride, 1994). In the absence of salt, the major source of alkalinity is mineral weathering: silicate hydrolysis and Na- and K-carbonate dissolution (McBride, 1994). Even if there is not a particularly large amount of Na^+ in the soil (as in the case of silicate hydrolysis or K-carbonate dissolution), the continuous production of anions may be greater than the buffering capacity of the soil. If Ca^{2+} were the dominant cation, it would buffer soil pH (limiting it to 8.5) by pulling anions out of solution through precipitation of calcite (Brady and Weil, 2008). Thus, the high pH indicates not a necessarily high bulk Na^+ content, but a relative dominance of this cation due to anion activity. This relationship may be the reason alkalinization and solonization are synonymous in soil science (Chesworth, 1992).

Physically, sodicity degrades soils – low salt, high pH conditions limit flocculation, which limits the formation of soil pores. Sodic conditions are often toxic due to low plant Na^{+}, OH^{-}, and HCO_3^{-} tolerances, and growth-limiting due to low air and water permeability (Brady and Weil, 2008). Soils throughout the site consistently displayed the high dispersion and low permeability characteristic of sodic soils in the field and laboratory, indicating this particular chemistry is not a localized phenomenon. As the Danilo Bitinj soils supported one of the largest early farming occupations in the region and continue to produce crops today (Moore et al., 2007a), these initial results led to a reexamination of the soil in search of the inputs or processes which could resolve detrimental chemistry and productive land-use (i.e., soil characteristics which compensate for the seemingly plant-toxic conditions). As the polje subsoil and parent material, a yellow and white silt, had yet to be identified, further investigation began with it.

X-ray diffraction (XRD) analysis reveals the subsoil to be composed of calcite, quartz, and potassium-feldspar, with calcite and quartz as the dominant phases (see chapter 3). Figure 4.3 shows diffraction spectra through the soil column using three of the samples tested previously for pH, conductivity, organic carbon content and stable isotope chemistry (Fadem et al., 2009). 135 cm corresponds to Danilo subsoil, 55 cm to the B horizon, and 35 cm to the A horizon. This mineralogy – consistent through the soil column – reveals a non-karst, possibly volcanic origin (see chapter 3). Aside from detrital input of lime- and dolostone clasts, weathering of karst bedrock produces only a small amount of residual material, including trace elements and heavy metals, such that without the addition of unconsolidated material soil development and depth are limited (Durn, 2003; chapter 3). Though Saharan aerosols may contribute a fine-grained carbonate and quartz component, it is unlikely these would form a continuous ~10-30 cm thick deposit in the base of a Dalmatian polje, as they are known to contribute only 0-20 μm yr^{-1} to soils throughout the Mediterranean (Kapur et al., 2001; Yaalon, 1997). As quartz is one of the two primary constituents of this soil from subsoil to surface (up to 2 m deep in places), we must infer a non-native origin for the soil parent. Underlying bedrock is consolidated interbedded Cretaceous

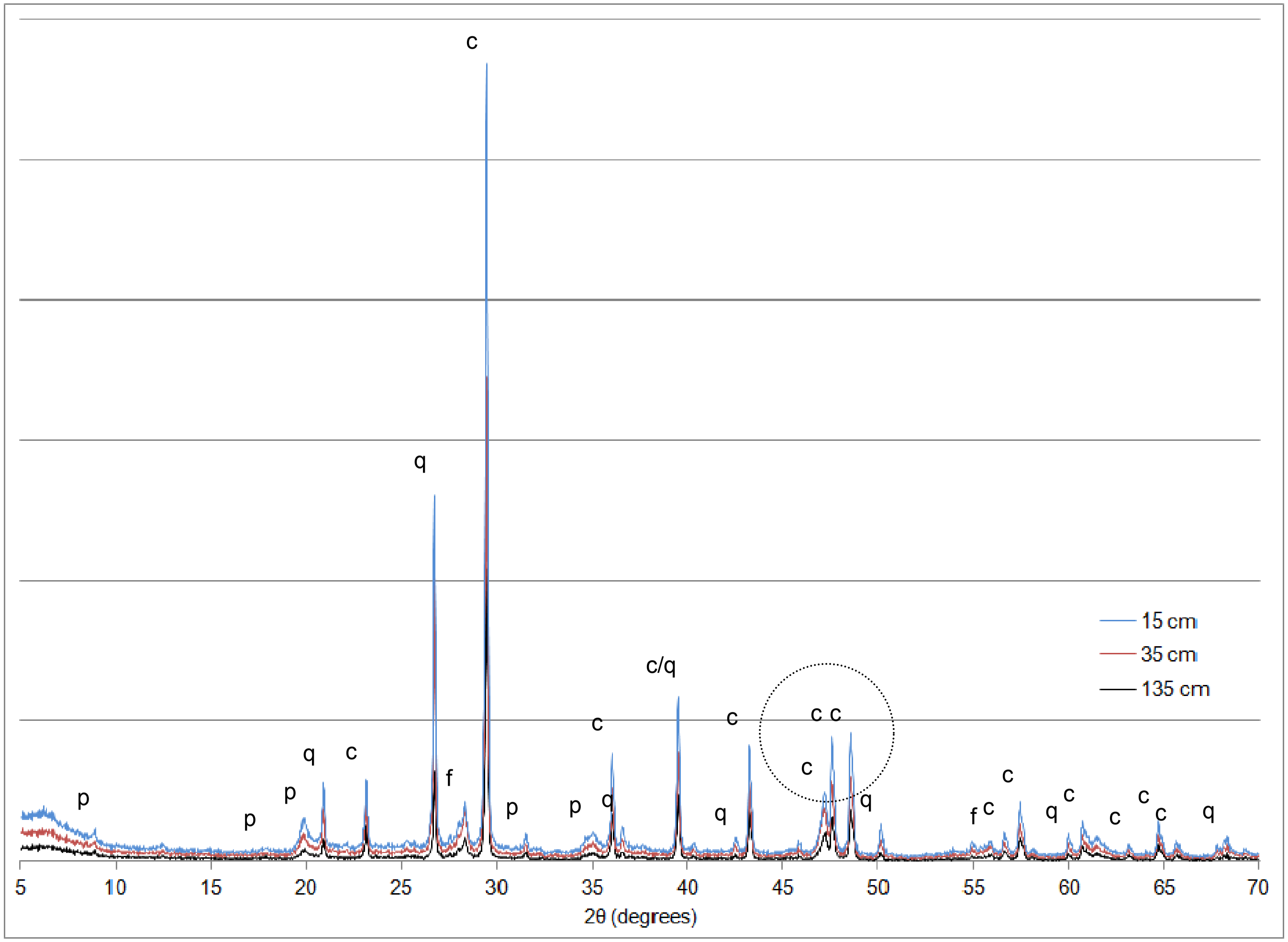

Figure 4.3. Danilo Bitinj site soil column X-ray diffraction spectra by sample depth. Mineral diffraction peaks are identified as follows: p-potassium feldspar, q-quartz, c-calcite, f-fluorite (fluorite was added for calibration). Circle marks potential location of Mg-carbonate peak shift.

and Tertiary lime- and dolostones (Perica et al., 2005). The only noticeable change through the profile from subsoil to surface is increased focus in some of the lower-intensity peaks. This effect could be achieved through eluviation of amorphous components in the absence of sufficient organic acids for further mineral degradation (Tan, 1986). One would expect calcite in Danilo soils regardless of parent material, due to high calcium and bicarbonate ion content in karst surface and groundwater (Dreybrodt and Gabrovšek, 2002; White, 1988). Alluvial waters at nearby Krka National Park (as well as at Plitvice Lakes National Park ~150 km to the north) continuously precipitate waterfall and barrier tufas (Lacković, 2005; Chafetz et al., 1994). However, quartz and K-Al-silicate indicate a foreign, possibly volcanic source (see chapter 3). This mineralogy, along with high soil pH is consistent with an alkaline volcanic parent material. Though the soil grain size is fine throughout (silty clay loam in hand test), consistent with the silty subsoil, the upper profile also contains 10-40% 0-10 cm carbonate gravel. If the parent is indeed volcanic rather than carbonate, the gravel component of the upper profile must have an alluvial or colluvial source.

Previously we published stable isotope data for Danilo Bitinj soil carbonates, but declined to interpret these data for paleoenvironmental information due to higher than ideal enrichment of $\delta^{13}C_{cc}$ relative to $\delta^{13}C_{om}$ and – subsequently – presumed contamination by detrital carbonates (Fadem et al., 2009). Here we re-examine these conclusions, given evidence suggesting the carbonates of the non-gravel component are in fact pedogenic rather than detrital. To confirm $\delta^{13}C$ organic matter values were not incorporating carbon from mineral phases, we altered the preparation method. Traditionally offline combustion methods for organic carbon call for combustion at 550°C (Tao et al., 2001; Vandeputte et al., 1996; Engel and Maynard, 1989; Boutton et al., 1983; Sofer, 1980; Buchanan and Corcoran, 1959). However, research has shown organic materials yield consistent isotopic results with combustion temperatures as low as 300°C (Ertl and Spitzy, 2004; Holt and Abrajano, 1991). Table 4.1 lists revised values for Danilo Bitinj SOM $\delta^{13}C$ combusted under vacuum in a CuO substrate at 375°C and purified to CO_2 using a

Table 4.1. Revised soil organic matter stable carbon isotope data.

Depth (cm)	$\delta^{13}C_{om}$ (‰ PDB)	$\delta^{13}C_{om} \rightarrow \delta^{13}C_{cc}$ Enrichment (‰)
15	-23.6 ± 0.8	17.0
35	-23.5 ± 0.1	17.3
55	-22.1 ± 0.2	13.1
75	-23.5 ± 0.2	15.6
95	-24.2 ± 0.5	16.5
115	-23.3 ± 0.7	18.2
135	-24.0 ± 0.0	18.4

vacuum extraction line. We measured isotopic ratios of oxidized SOM carbon samples using a Thermo MAT 252 mass spectrometer. The enrichment in carbonate $\delta^{13}C$ compared to that of SOM should ideally be 11-16‰ if carbonates are viable paleoenvironmental proxies precipitated as organic matter is produced (Nordt, 2001; Cerling and Quade, 1993). Though the average enrichment is 0.5‰ lower with the new combustion temperature (16.6‰, previously 17.1‰), range and standard deviation are higher (2.1‰ and 1.8‰, previously 1.4‰ and 0.9‰, respectively). Highest enrichment values occur in the subsoil. The lowest enrichment value occurs at 55 cm depth (near the top of the B horizon). Though the range of variation in $\delta^{13}C$ is higher, all values are still well within the range for C_3 plants (those tolerant to cool, moist conditions) (Hoefs, 1997).

Soil chemistry argues against the incorporation of detrital carbonate in the soil carbonate pool. The solubility of Ca- and Mg-carbonates decreases with increasing pH (Pokrovsky et al., 2005; Pokrovsky et al., 1999; Pokrovsky and Schott, 1999; Birkeland, 1990; Morse, 1990). Carbonate dissolution is inhibited due to the high carbonate and bicarbonate anion content of alkaline solutions (Pokrovsky and Schott, 1999). Thus the carbonate gravels of the upper profile should remain intact, while any Ca^{2+} ions entering the soil in solution should precipitate. Additionally, though local bedrock is interbedded lime- and dolostone (Perica et al., 2005), XRD spectra exhibit no Mg-carbonate contribution (Figure 4.3). If Mg were present in the soil carbonate mineral lattice in any amount, diffraction peaks at 48 and 49°2θ would shift to the right, probably due to variation in Ca-O versus Mg-O bond-length (Doner and Lynn, 1989). Thus soil parent material is non-carbonate, soil conditions do not serve to break down colluvial carbonates, and mineralogy exhibits no detrital Mg-carbonate component.

Lastly, the soil carbonate stable isotope chemistry itself argues against contamination by marine carbonate material. Modern marine carbonates have positive $\delta^{18}O$ and $\delta^{13}C$ values (Rao, 1996), while values for ancient marine materials fall between -2 and 2‰ PDB (Ryskov et al., 2000). Carbonate rock units may be isotopically depleted if subjected to meteoric diagenesis, but

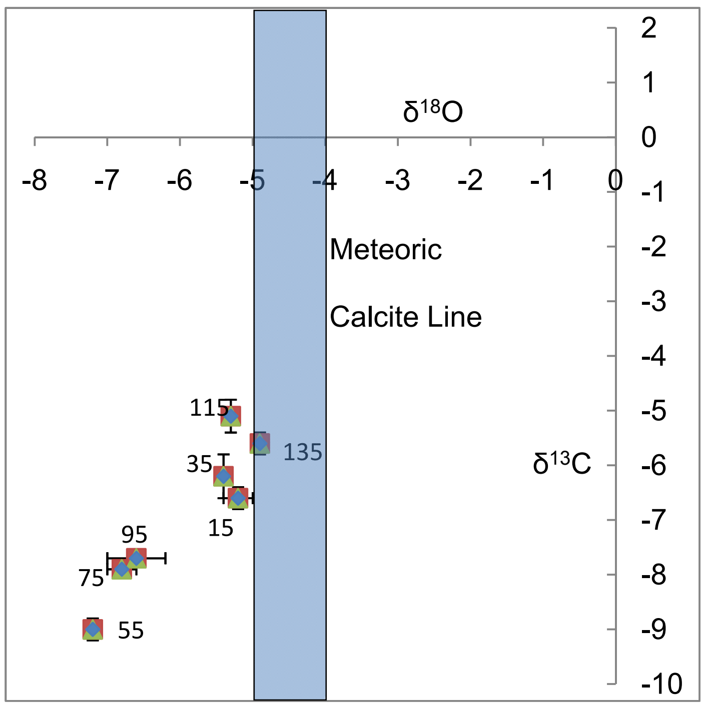

Figure 4.4. Cross-plot of Danilo Bitinj soil pedogenic carbonate stable isotope ratios. Points are labelled with sample depth (cm).

such depletion is in fact due to the depleted δ^{13}C of soil CO_2 (Morse and Mackenzie, 1990). A cross-plot of our carbonate stable isotope data showing Morse and MacKenzie's (1990) meteoric calcite line shows that our carbonates are at or below the minimum range of values for marine-affected carbonates (Figure 4.4), indicating a low likelihood of contribution to these ratios by isotopes fractionated in equilibrium with marine conditions. Isotopic analysis of local bedrock and of soil gravels from inner to outer clast would help us better understand the particular carbonate kinetics of this soil body and confirm the identity of its soil carbonates.

Comparing revised soil organic matter δ^{13}C data with carbonate data, relative changes (increases and decreases in the profile) are consistent (Figure 4.5). This relationship is expected for local plant populations responding to changing meteoric/regional water conditions (i.e., populations more tolerant to drought in times of drought). Paleoclimatic inferences from soil stable isotopes are based on the direct relationships between (1) plant carbon fractionation (characteristic to cold and moisture tolerant C_3 vs. heat and drought tolerant C_4 metabolism) and SOM δ^{13}C; and (2) meteoric water fractionation (with increasing dryness enriching rain-/snowfall in δ^{18}O) and pedogenic carbonate δ^{18}O (Nordt, 2001; Cerling and Quade, 1993). Soil isotopic composition at the base of the profile (110-140 cm) indicates conditions similar to those creating the modern soil (Figure 4.5). The slight decrease in δ^{13}C and δ^{18}O from 90-100 cm indicates cooler, moister conditions with plant populations responding in kind by becoming less drought-tolerant. δ^{18}O remains stable through 50 cm depth, indicating relatively stable meteoric water conditions, while δ^{13}C steadily increases from 80-50 cm, indicating more drought-tolerant plant populations. The topsoil from 0-40 cm reflects modern conditions: local plants are predominantly grasses and grapevines; the moisture regime is Mediterranean/xeric with cool, wet winters and very hot, dry summers.

Though the differences in isotopic ratios with depth are real (i.e., larger than the deviation within individual samples), sample-to-sample variations are within 1.4‰ for δ^{13}C and 1.8‰ for δ^{18}O, which may imply local paleoclimatic stability, as large-scale changes in plant population

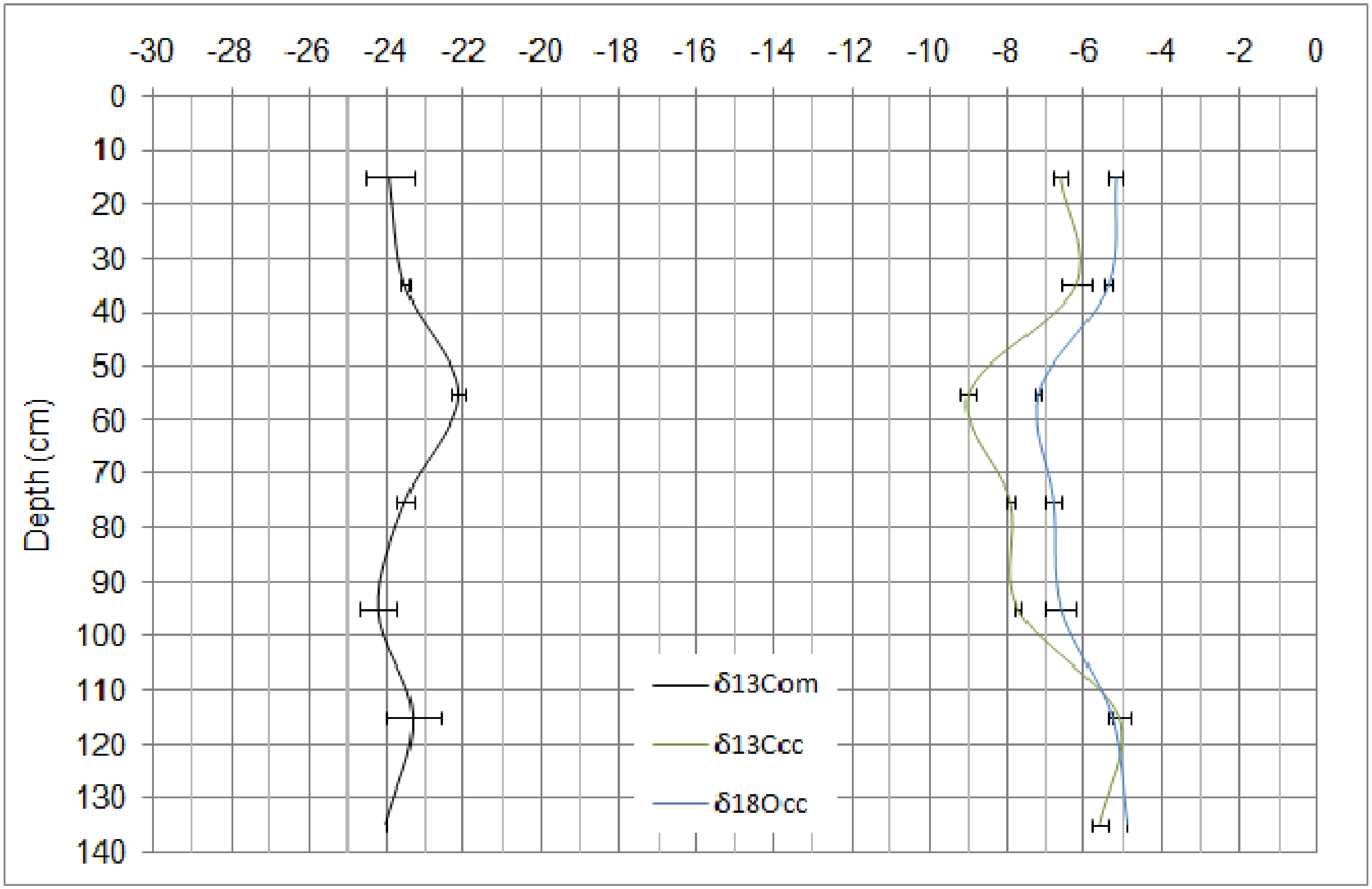

Figure 4.5. Danilo Bitinj site soil organic matter (om) and pedogenic carbonate (cc) stable carbon and oxygen isotopic data. Values are relative to PDB.

and/or moisture regime involve changes of 5-10‰ (e.g., Nordt, 2001, 1994). The time period during which any paleoclimatic changes indicated by the isotopic profile occurred remains to be seen, though Middle Neolithic artifacts dating to ~7000 radiocarbon years BP were uncovered throughout (Moore et al., 2007a). Additionally the range in carbonate $\delta^{18}O$ (2.3‰) is close to the range in SOM $\delta^{13}C$ (2.1‰), indicating a similar range of variation in fractionation by plant populations and of meteoric waters for the life of the soil. While regional climate records are also important for archaeological interpretation, local and regional records are fundamentally different sources of information. A given landscape may be located in a stressed region while containing resource-buffered refugia (*sensu* Gustafson and Wegener, 1998). As humans occupy discrete portions of the landscape, it is important to investigate both the local and regional climate records to understand the environmental factors impacting behavioral decisions. Geoarchaeological investigation in the Columbia Plateau has revealed a climate-stress buffering mechanism specific to xeric valley-bottoms with predominantly fine-grained deposits (Huckleberry and Fadem, 2007; Davis and Schweger, 2004; Davis et al., 2002). If Danilo were a climate refuge, we would expect a much lower range of variation in SOM $\delta^{13}C$ than carbonate $\delta^{18}O$, due to local vegetation community stability in the face of changing regional moisture conditions (Huckleberry and Fadem, 2007; Davis et al., 2002). These soil stable isotope data indicate productivity-limiting climate is not the cause of differential productivity in this area (at least during the life of this soil). Leone et al. (2000) present the only regional soil isotope study similar to that here, a pedogenic carbonate isotope analysis of a continuous 2.5 Ma profile in central Italy. They also interpret relative paleoclimatic stability through time even though their data exhibit a slightly greater range of variation than those here (~3‰ in $\delta^{13}C$ and $\delta^{18}O$). Their soil is also higher overall in $\delta^{18}O$ and lower in $\delta^{13}C$, indicating either hotter, drier conditions in central Italy than in central Dalmatia for at least the last ~2000 years or contamination from marine carbonates.

The Pokrovnik Site

The village of Pokrovnik is located ~10 km north-northeast of Danilo Polje. The Pokrovnik site is found adjacent to the village at ~260 m above sea level (Figure 4.6). Although the surrounding morphology cannot undeniably be termed 'polje', the site lies in planar fields with ridges up to 360 m elevation directly to the northeast and east. Accompanying plains extend northwest-southeast, as would be expected of polje-bottom plains. It is therefore possible the Pokrovnik site once resided in a polje like Danilo, whose landform characteristics have been overwritten by the nearby Krka alluvial system. Samples are from a single 220-cm profile in Pokrovnik archaeological trench 'A' (Figure 4.6), taken every 20 cm from the surface to the parent material (i.e., from sample A1 – 10-20 cm depth to sample A11 – 210-220 cm) (Table 4.2). The soil is fine (clay, silty-clay, and silt loams) and dark to very dark brown in color (7.5 YR Munsell hue) with medium blocky and prismatic structures (Figure 4.7). There are two fines layers separated by a thin gravel layer at the base of the profile. The fines themselves are the only portion of the profile without a gravel component; the upper profile consists of 10-30% gravel. There is a transitional zone between the lower fines layer and the bedrock consisting of 80% 0-50 cm gravel and 20% clay loam. The fines appear to have no relationship to the bedrock; thus they are the soil parent material.

We tested 11 samples from Trench A of the Pokrovnik site taken in 20-cm intervals (Figure 4.7). As with Danilo Bitinj, we measured organic carbon content using the Walkley-Black method, and pH_{H2O} and electric conductivity after 1 h of mechanical mixing of a 1:5 soil paste (Table 4.2 and Figure 4.7). Mechanical mixing was necessitated by soil hardness and impermeability. For the eleven Pokrovnik samples, conductivity ranges from 0.067-0.201 dS/m; pH, from 7.7-9.1; and organic carbon, from 0.59-3.05%. These attributes indicate very low salt content, neutral to alkaline soil solution, and moderate fertility. In all three attributes there is variation both at the surface and in the subsoil, while the B horizon (sample depth 55-135 cm) is relatively stable. Conductivity is lower and pH higher in the fines layers of the subsoil, with

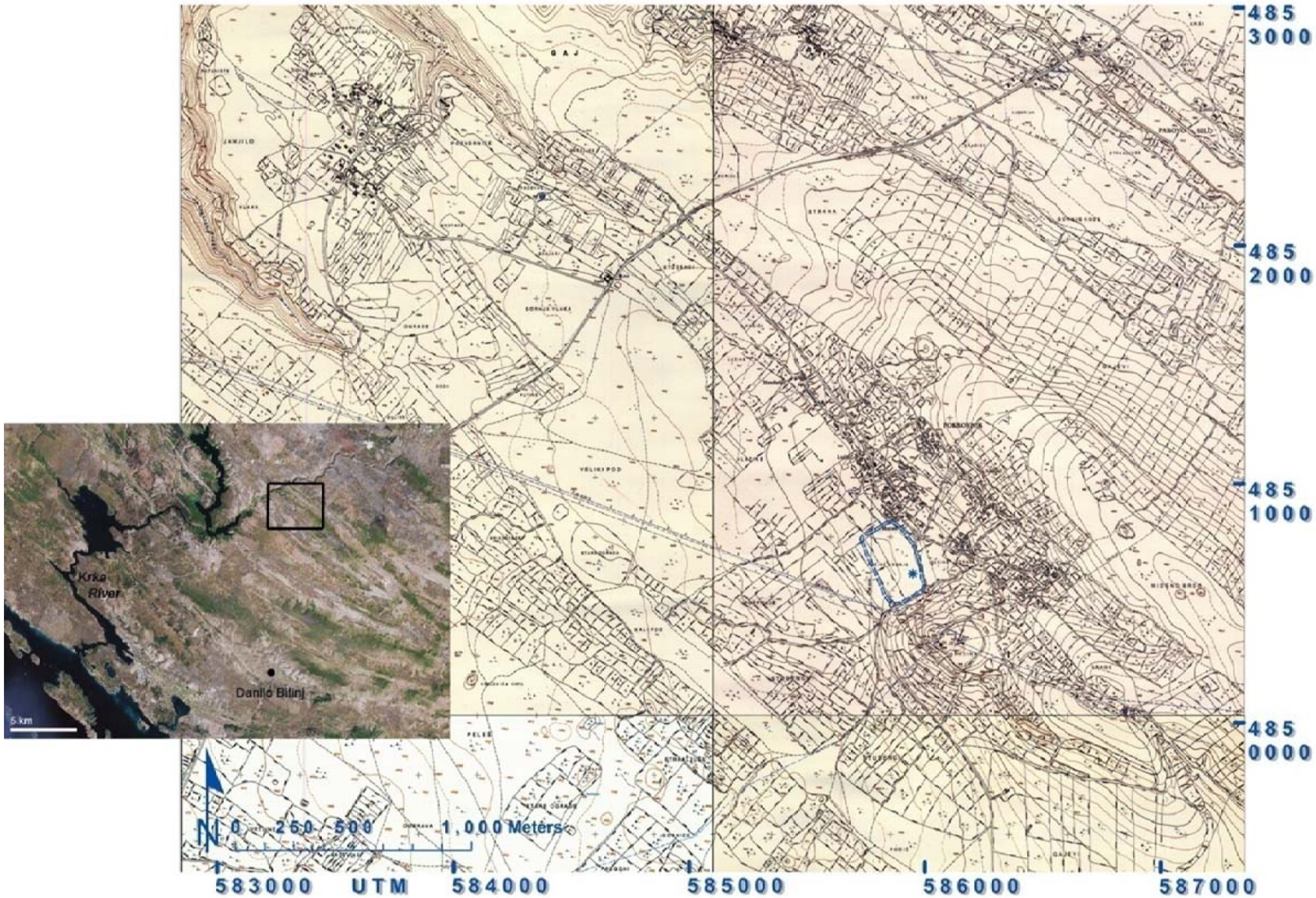

Figure 4.6. Topographic map of the Pokrovnik area with site boundary outlined and soil sampling locale marked. Inset is a modified LANDSAT image of the surrounding region. Rectangle shows the topographic map location.

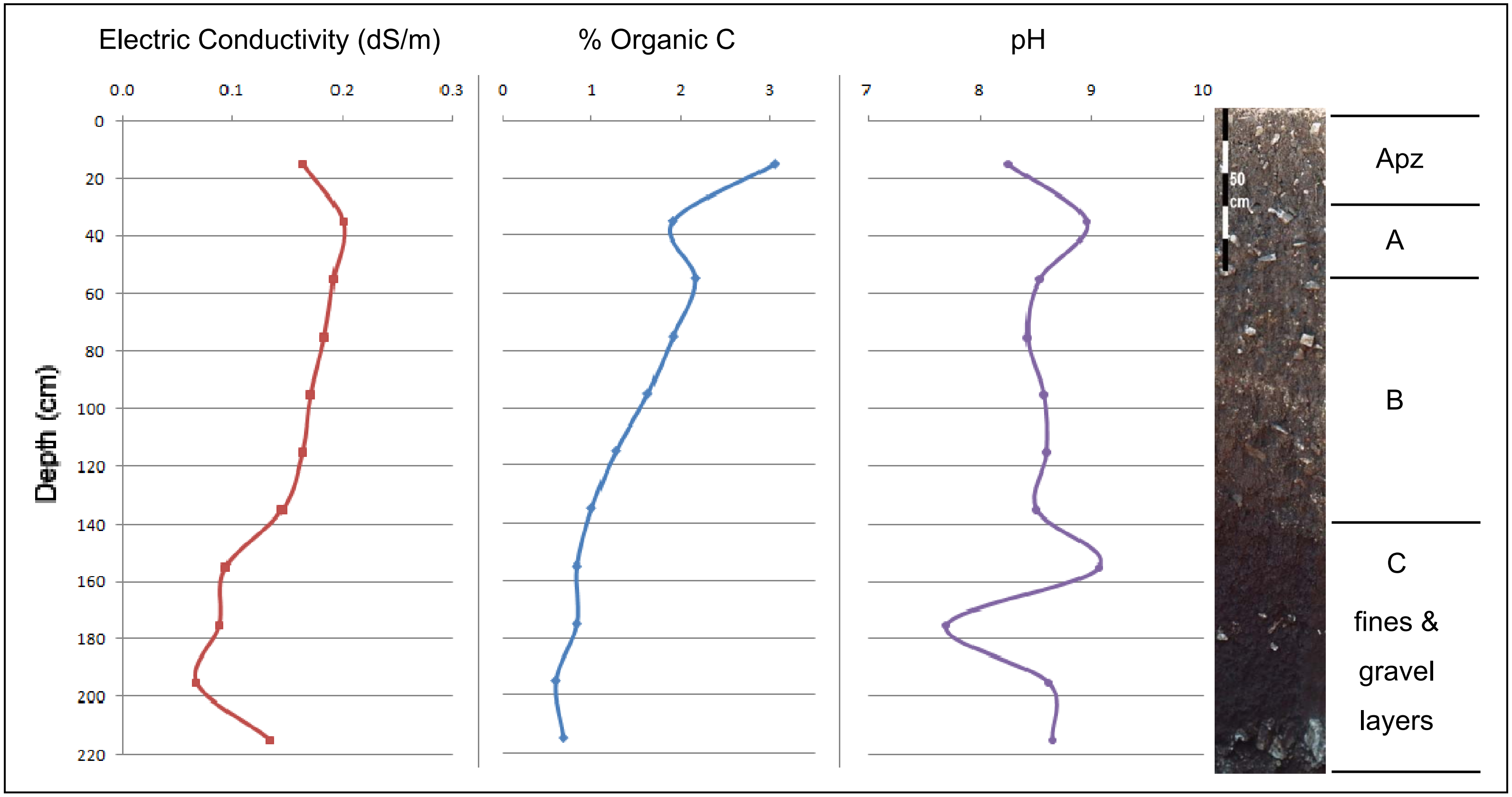

Figure 4.7. Simplified soil profile and chemical data for the Pokrovnik site.

Table 4.2. Pokrovnik soil chemical data.

Depth (cm)	Conductivity (dS/m)	pH	% Organic C	% Organic Matter
15	0.165	8.3	3.05	5.26
35	0.201	9.0	1.91	3.29
55	0.192	8.5	2.17	3.74
75	0.184	8.4	1.92	3.30
95	0.171	8.6	1.63	2.81
115	0.164	8.6	1.27	2.19
135	0.146	8.5	1.00	1.73
155	0.094	9.1	0.83	1.44
175	0.088	7.7	0.83	1.44
195	0.067	8.6	0.59	1.02
215	0.135	8.6	0.68	1.18

diversions between them at the gravel interlayer. There is also a slight increase at the gravel interlayer in organic carbon, which otherwise increases steadily from the subsoil to the living surface. We attribute surface variations in all three parameters to the immediate A horizon processes of depletion and contribution of salts, nutrients, and organic acids from plant life and decay (c.f., Birkeland, 1999). Overall the Pokrovnik soil is not as sodic as Danilo Bitinj soil; however, Pokrovnik subsoil fines layers exhibit a roughly equivalent combination of high pH and low conductivity (Figure 4.8). Pokrovnik soil contains more organic carbon than Danilo soil – by more than double (1.55%) at the surface. pH alone does not affect organic carbon accumulation (Martin and Haider, 1986), but sodicity promotes its dissolution and dispersion (Brady and Weil, 2008). Though many factors affect differential pedogenesis, the enhanced ability of the Pokrovnik soil to accumulate organic matter appears to have provided the appropriate feedback for greater soil development and departure from parent material chemistry.

Initial measurements (prepared and taken in the manner described above) of Pokrovnik site SOM $\delta^{13}C$ ranges from -22.8 to -25.8‰ PDB, indicating unequivocally C_3-dominant populations similar to those at Danilo. Due to further similarity between Pokrovnik and Danilo Bitinj in subsoil mineralogy, we believe more detailed investigation of Pokrovnik soil isotope chemistry will prove fruitful. X-ray diffraction analysis of the Pokrovnik lower fines layer reveals quartz and potassium-aluminum-silicate, but no crystalline carbonates (see chapter 3). Most likely the original deposit contained no carbonate and its fine-grained nature impedes groundwater flow (and subsequent carbonate influx). It is also possible the deposit once contained calcite, which has since eluviated, but this is not likely given its proximity to the carbonate bedrock (40-80 cm), distance from the soil surface (125-165 cm), and relatively high pH (8.5). The upper profile may contain calcite, as it has a more neutral pH, is more permeable, and consists of 10-30% 0-10 cm carbonate gravel. How much calcite there is and whether it precipitated in isotopic equilibrium with soil CO_2 remains to be seen.

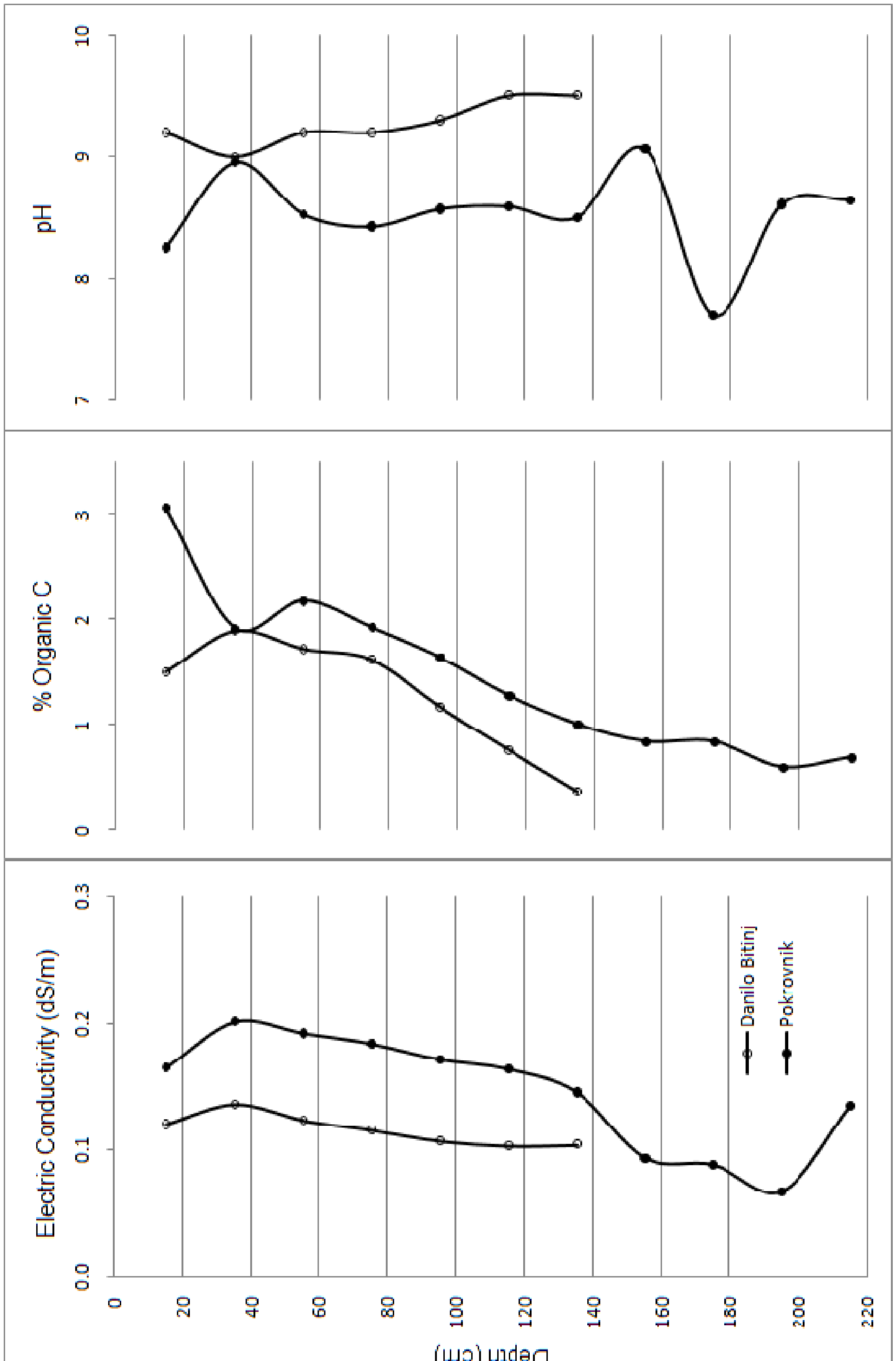

Figure 4.8. Comparative soil chemistry.

Soil Organic Matter Radiocarbon

We prepared samples the same way for radiocarbon as for stable carbon isotope analysis: as CO_2 gas isolated from whole soil combusted under vacuum at 375°C in a CuO substrate. Samples were then graphitized to pure carbon and analyzed for $^{14}C/^{13}C$ at the University of Arizona National Science Foundation Accelerator Mass Spectrometry Facility (Table 4.3). F values are the fraction of modern carbon in the sample, where F=1 is equivalent to 0 radiocarbon years (1950 C.E.) and F=0 is equivalent to 49,900 radiocarbon years (Donahue et al., 1990). We used the University of Oxford OxCal 4.1 program to calibrate radiocarbon dates to calendar years BP. Each date represents the apparent mean residence time of the soil organic carbon, or average age of the carbon in the sample, rather than an instantaneous date like those of wood, bone, or shell (Trumbore, 1996; Stein, 1992; Geyh et al., 1971; Scharpenseel, 1971). One may also consider SOM ^{14}C dates as minimum ages for the onset of soil organic carbon accumulation (Driese et al., 2005; Scharpenseel and Schiffmann, 1977).

The Danilo soil ranges in mean age from 0-2052.5±143.5 years BP, while Pokrovnik soil ranges from 624±65 to 6028±154 BP (Table 4.3). At both sites mean age increases from the surface downward, except in the case of the deepest sample. Figure 4.9 displays how soil chemistry varies with mean age. The surface soil at Danilo contains over 100% modern carbon, indicating no measurable contribution from carbon older than 1950 in the A horizon (Krull et al., 2005). The organic carbon in Danilo Bitinj soil and the upper Pokrovnik profile is much younger on average than the archaeological material it contains (dated to ~7000 calibrated years BP) (Moore et al., 2007a). While this discrepancy is consistent with soil processes that dissolve organic matter through time (leaving fewer ancient residues), analyzing more of the profile for radiocarbon would help us better understand the nature of the variation. We may still correlate organic matter $\delta^{13}C$ values with ^{14}C ages, as these are isotope ratios for the same soil aliquot.

Table 4.3. Soil organic matter radiocarbon data.

Site	Depth	Fraction Modern C	^{14}C Age BP	Calibrated Age BP
Danilo Bitinj	35	1.0208 ± 0.0043	post-bomb	
	95	0.6340 ± 0.0038	3,661 ± 49	2052.5 ± 143.5
	135	0.6919 ± 0.0038	2,958 ± 44	1194.5 ± 172.5
Pokrovnik	35	0.8297 ± 0.0038	1,500 ± 37	624.0 ± 65.0
	95	0.6746 ± 0.0033	3,162 ± 39	1379.0 ± 67.0
		0.6823 ± 0.0032	3,070 ± 38	
	155	0.4021 ± 0.0032	7,319 ± 63	6208.0 ± 154.0
	215	0.4975 ± 0.0034	5,609 ± 55	4445.5 ± 99.5

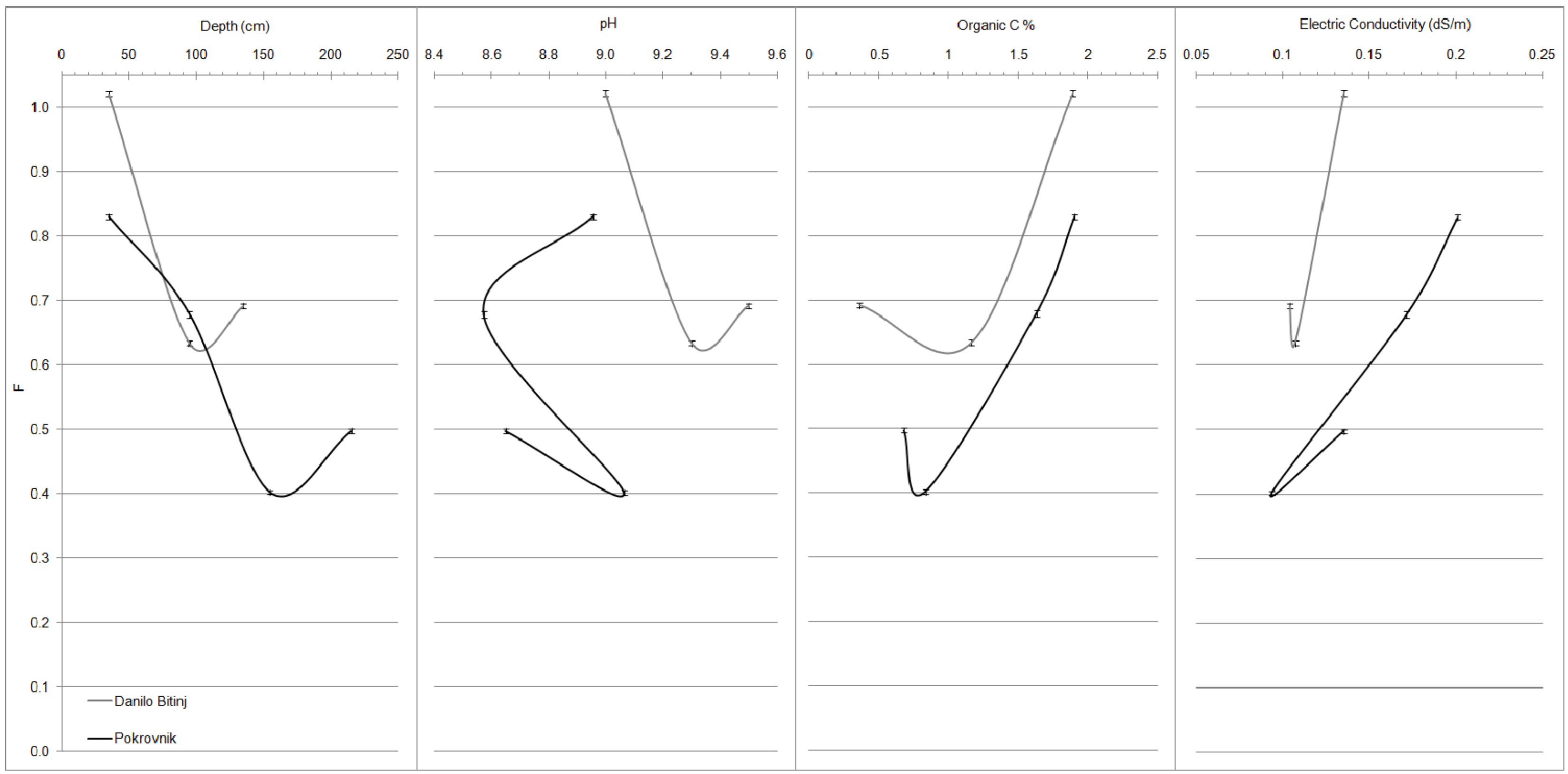

Figure 4.9. Danilo Bitinj and Pokrovnik soil chemistry versus fraction of modern carbon.

Discussion

Our re-examination of the Danilo Bitinj soil revealed its parent material does not conform to *a priori* expectations. The coupling of the Danilo Bitinj and Pokrovnik datasets reveals a pattern of arable lowland development in volcanic parent materials involving two primary soil inputs: mineral contributions from the parent material and ions in groundwater solution (Figure 4.10). This dynamic resolves the observed soil characteristics, including the suite of minerals present in the soil column. As quartz is the mineral most resistant to weathering, and potassium feldspar the most resistant of the feldspars (Brady and Walther, 1989), these may be the remnants of a more diverse pre-pedogenesis deposit, which could inhibit sourcing efforts. In particular we suspect Na-feldspars to have been present and possibly contributed to soil sodicity, although as stated above, a high bulk Na^+ content is not necessary to attain alkalinity. We hypothesize that localized acidity at plant roots counteracts soil sodicity allowing sufficient remediation for support of plant life as observed by Qadir et al. (2005). In this case the initial crop introduced to sodic conditions would have to have at least limited resistance to sodic conditions, unlike wheat (*Triticum aestivum*) (Murtaza et al., 2009). However, the abundant Ca^{2+} and Mg^{2+} in groundwater may provide enough buffering capacity to allow plants of low tolerance to take root and initiate the localized remediation. These hypotheses would best be tested experimentally. Such a feedback mechanism would account for the difference in pH between Danilo Bitinj and Pokrovnik: if the two parent materials began with similar pedochemical conditions, their chemical divergence may be the result of the Danilo Bitinj soil's lying fallow for a substantial amount of time. Continued cultivation at Pokrovnik may have allowed for maintenance of more neutral pH and accumulation of soil organic matter. Conversely cessation of cultivation at Danilo Bitinj would have reduced phytoremediative effects, raising the pH and promoting the dissolution of soil organic matter.

A polje-bottom soil with non-carbonate parent material – despite ubiquitously carbonate terrain – coincides with the apparent cessation of karstic surface processes within the polje (Fadem et al., 2009), as burial of soluble bedrock with volcanic material typically inhibits further

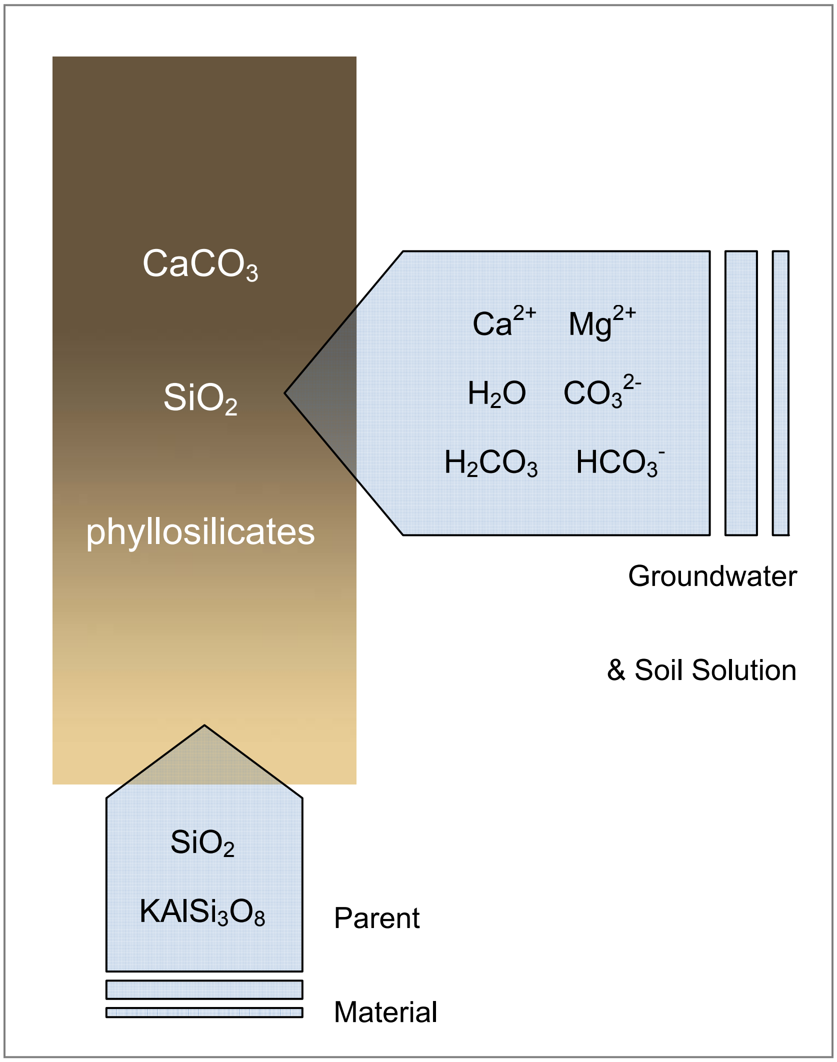

Figure 4.10. Scenario of soil inputs and precipitates based on soil chemistry and mineralogy.

karst development (Osborne, 2002). Soil stable isotope data also supports a non-climatic cause for differential productivity, as Danilo Bitinj – though a stable and archaeologically exploited resource patch – does not appear to have been a climate refuge. If this scenario is born out in other central Dalmatian poljes, the soil dynamic observed at Danilo and Pokrovnik would define the systematic interaction of volcanic outfall, karst geomorphology, and agricultural land-use for central Dalmatia for at least the last 7000 calendar years. A regional pattern of non-karst basin fill would also explain the classification of polje-bottoms as a separate Croatian engineering geology region, the remaining three of which are bedrock-delimited (Janjić, 1985). This scenario would also imply a pattern (and mutual exclusivity) of silicic, sodic, light-colored agriculturally viable soils in geomorphic depressions; and fersiallitic, iron oxide-rich, heavy and trace metal-rich, non-arable terra rossa wherever else soil cover occurs. Further regional implications include the ability of volcanic episode identification – if possible – to provide limiting ages for soil inception, and the ability of soil survey to identify other potential early farming locales.

As the characteristics we would use for direct comparison with Italian volcanic soils of a variety of ages (up to 100 ka) are by nature largely amorphous (Barbera et al., 2008; Egli et al., 2008; Mirabella et al., 2005; García-Rodeja et al., 2004) it is difficult to evaluate their similarity given the current datasets. For a full comparison and evaluation of these soils as Italian ejecta-based andisols, we recommend analysis of pH_{NaF}, $\Delta pH_{(H20\text{-}KCl)}$, and acid oxalate extraction to ascertain colloid content and the presence of alumino-mineral complexes. Should direct measurement of plant-available Na^+ prove necessary, this attribute may be analyzed using atomic absorption spectroscopy. Geological and geochemical mapping of the local bedrock surrounding the sites would inform both polje and soil dynamics. Acquisition of other Central Dalmatian paleoclimate records and continuing efforts to characterize and understand local soil stable isotope chemistry will further enhance our understanding of the environmental context of earliest European agriculture.

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Chapter 5. *Conclusion*

Agricultural diffusion research both globally and in our study region of Southeast Europe is turning from broad causal explanation to more complex explanatory models. Understanding the transition to agriculture therefore requires that we look not to a single primary forcing mechanism, but to the suite of environmental attributes impacting human behavioral decision-making. The transition to agriculture in central Dalmatia and, in particular, its manifestation at the Danilo Bitinj and Pokrovnik archaeological sites are the focus of Andrew Moore's Early Farming in Dalmatia Project (EFDP) (Moore et al., 2007a, 2007b). When coupled with EFDP archaeological, zooarchaeological, and paleobotanical results, this geoarchaeological study will allow integrative understanding of Dalmatian neolithization. The culture-matrix theoretical construct applied here is an attempt to theoretically unify geoarchaeological subfields and objectives – from traditional descriptive site geology to archaeometry.

This unification enabled not only more fruitful problematization between geoarchaeologist and archaeologists, but ultimately greater understanding of human-landscape interaction by encouraging a flexible, experiential research methodology. Cultural matrices are the ecological and geomorphological conditions of occupation, the interaction of past cultures with the nature and distribution of material resources, and the subsequent geo- and anthropogenic impact to cultural remains following occupation. The better we understand the geologic matrices of cultural change, the closer we will be to understanding cultural evolution itself. The body of work presented here is a site-specific geoarchaeological study providing a fabric typology, the implementation of which enables characterization and comparison of large ceramic artefact collections; and investigating ecologic selective pressures, the awareness of which enables a richer understanding of human-landscape interaction in Neolithic Dalmatia.

In the case that the material identifications here are not contradicted by future study, and the fertile substrate of the Central Dalmatian Early and Middle Neolithic is indeed discrete lowland volcanic deposits as hypothesized here, the chronology of deposition settlement will become crucial to the aims of the Early Farming in Dalmatia Project (EFDP). Chief factors affecting ultimate assessment of the transmission of agriculture into Dalmatia will be timing of ejecta deposition in relation to migration and/or communication and affect of volcanic outfall events on existing resource productivity and distribution. The pre-existing knowledge of the landscape and exploitation of resource by hunter-gatherers occupying Dalmatia prior to neolithization would have framed their interaction with farmers. Whether volcanic outfall severely limited or altered the distribution of those resources would have in turn greatly impacted the cost-benefit potential of a change in technology. In terms of greatest cultural significance, I would recommend focus on the chronology and magnitude of these depositional events as the focus of future EFDP geoarchaeological study.

Pedology

The Danilo Bitinj soil is a modern, moderately developed Mediterranean soil containing Middle Neolithic cultural remains. This sodic (alkaline and nonconductive), xeric (subject to dry summers and wet winters) soil is composed primarily of calcite and quartz. The stable isotope stability and C_3-dominance of the plant community through the profile indicate a stable, relatively cool and moist environment through the life of the solum (Huckleberry and Fadem, 2007; Krull et al., 2005; Davis et al., 2002; Nordt, 2001; Boutton, 1996; Cerling and Quade, 1993). Though the dispersive properties of sodic soils may aid in soil organic matter averaging, there is currently no evidence to identify the Danilo soil as a recently exposed paleosol, as the minimum age for the onset of organic carbon accumulation is 2052.5±143.5 cal BP (from a sample at 95 cm depth). The Pokrovnik soil is also a living, moderately developed, xeric soil with a stable C_3 plant community over the life of the soil and sodic, quartz-rich parent material. In contrast to the Danilo soil, this further inland soil is less sodic in its upper horizons and contains Early and Middle Neolithic artifacts. The Pokrovnik parent material, which curiously contains no calcite despite surrounding carbonate bedrock, has a minimum age of 6028±154 cal BP (at 155 cm depth) with mean carbon residence time decreasing toward the surface (624.0 ± 65.0 at 35 cm depth).

Given the pedologic analyses presented here, the Danilo Bitinj and Pokrovnik soils still present a particular problem for classification. The chief property of an andisol (USDA classification) or andosol (FAO classification) is that it form in volcanic ejecta. Under either classification scheme one cannot say whether soils do or do not have diagnostic andic soil properties without oxalate extraction (for which AAS or ICP analysis could possibly substitute), accompanied by bulk density and phosphate retention analyses (FAO/ISRIC/IUSS, 2006; Soil Survey Staff, 1999). Even if the diagnostic properties were present, classification would still be problematic. Of the currently recognized USDA soil order-subgroup-great group combinations, those closest to site soils given the current information are Typic Haploxerand and Sodic Xeric Haplocambid (Soil Survey Staff, 1999). While classifying soils to either aforementioned group would include key characteristics (sodicity, xeric moisture regime, clay skin presence), as a description it would be based more on what the soils lack than what they contain. For example, these names usually describe chromic (Munsell chroma >4) soils; those at Danilo Bitinj and Pokrovnik are very dark (chroma 2-3), yet overall do not have the organic carbon content to qualify for melanic subgroups (much less umbric or mollic). Of FAO classification the closest is Silandic Andosol, for which a pH>5 and oxalate-extractable Si content ≥0.6% is required (FAO/ISRIC/IUSS, 2006). While the soils here were not tested by traditional means (in terms of andosol evaluation), they certainly have a pH>5 and a high Si content. Site soils seem more appropriately classed as solonetz (black alkali, solonec) following the traditional/European systems of classification[4] (Brady and Weil, 2008; Briggs et al., 1997; Antić et al., 1982). Solonetz sodicity naturally disperses humic matter, making soils appear dark despite low organic matter content (Brady and Weil, 2008; Briggs et al., 1997). Even for this classification, however, the manifestations seen in archaeological trenches and off-site test pits are atypical, as they lack a columnar B horizon.

[4] The soils do not qualify as soil group Solonetz under FAO classification, as they do not exhibit a natric horizon (FAO/ISRIC/IUSS, 2006).

The Karst Landscape

The fact that central Dalmatia resides in the path of neolithization requires that it be understood in terms of differential resource stability and productivity (Winterhalder and Goland, 1997). In other words, what selected the Danilo Bitinj and Pokrovnik sites for Neolithic settlement over others in the surrounding Dinaric karst? Soil stable isotope chemistry attests to plant population stability in these locales. The coincidence of the Danilo Bitinj and Pokrovnik settlements with non-carbonate soil parent materials, as well as lack of productivity in the surrounding karst terrain, point to an underlying geologic/geomorphic rather than a climatic control on resource distribution (patchiness) in the Dalmatian landscape. The interaction of karst geomorphology and non-carbonate fill defines the model for Neolithic site choice and modern agricultural land-use presented here. This geomorphic control does not mean that resources exist nowhere else, nor that climate has no influence. On the contrary, regardless of use or exposure prior to occupation (beginning at least 7000 cal BP) (Moore et al., 2007a), a dry period like the one evidenced in lagoon cores from the Dalmatian coast (also beginning ~7000 BP) (Wunsam et al., 1999; Jahns and van den Bogaard, 1998) would have focused procurement efforts on stable, productive resource patches like Danilo Bitinj and Pokrovnik.

Future Work

Indeterminate soil type and uncertain polje-karst morphogenesis (Gams, 2005, 1978; Nicod, 2003; White, 1988; Wenzens, 1977) may be symptoms of a higher-order regional complexity. In fact Ford (2002:32) deems the Classical Karst region, in which central Dalmatia resides, 'too complicated' for the study of karst process and evolution, attributing the singularity and complexity of the Dinaric karst firstly to the complex geologic structure and secondly to the hydrologic and geomorphic dominance of poljes. The Dinaric karst hosts the largest number of poljes (130) of any karst terrain (Ford, 2002; Božičević, 1992; White, 1988; Gams, 1978), while bedrock structure and polje morphology continue to co-evolve due to tectonic activity in the Adriatic microplate (Dragičević et al., 1999). Thus the Dalmatian polje-karst is unsuitable as a geologic case-study any single process and its evolution, both surficial and subterranean, presents an investigative challenge.

Nevertheless, there are several discrete lines of inquiry that will enhance our understanding of the central Dalmatian foraging-to-farming behavioural evolution. The confirmation and/or more specific identification of alkaline agricultural substrate in surficial sediment sinks would best be conducted through further elemental and mineralogical analysis of polje and valley subsoils and comparison to known tephra deposits. Tephrostratigraphy of Adriatic bottom and coastal Dalmatian lagoon sediments suggests that – at the very least – volcanic outfall is a noticeable contributor to sedimentary deposits in this region (Calanchi et al., 1998; Jahns and van den Bogaard, 1998). Outfall event identification would be invaluable in limiting the ages of basin formation, soil inception, and site occupation. Systematic regional pedological and archaeological survey will help to confirm the co-occurrence of non-karst fill and early agriculture, as well as provide potential ceramic source materials for characterization and comparison to Neolithic assemblages. While the characterization and comparison of site parent materials and ceramic artifacts presented here suggests on-site deposits and ceramic sources may share a common chemical population, a true ceramics sourcing study will require analysis of many hundreds of artifacts and potential source materials by neutron activation analysis. Such a study would add greatly to our understanding of the central Dalmatian transition to agriculture, as the co-occurrence of food production and ceramics raw material acquisition would have localized subsistence efforts and decreased the costs of the drastic change in subsistence strategy implied by neolithization. Additional local and central Dalmatia-specific paleoclimatological study of lake cores and river tufas, as well as continuing examination of soil stable isotope chemistry will enhance our understanding of the scale and complexity of behaviour-selective mechanisms acting on these earliest European farming communities.

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Appendix 1. Study locations.

Site	Easting	Northing	Type	ID	Sampled
Danilo Bitinj	583916	4840705	Bedrock	5	Y
Danilo Bitinj	583498	4840972	Bedrock	7	Y
Danilo Bitinj	584001	4841519	Bedrock	8	Y
Danilo Bitinj	581937	4841327	Bedrock	10	Y
Danilo Bitinj	580489	4842325	Bedrock	11	Y
Danilo Bitinj	580513	4841925	Bedrock	12	Y
Danilo Bitinj	579598	4843173	Bedrock	13	Y
Danilo Bitinj	579416	4842167	Bedrock	14	Y
Danilo Bitinj	579621	4842500	Bedrock	15	Y
Danilo Bitinj	580403	4841649	Bedrock	16	Y
Danilo Bitinj	580513	4840611	Bedrock	17	Y
Danilo Bitinj	581454	4840515	Bedrock	18	Y
Danilo Bitinj	581978	4839940	Bedrock	19	Y
Danilo Bitinj	582374	4838902	Bedrock	20	Y
Danilo Bitinj	582493	4839683	Test Pit	1	Y
Danilo Bitinj	582537	4840137	Test Pit	2	Y
Danilo Bitinj	582998	4839754	Test Pit	3	Y
Danilo Bitinj	583101	4839693	Test Pit	4	Y
Danilo Bitinj	583048	4839579	Test Pit	5	Y
Danilo Bitinj	582990	4839609	Test Pit	6	Y
Danilo Bitinj	583199	4839953	Test Pit	7	Y
Danilo Bitinj	583214	4840074	Test Pit	8	Y
Danilo Bitinj	583193	4840148	Test Pit	9	Y
Danilo Bitinj	582777	4840015	Test Pit	11	Y

Appendix 1. Study locations.

Site	Easting	Northing	Type	ID	Sampled
Danilo Bitinj	582669	4839913	Test Pit	12	Y
Danilo Bitinj	583118	4839870	Trench	A	Y
Danilo Bitinj	583080	4839775	Trench	B	Y
Danilo Bitinj	583127	4839919	Trench	C	Y
Danilo Bitinj	583014	4839897	Trench	D	Y
Danilo Bitinj	583046	4839873	Trench	E	Y
Danilo Bitinj	583004	4839889	Well	1	N
Danilo Bitinj	583749	4840080	Well	2	N
Danilo Bitinj	585203	4839270	Well	3	N
Danilo Bitinj	582725	4839820	Well	4	N
Danilo Bitinj	582829	4839835	Well	5	N
Danilo Bitinj	582078	4840637	Well	6	N
Danilo Bitinj	581789	4840437	Well	7	N
Danilo Bitinj	583008	4839687	Well	8	N
Danilo Bitinj	583501	4840638	Well	9	N
Danilo Bitinj	584953	4839183	Well	10	N
Danilo Bitinj	583899	4839869	Well	11	N
Danilo Bitinj	583740	4840612	Well	12	N
Danilo Bitinj	583317	4839814	Well	13	N
Danilo Bitinj	583677	4839790	Well	14	N
Danilo Bitinj	582356	4840501	Well	15	N
Danilo Bitinj	580516	4841928	Well	16	N
Danilo Bitinj	583748	4840077	Well	17	N
Danilo Bitinj	584424	4839802	Well	18	N

Appendix 1. Study locations.

Site	Easting	Northing	Type	ID	Sampled
Danilo Bitinj	584424	4839802	Well	19	N
Danilo Bitinj	581898	4840424	Well	20	N
Danilo Bitinj	580224	4842074	Well	21	N
Danilo Bitinj	583320	4839819	Well	22	N
Danilo Bitinj	583702	4839720	Well	23	N
Dinara	606333	4884128	Surface Soil	1	Y
Dinara	606473	4883940	Surface Soil	2	Y
Dinara	607758	4883573	Surface Soil	3	Y
Pokrovnik	585695	4850749	Bedrock	1	Y
Pokrovnik	585845	4850464	Bedrock	4	Y
Pokrovnik	586132	4850695	Bedrock	5	Y
Pokrovnik	587124	4850227	Bedrock	9	Y
Pokrovnik	586087	4851189	Bedrock	10	Y
Pokrovnik	585894	4850622	Test Pit	1	Y
Pokrovnik	585868	4850683	Test Pit	2	Y
Pokrovnik	585839	4850729	Test Pit	3	Y
Pokrovnik	585829	4850602	Test Pit	4	Y
Pokrovnik	585832	4850543	Test Pit	5	Y
Pokrovnik	585733	4850703	Test Pit	6	Y
Pokrovnik	585460	4850568	Test Pit	7	Y
Pokrovnik	585860	4850789	Test Pit	8	Y
Pokrovnik	586125	4850639	Test Pit	9	Y
Pokrovnik	585949	4850623	Trench	A	Y
Pokrovnik	585923	4850680	Trench	B	Y

Appendix 1. Study locations.

Site	Easting	Northing	Type	ID	Sampled
Pokrovnik	585937	4850655	Trench	C	Y
Pokrovnik	585933	4850648	Trench	C	Y
Pokrovnik	585962	4850600	Trench	D	Y
Pokrovnik	586013	4850559	Well		N

Appendix 2. Early Farming in Dalmatia Project soil sample inventory.

Sample #	Average Depth	Collection Date	Site	Residence
A-1A	15	16-Jul-05	Danilo Bitinj	Washington University
A-1B	15	16-Jul-05	Danilo Bitinj	Washington University
A-1C	15	16-Jul-05	Danilo Bitinj	Šibenik Museum
A-2A	35	16-Jul-05	Danilo Bitinj	Washington University
A-2B	35	16-Jul-05	Danilo Bitinj	Washington University
A-2C	35	16-Jul-05	Danilo Bitinj	Šibenik Museum
A-3A	55	16-Jul-05	Danilo Bitinj	Washington University
A-3B	55	16-Jul-05	Danilo Bitinj	Washington University
A-3C	55	16-Jul-05	Danilo Bitinj	Šibenik Museum
A-4A	75	16-Jul-05	Danilo Bitinj	Washington University
A-4B	75	16-Jul-05	Danilo Bitinj	Washington University
A-4C	75	16-Jul-05	Danilo Bitinj	Šibenik Museum
A-5A	95	16-Jul-05	Danilo Bitinj	Washington University
A-5B	95	16-Jul-05	Danilo Bitinj	Washington University
A-5C	95	16-Jul-05	Danilo Bitinj	Šibenik Museum
A-6A	115	16-Jul-05	Danilo Bitinj	Washington University
A-6B	115	16-Jul-05	Danilo Bitinj	Washington University
A-6C	115	16-Jul-05	Danilo Bitinj	Šibenik Museum
A-7A	135	16-Jul-05	Danilo Bitinj	Washington University
A-7B	135	16-Jul-05	Danilo Bitinj	Washington University
A-7C	135	16-Jul-05	Danilo Bitinj	Šibenik Museum
B-1A	15	7-Jul-05	Danilo Bitinj	Washington University
B-1B	15	7-Jul-05	Danilo Bitinj	Washington University

Appendix 2. Early Farming in Dalmatia Project soil sample inventory.

Sample #	Average Depth	Collection Date	Site	Residence
B-1C	15	7-Jul-05	Danilo Bitinj	Šibenik Museum
B-2A	35	7-Jul-05	Danilo Bitinj	Washington University
B-2B	35	7-Jul-05	Danilo Bitinj	Washington University
B-2C	35	7-Jul-05	Danilo Bitinj	Šibenik Museum
B-3A	55	7-Jul-05	Danilo Bitinj	Washington University
B-3B	55	7-Jul-05	Danilo Bitinj	Washington University
B-3C	55	7-Jul-05	Danilo Bitinj	Šibenik Museum
B-4A	75	7-Jul-05	Danilo Bitinj	Washington University
B-4B	75	7-Jul-05	Danilo Bitinj	Washington University
B-4C	75	7-Jul-05	Danilo Bitinj	Šibenik Museum
B-5A	95	7-Jul-05	Danilo Bitinj	Washington University
B-5B	95	7-Jul-05	Danilo Bitinj	Washington University
B-5C	95	7-Jul-05	Danilo Bitinj	Šibenik Museum
B-6A	115	7-Jul-05	Danilo Bitinj	Washington University
B-6B	115	7-Jul-05	Danilo Bitinj	Washington University
B-6C	115	7-Jul-05	Danilo Bitinj	Šibenik Museum
B-7A	135	7-Jul-05	Danilo Bitinj	Washington University
B-7B	135	7-Jul-05	Danilo Bitinj	Washington University
B-7C	135	7-Jul-05	Danilo Bitinj	Šibenik Museum
B-8A	155	7-Jul-05	Danilo Bitinj	Washington University
B-8B	155	7-Jul-05	Danilo Bitinj	Washington University
B-8C	155	7-Jul-05	Danilo Bitinj	Šibenik Museum
B-9A	175	7-Jul-05	Danilo Bitinj	Washington University

Appendix 2. Early Farming in Dalmatia Project soil sample inventory.

Sample #	Average Depth	Collection Date	Site	Residence
B-9B	175	7-Jul-05	Danilo Bitinj	Washington University
B-9C	175	7-Jul-05	Danilo Bitinj	Šibenik Museum
B-10A	195	7-Jul-05	Danilo Bitinj	Washington University
B-10B	195	7-Jul-05	Danilo Bitinj	Washington University
B-10C	195	7-Jul-05	Danilo Bitinj	Šibenik Museum
B-11A	215	7-Jul-05	Danilo Bitinj	Washington University
B-11B	215	7-Jul-05	Danilo Bitinj	Washington University
B-11C	215	7-Jul-05	Danilo Bitinj	Šibenik Museum
C-1A	15	16-Jul-05	Danilo Bitinj	Washington University
C-1B	15	16-Jul-05	Danilo Bitinj	Washington University
C-1C	15	16-Jul-05	Danilo Bitinj	Šibenik Museum
C-2A	35	16-Jul-05	Danilo Bitinj	Washington University
C-2B	35	16-Jul-05	Danilo Bitinj	Washington University
C-2C	35	16-Jul-05	Danilo Bitinj	Šibenik Museum
C-3A	55	16-Jul-05	Danilo Bitinj	Washington University
C-3B	55	16-Jul-05	Danilo Bitinj	Washington University
C-3C	55	16-Jul-05	Danilo Bitinj	Šibenik Museum
C-4A	75	16-Jul-05	Danilo Bitinj	Washington University
C-4B	75	16-Jul-05	Danilo Bitinj	Washington University
C-4C	75	16-Jul-05	Danilo Bitinj	Šibenik Museum
C-5A	95	16-Jul-05	Danilo Bitinj	Washington University
C-5B	95	16-Jul-05	Danilo Bitinj	Washington University
C-5C	95	16-Jul-05	Danilo Bitinj	Šibenik Museum

Appendix 2. Early Farming in Dalmatia Project soil sample inventory.

Sample #	Average Depth	Collection Date	Site	Residence
C-6A	115	16-Jul-05	Danilo Bitinj	Washington University
C-6B	115	16-Jul-05	Danilo Bitinj	Washington University
C-6C	115	16-Jul-05	Danilo Bitinj	Šibenik Museum
C-7A	135	16-Jul-05	Danilo Bitinj	Washington University
C-7B	135	16-Jul-05	Danilo Bitinj	Washington University
C-7C	135	16-Jul-05	Danilo Bitinj	Šibenik Museum
D-1A	15	11-Jul-05	Danilo Bitinj	Washington University
D-1B	15	11-Jul-05	Danilo Bitinj	Washington University
D-1C	15	11-Jul-05	Danilo Bitinj	Šibenik Museum
D-2A	35	11-Jul-05	Danilo Bitinj	Washington University
D-2B	35	11-Jul-05	Danilo Bitinj	Washington University
D-2C	35	11-Jul-05	Danilo Bitinj	Šibenik Museum
D-3A	55	11-Jul-05	Danilo Bitinj	Washington University
D-3B	55	11-Jul-05	Danilo Bitinj	Washington University
D-3C	55	11-Jul-05	Danilo Bitinj	Šibenik Museum
D-4A	75	11-Jul-05	Danilo Bitinj	Washington University
D-4B	75	11-Jul-05	Danilo Bitinj	Washington University
D-4C	75	11-Jul-05	Danilo Bitinj	Šibenik Museum
D-5A	95	11-Jul-05	Danilo Bitinj	Washington University
D-5B	95	11-Jul-05	Danilo Bitinj	Washington University
D-5C	95	11-Jul-05	Danilo Bitinj	Šibenik Museum
D-6A	115	11-Jul-05	Danilo Bitinj	Washington University
D-6B	115	11-Jul-05	Danilo Bitinj	Washington University

Appendix 2. Early Farming in Dalmatia Project soil sample inventory.

Sample #	Average Depth	Collection Date	Site	Residence
D-6C	115	11-Jul-05	Danilo Bitinj	Šibenik Museum
D-7A	135	11-Jul-05	Danilo Bitinj	Washington University
D-7B	135	11-Jul-05	Danilo Bitinj	Washington University
D-7C	135	11-Jul-05	Danilo Bitinj	Šibenik Museum
E-1A	15	16-Jul-05	Danilo Bitinj	Washington University
E-1B	15	16-Jul-05	Danilo Bitinj	Washington University
E-1C	15	16-Jul-05	Danilo Bitinj	Šibenik Museum
E-2A	35	16-Jul-05	Danilo Bitinj	Washington University
E-2B	35	16-Jul-05	Danilo Bitinj	Washington University
E-2C	35	16-Jul-05	Danilo Bitinj	Šibenik Museum
E-3A	55	16-Jul-05	Danilo Bitinj	Washington University
E-3B	55	16-Jul-05	Danilo Bitinj	Washington University
E-3C	55	16-Jul-05	Danilo Bitinj	Šibenik Museum
E-4A	75	16-Jul-05	Danilo Bitinj	Washington University
E-4B	75	16-Jul-05	Danilo Bitinj	Washington University
E-4C	75	16-Jul-05	Danilo Bitinj	Šibenik Museum
E-5A	95	16-Jul-05	Danilo Bitinj	Washington University
E-5B	95	16-Jul-05	Danilo Bitinj	Washington University
E-5C	95	16-Jul-05	Danilo Bitinj	Šibenik Museum
E-6A	115	16-Jul-05	Danilo Bitinj	Washington University
E-6B	115	16-Jul-05	Danilo Bitinj	Washington University
E-6C	115	16-Jul-05	Danilo Bitinj	Šibenik Museum
E-7A	135	16-Jul-05	Danilo Bitinj	Washington University

Appendix 2. Early Farming in Dalmatia Project soil sample inventory.

Sample #	Average Depth	Collection Date	Site	Residence
E-7B	135	16-Jul-05	Danilo Bitinj	Washington University
E-7C	135	16-Jul-05	Danilo Bitinj	Šibenik Museum
T1-1	15	12-Jul-06	Danilo Bitinj	Washington University
T1-2	35	12-Jul-06	Danilo Bitinj	Washington University
T1-3	55	12-Jul-06	Danilo Bitinj	Washington University
T1-4	75	12-Jul-06	Danilo Bitinj	Washington University
T1-5	95	12-Jul-06	Danilo Bitinj	Washington University
T2-1	15	12-Jul-06	Danilo Bitinj	Washington University
T2-2	35	12-Jul-06	Danilo Bitinj	Washington University
T2-3	55	12-Jul-06	Danilo Bitinj	Washington University
T3-1	15	12-Jul-06	Danilo Bitinj	Washington University
T3-2	35	12-Jul-06	Danilo Bitinj	Washington University
T3-40 cm	40	12-Jul-06	Danilo Bitinj	Washington University
T4-1	15	13-Jul-06	Danilo Bitinj	Washington University
T4-2	35	13-Jul-06	Danilo Bitinj	Washington University
T4-3	55	13-Jul-06	Danilo Bitinj	Washington University
T4-4	75	13-Jul-06	Danilo Bitinj	Washington University
T5-1	15	13-Jul-06	Danilo Bitinj	Washington University
T6-1	15	13-Jul-06	Danilo Bitinj	Washington University
T7-1	15	14-Jul-06	Danilo Bitinj	Washington University
T7-2	35	14-Jul-06	Danilo Bitinj	Washington University
T7-3	55	14-Jul-06	Danilo Bitinj	Washington University
T8-1	15	14-Jul-06	Danilo Bitinj	Washington University

Appendix 2. Early Farming in Dalmatia Project soil sample inventory.

Sample #	Average Depth	Collection Date	Site	Residence
T8-2	35	14-Jul-06	Danilo Bitinj	Washington University
T8-3	55	14-Jul-06	Danilo Bitinj	Washington University
T9-1	15	14-Jul-06	Danilo Bitinj	Washington University
T9-2	35	14-Jul-06	Danilo Bitinj	Washington University
T10-1	15	14-Jul-06	Danilo Bitinj	Washington University
T10-2	35	14-Jul-06	Danilo Bitinj	Washington University
T10-3	55	14-Jul-06	Danilo Bitinj	Washington University
T11-1	15	18-Jul-06	Danilo Bitinj	Washington University
T11-2	35	18-Jul-06	Danilo Bitinj	Washington University
T11-3	55	18-Jul-06	Danilo Bitinj	Washington University
T12-1	15	18-Jul-06	Danilo Bitinj	Washington University
T12-2	35	18-Jul-06	Danilo Bitinj	Washington University
T12-3	55	18-Jul-06	Danilo Bitinj	Washington University
T13-1	15	21-Jul-06	Danilo Bitinj	Washington University
T13-2	35	21-Jul-06	Danilo Bitinj	Washington University
T13-3	55	21-Jul-06	Danilo Bitinj	Washington University
T13-4	75	21-Jul-06	Danilo Bitinj	Washington University
T13-5	95	21-Jul-06	Danilo Bitinj	Washington University
T14-1	15	22-Jul-06	Danilo Bitinj	Washington University
T14-2	35	22-Jul-06	Danilo Bitinj	Washington University
T14-3	55	22-Jul-06	Danilo Bitinj	Washington University
		19-Jun-08	Grofova Jama	Washington University
A-1A	15	20-Jul-06	Pokrovnik	Washington University

Appendix 2. Early Farming in Dalmatia Project soil sample inventory.

Sample #	Average Depth	Collection Date	Site	Residence
A-1B	15	20-Jul-06	Pokrovnik	Washington University
A-1C	15	20-Jul-06	Pokrovnik	Drniš Museum
A-2A	35	20-Jul-06	Pokrovnik	Washington University
A-2B	35	20-Jul-06	Pokrovnik	Washington University
A-2C	35	20-Jul-06	Pokrovnik	Drniš Museum
A-3A	55	20-Jul-06	Pokrovnik	Washington University
A-3B	55	20-Jul-06	Pokrovnik	Washington University
A-3C	55	20-Jul-06	Pokrovnik	Drniš Museum
A-4A	75	20-Jul-06	Pokrovnik	Washington University
A-4B	75	20-Jul-06	Pokrovnik	Washington University
A-4C	75	20-Jul-06	Pokrovnik	Drniš Museum
A-5A	95	20-Jul-06	Pokrovnik	Washington University
A-5B	95	20-Jul-06	Pokrovnik	Washington University
A-5C	95	20-Jul-06	Pokrovnik	Drniš Museum
A-6A	115	20-Jul-06	Pokrovnik	Washington University
A-6B	115	20-Jul-06	Pokrovnik	Washington University
A-6C	115	20-Jul-06	Pokrovnik	Drniš Museum
A-7A	135	20-Jul-06	Pokrovnik	Washington University
A-7B	135	20-Jul-06	Pokrovnik	Washington University
A-7C	135	20-Jul-06	Pokrovnik	Drniš Museum
A-8A	155	20-Jul-06	Pokrovnik	Washington University
A-8B	155	20-Jul-06	Pokrovnik	Washington University
A-8C	155	20-Jul-06	Pokrovnik	Drniš Museum

Appendix 2. Early Farming in Dalmatia Project soil sample inventory.

Sample #	Average Depth	Collection Date	Site	Residence
A-9A	175	20-Jul-06	Pokrovnik	Washington University
A-9B	175	20-Jul-06	Pokrovnik	Washington University
A-9C	175	20-Jul-06	Pokrovnik	Drniš Museum
A-10A	195	20-Jul-06	Pokrovnik	Washington University
A-10B	195	20-Jul-06	Pokrovnik	Washington University
A-10C	195	20-Jul-06	Pokrovnik	Drniš Museum
A-11A	215	20-Jul-06	Pokrovnik	Washington University
A-11B	215	20-Jul-06	Pokrovnik	Washington University
A-11C	215	20-Jul-06	Pokrovnik	Drniš Museum
A-fines1	187.5	20-Jul-06	Pokrovnik	Washington University
A-fines1-bottom	202.5	20-Jul-06	Pokrovnik	Washington University
A-fines1-middle	187.5	20-Jul-06	Pokrovnik	Washington University
A-fines1-top	172.5	20-Jul-06	Pokrovnik	Washington University
A-fines2	145	20-Jul-06	Pokrovnik	Washington University
A-fines2-bottom	162.5	20-Jul-06	Pokrovnik	Washington University
A-fines2-middle	147.5	20-Jul-06	Pokrovnik	Washington University
A-fines2-top	127.5	20-Jul-06	Pokrovnik	Washington University
B-1A	15	10-Jul-06	Pokrovnik	Washington University
B-1B	15	10-Jul-06	Pokrovnik	Drniš Museum
B-2A	35	10-Jul-06	Pokrovnik	Washington University
B-2B	35	10-Jul-06	Pokrovnik	Drniš Museum
B-3A	55	10-Jul-06	Pokrovnik	Washington University

Appendix 2. Early Farming in Dalmatia Project soil sample inventory.

Sample #	Average Depth	Collection Date	Site	Residence
B-3B	55	10-Jul-06	Pokrovnik	Drniš Museum
B-4A	75	10-Jul-06	Pokrovnik	Washington University
B-4B	75	10-Jul-06	Pokrovnik	Drniš Museum
C-E-1A	15	19-Jul-06	Pokrovnik	Washington University
C-E-1B	15	19-Jul-06	Pokrovnik	Drniš Museum
C-E-2A	35	19-Jul-06	Pokrovnik	Washington University
C-E-2B	35	19-Jul-06	Pokrovnik	Drniš Museum
C-E-3A	55	19-Jul-06	Pokrovnik	Washington University
C-E-3B	55	19-Jul-06	Pokrovnik	Drniš Museum
C-E-4A	75	19-Jul-06	Pokrovnik	Washington University
C-E-4B	75	19-Jul-06	Pokrovnik	Drniš Museum
C-W-1A	15	19-Jul-06	Pokrovnik	Washington University
C-W-1B	15	19-Jul-06	Pokrovnik	Drniš Museum
C-W-2A	35	19-Jul-06	Pokrovnik	Washington University
C-W-2B	35	19-Jul-06	Pokrovnik	Drniš Museum
C-W-3A	55	19-Jul-06	Pokrovnik	Washington University
C-W-3B	55	19-Jul-06	Pokrovnik	Drniš Museum
C-W-4A	75	19-Jul-06	Pokrovnik	Washington University
C-W-4B	75	19-Jul-06	Pokrovnik	Drniš Museum
C-W-5A	95	19-Jul-06	Pokrovnik	Washington University
C-W-5B	95	19-Jul-06	Pokrovnik	Drniš Museum
C-W-6A	115	19-Jul-06	Pokrovnik	Washington University
C-W-6B	115	19-Jul-06	Pokrovnik	Drniš Museum

Appendix 2. Early Farming in Dalmatia Project soil sample inventory.

Sample #	Average Depth	Collection Date	Site	Residence
D-1A	15	23-Jul-06	Pokrovnik	Washington University
D-1B	15	23-Jul-06	Pokrovnik	Washington University
D-1C	15	23-Jul-06	Pokrovnik	Drniš Museum
D-2A	35	23-Jul-06	Pokrovnik	Washington University
D-2B	35	23-Jul-06	Pokrovnik	Washington University
D-2C	35	23-Jul-06	Pokrovnik	Drniš Museum
D-3A	55	23-Jul-06	Pokrovnik	Washington University
D-3B	55	23-Jul-06	Pokrovnik	Washington University
D-3C	55	23-Jul-06	Pokrovnik	Drniš Museum
D-4A	75	23-Jul-06	Pokrovnik	Washington University
D-4B	75	23-Jul-06	Pokrovnik	Washington University
D-4C	75	23-Jul-06	Pokrovnik	Drniš Museum
D-5A	95	23-Jul-06	Pokrovnik	Washington University
D-5B	95	23-Jul-06	Pokrovnik	Washington University
D-5C	95	23-Jul-06	Pokrovnik	Drniš Museum
D-6A	115	23-Jul-06	Pokrovnik	Washington University
D-6B	115	23-Jul-06	Pokrovnik	Washington University
D-6C	115	23-Jul-06	Pokrovnik	Drniš Museum
D-7A	135	23-Jul-06	Pokrovnik	Washington University
D-7B	135	23-Jul-06	Pokrovnik	Washington University
D-7C	135	23-Jul-06	Pokrovnik	Drniš Museum
D-8A	155	23-Jul-06	Pokrovnik	Washington University
D-8B	155	23-Jul-06	Pokrovnik	Washington University

Appendix 2. Early Farming in Dalmatia Project soil sample inventory.

Sample #	Average Depth	Collection Date	Site	Residence
D-8C	155	23-Jul-06	Pokrovnik	Drniš Museum
D-9A	175	23-Jul-06	Pokrovnik	Washington University
D-9B	175	23-Jul-06	Pokrovnik	Washington University
D-9C	175	23-Jul-06	Pokrovnik	Drniš Museum
D-10A	195	23-Jul-06	Pokrovnik	Washington University
D-10B	195	23-Jul-06	Pokrovnik	Washington University
D-10C	195	23-Jul-06	Pokrovnik	Drniš Museum
D-11A	215	23-Jul-06	Pokrovnik	Washington University
D-11B	215	23-Jul-06	Pokrovnik	Washington University
D-11C	215	23-Jul-06	Pokrovnik	Drniš Museum
T1-1	15	6-Jul-06	Pokrovnik	Washington University
T1-2	35	6-Jul-06	Pokrovnik	Washington University
T1-3	55	6-Jul-06	Pokrovnik	Washington University
T2-1	15	8-Jul-06	Pokrovnik	Washington University
T2-2	35	8-Jul-06	Pokrovnik	Washington University
T2-3	55	8-Jul-06	Pokrovnik	Washington University
T2-4	75	8-Jul-06	Pokrovnik	Washington University
T2-37 cm	37	8-Jul-06	Pokrovnik	Washington University
T3-1	15	7-Jul-06	Pokrovnik	Washington University
T3-2	35	7-Jul-06	Pokrovnik	Washington University
T3-3	55	7-Jul-06	Pokrovnik	Washington University
T3-4	75	7-Jul-06	Pokrovnik	Washington University
T4-1	15	8-Jul-06	Pokrovnik	Washington University

Appendix 2. Early Farming in Dalmatia Project soil sample inventory.

Sample #	Average Depth	Collection Date	Site	Residence
T4-2	35	8-Jul-06	Pokrovnik	Washington University
T4-3	55	8-Jul-06	Pokrovnik	Washington University
T5-1	15	10-Jul-06	Pokrovnik	Washington University
T6-1	15	10-Jul-06	Pokrovnik	Washington University
T6-2	35	10-Jul-06	Pokrovnik	Washington University
T6-3	55	10-Jul-06	Pokrovnik	Washington University
T6-4	75	10-Jul-06	Pokrovnik	Washington University
T7-1	15	10-Jul-06	Pokrovnik	Washington University
T8-1	15	19-Jul-06	Pokrovnik	Washington University
T8-2	35	19-Jul-06	Pokrovnik	Washington University
T8-3	55	19-Jul-06	Pokrovnik	Washington University
T9-1	15	22-Jul-06	Pokrovnik	Washington University
T9-2	35	22-Jul-06	Pokrovnik	Washington University

Appendix 3. Ceramic sample numbers and artifact provenance labels.

Site	Sample	Collection Date	Year	Trench	□	Δ	O
Danilo Bitinj	1	12-Jul	2005	A	844	44	701
Danilo Bitinj	2	12-Jul	2005	E	164	12	137
Danilo Bitinj	3	11-Jul	2005	E	148	12	135
Danilo Bitinj	4	6-Jul	2005	E	95	7	84
Danilo Bitinj	5	5-Jul	2005	A	784	35	645
Danilo Bitinj	6	5-Jul	2005	A	784	35	645
Danilo Bitinj	7	8-Jul	2005	A	821	43	676
Danilo Bitinj	8	8-Jul	2005	A	812	42	672
Danilo Bitinj	9	9-Jul	2005	A	825	42	684
Danilo Bitinj	10	8-Jul	2005	A	812	42	672
Danilo Bitinj	11	12-Jul	2005	E	164	12	137
Danilo Bitinj	12	5-Jul	2005	A	784	35	645
Danilo Bitinj	13	11-Jul	2005	E	144	11	132
Danilo Bitinj	14	8-Jul	2005	A	812	42	672
Danilo Bitinj	15	12-Jul	2005	E	164	12	137
Danilo Bitinj	16	11-Jul	2005	E	144	11	132
Danilo Bitinj	17	12-Jul	2005	E	164	12	137
Danilo Bitinj	18	12-Jul	2005	E	157	14	149
Danilo Bitinj	19	12-Jul	2005	E	157	14	149
Danilo Bitinj	20	11-Jul	2005	E	144	11	132
Danilo Bitinj	21	6-Jul	2005	E	95	7	84
Danilo Bitinj	22	5-Jul	2005	A	784	35	645

Appendix 3. Ceramic sample numbers and artifact provenance labels.

Site	Sample	Collection Date	Year	Trench	□	Δ	O
Danilo Bitinj	23	12-Jul	2005	E	164	12	137
Danilo Bitinj	24	6-Jul	2005	E	95	7	84
Danilo Bitinj	25	11-Jul	2005	E	144	11	132
Danilo Bitinj	26	12-Jul	2005	E	164	12	137
Danilo Bitinj	27	13-Jul	2005	A	873	46	732
Danilo Bitinj	28	5-Jul	2005	A	784	35	645
Danilo Bitinj	29	13-Jul	2005	A	873	46	732
Danilo Bitinj	30	14-Jul	2005	E	190	14	180
Danilo Bitinj	31	13-Jul	2005	E	183	13	155
Danilo Bitinj	32	23-Jun	2005	C		15	151
Danilo Bitinj	33	14-Jul	2005	E	190	14	180
Danilo Bitinj	34	14-Jul	2005	E	190	14	180
Danilo Bitinj	35	14-Jul	2005	E	190	14	180
Danilo Bitinj	36	13-Jul	2005	E	183	13	155
Danilo Bitinj	37	14-Jul	2005	A	897	44	750
Danilo Bitinj	38	13-Jul	2005	E	182	14	163
Danilo Bitinj	39	14-Jul	2005	E	190	14	180
Danilo Bitinj	40	13-Jul	2005	A	190	46	180
Danilo Bitinj	41	14-Jul	2005	E	190	14	180
Danilo Bitinj	42	11-Jul	2005	E	144	11	132
Danilo Bitinj	43	13-Jul	2005	A	873	46	732
Danilo Bitinj	44	14-Jul	2005	A	897	44	750

Appendix 3. Ceramic sample numbers and artifact provenance labels.

Site	Sample	Collection Date	Year	Trench	□	Δ	O
Danilo Bitinj	45	15-Jul	2005	E		19	190
Danilo Bitinj	46	12-Jul	2005	E	164	12	137
Danilo Bitinj	47	12-Jul	2005	E	170	13	142
Danilo Bitinj	48	27-Jun	2005	A	660	34	544
Danilo Bitinj	49	11-Jul	2005	E	144	11	132
Pokrovnik	1	18-Jul	2006	D	367	19	319
Pokrovnik	2	18-Jul	2006	D	367	19	319
Pokrovnik	3	18-Jul	2006	D	367	19	319
Pokrovnik	4	18-Jul	2006	D	367	19	319
Pokrovnik	5	18-Jul	2006	D	367	19	319
Pokrovnik	6	18-Jul	2006	D	367	19	319
Pokrovnik	7	18-Jul	2006	D	367	19	319
Pokrovnik	8	15-Jul	2006	A	387	33	322
Pokrovnik	9	15-Jul	2006	A	387	33	322
Pokrovnik	10	15-Jul	2006	A	387	33	322
Pokrovnik	11	30-Jun	2006	D	114	6	106
Pokrovnik	12	30-Jun	2006	D	114	6	106
Pokrovnik	13	30-Jun	2006	D	114	6	106
Pokrovnik	14	20-Jun	2006	A	52	3	42
Pokrovnik	15	20-Jun	2006	A	52	3	42
Pokrovnik	16	21-Jun	2006	A	62	4	50
Pokrovnik	17	21-Jun	2006	A	62	4	50

Appendix 3. Ceramic sample numbers and artifact provenance labels.

Site	Sample	Collection Date	Year	Trench		Δ	O
Pokrovnik	18	21-Jun	2006	A	62	4	50
Pokrovnik	19	21-Jun	2006	A	62	4	50
Pokrovnik	20	21-Jun	2006	A	62	4	50