

Interdisciplinary Contributions to Archaeology

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Trekking the Shore

Changing Coastlines and
the Antiquity of Coastal Settlement

 Springer

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Chapter 18

Coastal South Africa and the Coevolution of the Modern Human Lineage and the Coastal Adaptation

Curtis W. Marean

The fossil record indicates that *Homo sapiens* appears sometime around 195–160 ka (White et al. 2003; Clark et al. 2003; McDougall et al. 2005; Smith et al. 2007). Evolutionary genetics (Ingman et al. 2000; Tishkoff et al. 2007; Gonder et al. 2007; Fagundes et al. 2007; Behar et al. 2008) point to the time between 200 and 100 ka as the origin point for the modern human lineage. Modern humans have relatively very low genetic diversity that is best explained by one or more population bottlenecks late in the evolution of the lineage, with estimates for the first bottleneck ranging from 144 ka (103,535–185,642 ka 95%CI) (Fagundes et al. 2007) to 194.3 ± 32.5 ka (Gonder et al. 2007) to 203 ± 12.6 ka (Behar et al. 2008). Fagundes et al. (2007) estimate the effective population of that bottleneck at ~600 (76–1,620 95%CI). A computer simulation by Rogers reported in (Ambrose 1998) suggests that this bottlenecked population was a single contiguous breeding group in one region, since if this population sampled a broad range of populations across Africa the original genetic variation would have been preserved. This bottleneck seems to have occurred during the glacial MIS6 (~195–125 ka), one of the longest coldest stages of the Quaternary (Petit et al. 1999), during which time Africa would have been primarily dry with relatively few isolated refugia. Paleoanthropologists now have a gripping question to address – where did this progenitor population arise, how, and why there?

A related question addresses the timing and circumstances of the origins of cognitive complexity (McBrearty and Brooks 2000; Henshilwood and Marean 2003; Wadley 2003). Paleoanthropologists use various proxies in the archaeological record to try to identify its presence and scope, including artifactual markers of symbolic thought (Henshilwood et al. 2004), and the development of complex technologies (McBrearty and Brooks 2000) that signal the unique ability of humans

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to successively build on prior knowledge over generations (Tomasello 1994, 1999). This “ratchet effect” refers to incremental adjustments to technological procedures already in place. Along with this, modern humans excel at novel “outside-the-box” connections of seemingly unrelated phenomena (Pfenninger 2001; Andreasen 2006). These can result in sharp technological advances with high fitness benefits, and these new creations provide the input to the ratchet effect.

The South African archaeological record provides the richest and oldest evidence for the material cultural complexity that we anticipate will reflect this advanced cognition. It appears during the Middle Stone Age (MSA, dating between 280 and ~35 ka), the technological stage that spans the origins of modern humans. This material cultural complexity has been repeatedly pointed to as a potential indicator of behavioral modernity (McBrearty and Brooks 2000; Henshilwood and Marean 2003; Marean and Assefa 2005). Here, and particularly on the coast, are found early examples of material cultural complexity that predate by some 20,000 years the “Human Revolution” of 50–40 ka. Some researchers once considered this 50–40 ka break in material culture to be worldwide (Mellars 1973; Klein 1998, 2000), but now it is widely accepted that this material cultural complexity occurs much earlier than 50 ka in Africa (McBrearty and Brooks 2000; Henshilwood and Marean 2003; Marean and Assefa 2005). The evidence includes the production of bone tools such as points (Henshilwood et al. 2001a; d’Errico and Henshilwood 2007; Backwell et al. 2008), beads (Henshilwood et al. 2004; d’Errico et al. 2005), large quantities of worked and unworked pigments (Watts 1999, 2002), decorated ochre (Henshilwood et al. 2002; Mackay and Welz 2008), and most recently lithic heat treatment (Brown et al. 2009) in MSA sites. At this stage in research, this burst of complexity appears to occur between 120 and 70 ka, but it is important to note that there is currently only a handful of sites in all of Africa that are directly dated to the prior marine isotope stage 6 (MIS6, ~195–125 ka). Pinnacle Point 13B (PP13B) is one of these. Interestingly, PP13B also provides our earliest evidence (~164 ka) for marine shellfish exploitation, as well as the best dated earliest evidence for the use and modification of pigments (Marean et al. 2007). I think that this lack of evidence for a period of material cultural complexity prior to 120 ka is largely an illusion born of a lack of sites.

Why has the South African coast produced such a rich record of behavioral complexity so early? I will argue below that this record reflects a unique confluence of context and evolutionary events, with marine shellfish collection being a key ingredient. I hypothesize that the progenitor population, the small bottlenecked group detected in the genetic analyses, was on the south coast of South Africa exploiting the rich shellfish beds and geophyte food resources. Together, these food resources presented an ideal nutrition package during the long cold glacial of MIS6. But this also raises an important question – why did hominins wait so long to expand their diet to the sea? I provide a hypothesis to explain this late dietary expansion to sea foods and suggest that this is further evidence that these hominins on the shore of South Africa had evolved a special cognitive system, one that already had in place the working memory and executive functions required to map a mobility system to lunar patterns and tidal rhythms. Modern humans are a terrestrial

mammal that, in some cases, has a persistent use of marine resources that develops into a *coastal adaptation* characterized by technological and cultural peculiarities. This coupling of a terrestrial pedigree to focused utilization of sea resources reinforced through embedded cultural knowledge is another uniquely human adaptation among the primates and thus warrants careful consideration as to its origins and impact.

Environmental Context on the South Coast

The Cape Floral Region (CFR, Fig.18.1), a thin strip of land stretching from the east to the west coast, has many special characteristics (Cowling 1992; Goldblatt 1997; Cowling and Lombard 2002; Goldblatt and Manning 2002). This relatively small 90,000 km² region has about 9,000 plant species, making its diversity near to that of tropical rainforests with larger area, rainfall, and energy, and it has a very high diversity of endemic floral taxa (69%). The three largest vegetation types are fynbos, renosterveld, and succulent Karoo. Fynbos, the largest of the three, is dominated by mainly low-height, nonsprouting (postfire) shrubs with limited dispersal, few grasses, and few trees. Pinnacle Point is nearly exactly in the middle of the east–west extent of the CFR, and today it is the location of limestone and sandstone fynbos. At Pinnacle Point (average annual rainfall=375 mm, average annual temperature=17°C), more rain falls in the summer than winter and it is overall bimodel, and the region is warmed by the Agulhas current (Fig.18.1).

The diversity of geophytes (17% of all species) in the CFR is of special importance to hunter-gatherers – this diversity far exceeds other Mediterranean-climate biomes (Cowling and Proches 2005; Proches et al. 2005). It is widely recognized that geophytes were likely a prominent component in hominin diet (Hatley and Kappelman 1980; Wrangham et al. 1999). Geophytes are a preferred food source generally for the Khoi-San hunter-gatherers of the southern Africa subregion (Tanaka 1969; Lee 1975) and of hunter-gatherers more generally in Africa (Vincent 1984, 1985). Geophyte remains are abundant in Later Stone Age (LSA) archaeological sediments (Parkington 1980, 1981). Geophytes typically have high yields of carbohydrate, temporal predictability, and humans face a relative lack of competitors for their exploitation compared to aboveground fruits, nuts, and seeds. I differ from Parkington who writes “Arguably it was the incentive provided by the poor and seasonal resources of the near coastal landscape juxtaposed to very productive intertidal ecosystems that persuaded people to experiment with and then emphasize the collection of marine foods.” (Parkington 2001:330) This superdiversity of bulbs must have been extremely productive for hunter-gatherers, and the seasonality reduced in the bimodel rainfall south coast.

The CFR is distributed in a long thin line along one of the richest coastlines in the world (Branch and Branch 1992; Bustamante and Branch 1996), at the confluence of the Benguella Upwelling and the Agulhas Current (Lutjeharms et al. 2001). This creates a varying oceanic environment from west (cold water, lower diversity,

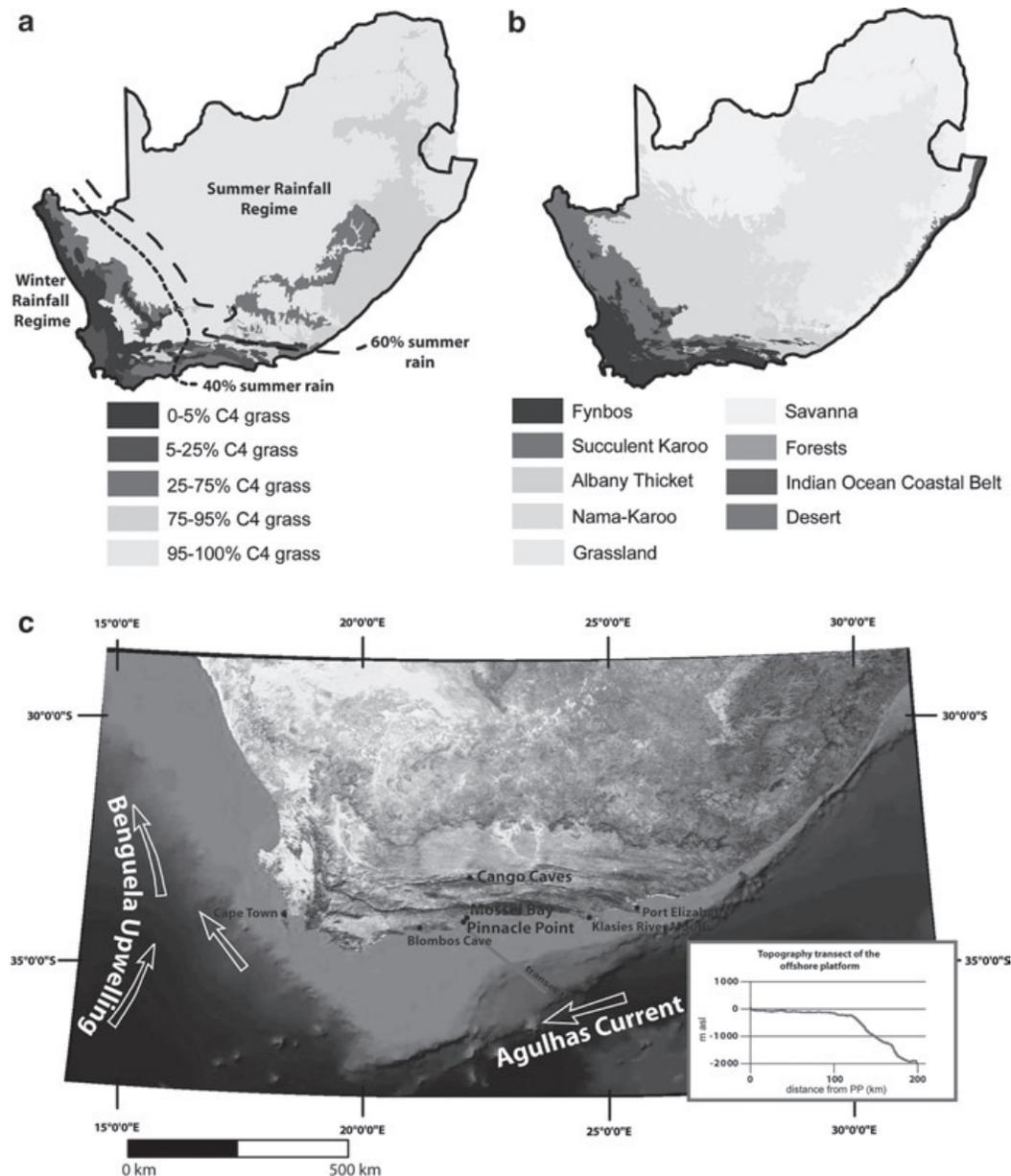


Fig. 18.1 Location of Pinnacle Point and other sites cited in the text in South Africa, the major vegetation zones, distribution of C3 and C4 grasses and configuration of offshore platform. (a) Distribution of C4 grasses as a percentage of all grasses (from Vogel 1978) (b) distribution of vegetation biomes in South Africa, (c) the location of sites mentioned relative to the coast and offshore platform. Base image of South Africa and oceanic topography from NASA World Wind, and the offshore platform transect was generated from the 3D Paleoscape model (Fisher et al. 2010)

greater biomass) to east (warmer water, increasing diversity, lower biomass) but with a mix of cold and warm eddies along the south coast. The result is that the south coast provides a diverse and dense shellfish population on the rocky intertidal zones of the quartzitic sandstones of the Table Mountain Group (TMS) and coastal beach rocks and eolianites, as well as sandy beach species. Once a forager expands

their diet to shellfish, the south coast provides an excellent protein source in the form of shellfish. Other protein sources are available as well, including Cape Fur seal, which can be hunted at onshore rookeries, or scavenged from wash-ups (Parkington 1976, 1977; Marean 1986). A diverse rocky shoreline fish population rounds out the marine offerings (van der Elst 2000), and seabirds are available for hunting and as wash-ups (Avery 1987).

The glacial aridity that depresses terrestrial productivity has a more ameliorated impact on shellfish densities and diversity, and in fact biomass increases as ocean temperatures decrease across the south coast (Branch and Branch 1992). Geophytes are well adapted to arid conditions, and the high endemic diversity of this group in the CFR shows clearly that geophytes were always abundant even during the harshest climate cycles (Proches et al. 2005, 2006). So both shellfish and geophytes would have remained a stable source of food through the glacial MIS cycle.

The bi-model rainfall of the south coast, and the relatively less harsh climate compared to the west coast, makes this region relatively lacking in seasonality. This geographic confluence of diverse geophytes, rich shellfish beds, and ameliorated climate provide a unique (for Africa) rich co-association of carbohydrate and protein that even during cold dry conditions of MIS6 would have continued to be productive and predictable, unlike other African floral and faunal biomes from interior locations and further to the west. This produced a singularly rich refugium zone for early modern humans during MIS6 on the south coast. I call this the Cape Floral Region – South Coast Model for the origins of modern humans (Marean 2008).

The gradual slope of the Agulhas bank produced a Pleistocene coastline that regressed and transgressed in association with glacials and interglacials, respectively. We have developed a 3D paleoscape model that generates estimates of the distance and placement of the coastline at 1.5 ka increments through the last 440,000 years (Marean et al. 2007; Fisher et al. 2010). This model shows us that the coastline was at times as far away as 90 km during glacial maxima. A high-resolution speleothem record, dated between 92 and 55 ka (Bar-Matthews et al. 2010), suggests that during colder periods, as the sea level dropped, the south coast received more summer rain and the neocoastline was enveloped in more C4 grassy vegetation. The CFR may have followed the coastline out onto the Agulhas bank.

The Evolution of the Coastal Adaptation

Systematic coastal adaptations are well-known throughout the world where coastal resources are productive (Erlandson 2001). Hunter-gatherers may occasionally exploit coastal and littoral foods to supplement a largely terrestrial diet, and other terrestrial mammals (such as baboons, Hall 1962) do this as well. But there are many ethnographic examples of hunter-gatherer adaptations of varying levels of complexity *focused* on coastal resources, such as the Australian Gidjingali shellfish collectors (Meehan 1982), the Tlingit of the Northwest coast of North America (Moss 1993), and the Chumash of California (Gamble 2008).

In these *coastal adaptations*, hunter-gatherers design mobility systems to intercept the coast for significant portions of the year (or even stay there all year), the people receive a substantial portion of their protein from shellfish and fish, they embed in cultural knowledge and traditions the importance of the lunar scheduling of the tides, and they schedule their activities, and sometimes world-view, around the tidal rhythms of the sea. Some of this complex lunar-tidal cultural knowledge characteristic of people with coastal adaptations has been captured in rare hunter-gatherer ethnography and historical literature (Meehan 1982; Moss 1993; Gamble 2008) but is better known from populations that are now either food producers or embedded in agricultural economies (Cordell 1974; Alves et al. 2005; Nishida et al. 2006a, b). In archaeological contexts, this coastal adaptation is archaeologically manifested by substantial portions of marine animals occurring as food remains in archaeological sites, or even “shell middens,” where the sedimentary matrix is substantially or predominantly shell (Erlandson and Moss 2001; Erlandson 2001). Other ways to identify a coastal adaptation include stable isotope analysis of skeletal material (Sealy and Van der Merwe 1987; Sealy and Sillen 1988), but to date such analyses have not been conducted on the rather small South African MSA hominin sample.

The South African archaeological record provides the world’s earliest and richest record for the origins and evolution of the coastal adaptation. Until recently, this record was restricted to sites that postdate the MIS5e high sea stand (~123 ka). This is almost certainly due to a series of related phenomena. First, many of the caves and rockshelters in coastal South Africa are below +10 msl, and thus the sediments were subject to being washed out or seriously eroded by the MIS5e high sea stand, which stood at +5–6 msl (Hearty et al. 2007). Second, MIS6 populations were likely quite small, and probably focused their residential core near the coast, which during MIS6 would put their sites out on the coastal platform, and now underwater, on much of the South African coast (Marean et al. 2007; Fisher et al. 2010).

These post-MIS5e MSA sites (Fig. 18.2 and 18.3), with rich records of shellfish collection, include Klasies River (Singer and Wymer 1982; Deacon and Geleijnse 1988), on the Tzitzikamma on the east portion of the south coast, and Blombos Cave (Henshilwood et al. 2001b), on the west of the south coast. Die Kelders Cave 1 is a difficult case because identifiable shellfish are not preserved in the MSA deposits, but traces of shellfish have been identified in micromorphology (Goldberg 2000), so it is possible that shellfish were once well represented there. Cape fur seal remains appear regularly but at low levels through the sequence (Marean et al. 2000; Klein and Cruz-Uribe 2000). The Die Kelders Cave 1 dating results so far have produced widely scattered ages (Feathers and Bush 2000; Schwarcz and Rink 2000). For these reasons, I do not discuss it further here. A more recently excavated site, Ysterfontein 2, has several occupations with dense shellfish representation (Halkett et al. 2003; Avery et al. 2008). However, the age of the deposits is unclear, so it is currently impossible to fit the sequence into an analysis of the development of a marine adaptation. Pinnacle Point provides a unique sequence by virtue of its extension into MIS6 at PP13B. PP5–6 is currently under excavation and provides a sequence so far back to ~80 ka and likely older (Brown et al. 2009), but the shellfish have not yet been studied.

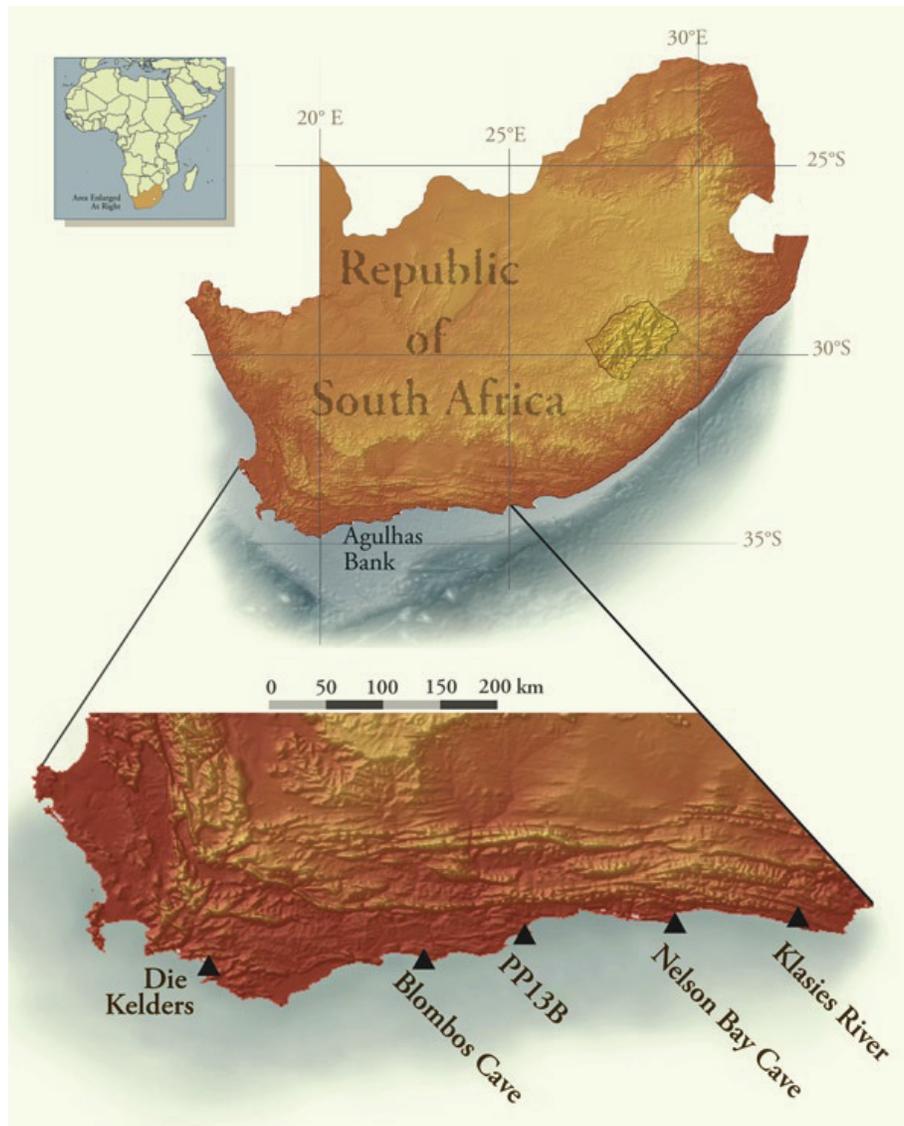


Fig. 18.2 Map of the major sites mentioned in the text

In Tables 18.1 and 18.2, I summarize the record from this set of sites. The shellfish from Blombos Cave have been reported in a preliminary manner (Henshilwood et al. 2001b), while the Klasies River shellfish have received more detailed treatment (Voigt 1973; Thackeray 1988). PP13B have been described in detail (Marean et al. 2007; Jerardino and Marean 2010). Along the left column of each table, I establish several temporal spans that range from ~170 to ~50 ka, which is currently the maximum dated time range of the coastal MSA. Most of the ages in South Africa have been determined by optically stimulated luminescence (OSL), thermoluminescence (TL), and electron spin resonance (ESR). With each of these techniques, the 2-sigma precision is often at 10–30% of the age. In the case of TL and ESR, there is often significant scatter to the published ages from the same layers, while this is not so typical of single-grain OSL. Overall, this means that there

Table 18.1 The appearance of exploitation of rocky shores and both rocky and sandy shores in shellfish collections from four archaeological sites along the south coast of South Africa

Age ka	Blombos Cave	PP13B	PP9	Klasies River
70–50	X	X	X	Rocky/Sandy
90–70	Rocky	X	X	Sandy/Rocky Rocky
120–90	Rocky	Sandy/Rocky Rocky	Rocky	Rocky Rocky
125–120	X	Rocky	X	X
170–160	X	Rocky	X	X

If a site has two distinct occupations within a time interval, then this is indicated by more than one line of text within that time interval. An X indicates that no occupation is known or published during that time interval

Table 18.2 The appearance of different shellfish intertidal collection zones (Cochlear Zone, Lower Balanoid Zone, and Upper Balanoid Zone) in four archaeological sites along the south coast of South Africa

Age ka	Cochlear Zone (very low spring tide)	Lower Balanoid Zone (low spring tide)	Upper Balanoid Zone (low neap tide)
70–50	Klasies	Klasies	Klasies
	Klasies	Klasies	Klasies
90–70	Blombos	Klasies Blombos	Klasies Blombos
	Blombos	Blombos	Klasies Blombos
120–90		Klasies	Klasies PP13B PP9 PP13B PP9
125–120			PP13B
170–160			PP13B

Also indicated in parentheses is the minimum tide needed to safely exploit that zone on the south coast. If a site has two distinct occupations within a time interval, then this is indicated by the site being listed on more than one line of text within that time interval

is quite a bit of room for temporal uncertainty – I try to take this into account. In Table 18.1, I list the major sites across the top and then indicate if the site has an occupation in that temporal span (if not this is indicated by an “X”). If it does have an occupation, I indicate whether the shellfish signal a “rocky shore” exploitation, or a “sandy beach/rocky shore.” In the latter case, this is signaled by high frequencies of the sand mussel *Donax serra*. No sites show an exclusive use of sandy beaches. Rocky shore exploitation is signaled by mussels, various species of limpets, and *Turbo* (locally called alikreukal), and it is common to have an exclusive “rocky shore” signal.

In Table 18.2, I take the same sites and temporal groups and indicate the deepest portion of the intertidal zone that is represented by the shellfish. Over the last several years, I have made systematic observations on the safety of access and exposure of

shellfish at Pinnacle Point (a TMS rocky intertidal zone directly exposed to the Indian Ocean) and Tergniet/Rhebok (a gradually sloping planed-off beachrock and eolianite reef in a more protected context within Mossel Bay). These observations show that even at the top of the intertidal zone (Upper Balanoid Zone), where brown mussels dominate, regular safe collection is only possible during low tides. Further into the intertidal zone (Lower Balanoid and Cochlear Zone), this pattern is accentuated, and low spring tide is the only time one can gain safe access. Storms and rough seas further reduce periods of safe access. Thus, the range of shellfish exploited coupled to knowledge of their relative positions in the tidal zone is a potential proxy for how attentive hunter-gatherers are to the tidal rhythms of the sea, and how strictly they may be scheduling their visits to the coast.

While our sample from South Africa includes only a few sites, these few sites sample a wide range of time and provide adequate samples that have been well described. The summarization in Tables 18.1 and 18.2 clearly shows a temporally vectored change in the way these early modern humans exploited the intertidal zone. True shell middens first appear early in MIS5; however, I do want to caution that the lack of true shell middens at earlier periods may partially reflect dissolution of shell, as clearly happened at PP13B in the LC-MSA (Marean et al. 2007). The earliest occupations show an exclusive use of rocky intertidal zones and only the Upper Balanoid zone. This zone can be exploited at low neap tide but is best utilized at low spring tide. The relative lack of Lower Balanoid species is striking and may signal that people are not scheduling their visits during low spring tides or have not yet sufficiently intensified their coastal adaptation to the point that they have pushed into the harder to exploit limpets of the Lower Balanoid zone. This expansion first begins to appear within MIS5, where true shell middens appear at both PP13B and Klasies River. Klasies River shows a first expansion to the Lower Balanoid Zone, and sandy beach exploitation first appears at PP13B. After this, between 90 and 70 ka, there is a clear expansion to the full intertidal zone, all the way to the Cochlear Zone, regular production of shell middens, and use of sandy beaches and rocky shores. Given this apparent progression and intensification in coastal adaptation, I want to address a question that I always hear when I discuss the origins of the coastal adaptation – why did early humans wait so long to exploit the sea and set in motion this development of the coastal adaptation?

The Challenge of Systematic Coastal Foraging

Tropical hunter-gatherers utilize mobility systems that we can divide into an annual home range (the area used by a band within a year) and the daily foraging radius (the area surrounding a residential site that can be exploited in one daily trip) (Binford 1980, 1982; Kelly 1995). The ethnographic record from Africa, and in fact the larger record from tropical to subtropical regions, shows that the use of space around a residential site (camp or home base) is typified by daily foraging trips defined by what a person can walk out and back in one day, generally 8–12 km

(Binford 1980, 1983; Kelly 1995), and this is well illustrated in Khoi San ethnography (Lee 1972; Tanaka 1980; Silberbauer 1981).

This foraging radius is a zone that, over the time of its exploitation, will show depleting foraging returns (McArthur and Pianka 1966; Charnov 1976; Krebs and Davies 1981; Stephens and Krebs 1986; Smith 1991; Krebs et al. 1999). When hunter-gatherers place their residential site directly on the coast, then if they eschew coastal resources they are presented with a foraging radius of roughly 50% the size and potential return of a comparable foraging radius that is further to the interior and does not engulf the coast. This rather self-obvious result predicts that hunter-gatherers should very rarely locate their residential sites at the coast if they do not forage off coastal resources. Keeping in mind that a site on the coast has half the exploitable terrestrial area of a site more than 10 km inland, this means that we would not expect sites to be on the coast until hominins commanded the ability to drive up return rates from coastal resources to equal or surpass the returns for fully terrestrial site locations. How do hominins accomplish this?

The shellfish exploited by early modern humans on the south coast were all intertidal, so tidal variation is crucial to scheduling of coastal visits. Tidal variation occurs at several levels – yearly (the presence and absence of equinox tides), lunar month (spring and neap tides), and lunar day (low and high tides), with the latter two being most significant to a forager, though it has been noted that equinox tides are monitored and targeted by foragers (Meehan 1982; Kyle et al. 1997). Lunar monthly variation has two opposing states classified into spring and neap tides, which are driven by lunar position relative to the sun (Fig. 18.4). When the sun and moon align, their gravitational forces are additive and spring tides occur where the low tide is very low and the high tide is very high (tides “spring” back and forth). Spring tides correspond to full and new moons. When the sun and moon are not aligned, their gravitational force is subtractive, resulting in neap tides that hover more tightly around the midtidal (mean sea level) mark.

In areas with gradual vertical decline of the offshore platform, such as the south coast of South Africa, spring lows reveal substantial areas of the intertidal zone, and these are the most productive and safest times to collect intertidal shellfish (Meehan 1982; Lasiak and Dye 1989; Kyle et al. 1997; de Boer et al. 2002). In rocky shores, even foraging during spring lows requires vigilance for waves in the lowest exposed areas (Lower Balanoid and Cochlear zone). A neap tide forager must target a narrow band of productivity that is subject to sudden wave onset. Since most low tides occur during daylight only once per day, there is a very tight temporal band of productive collecting available.

Ethnographic and historical accounts of hunter-gatherers document that shellfish collecting is typically done by women and children (Bigalke 1973; Meehan 1982; Hockey and Alison 1986; Claassen 1991; Moss 1993; Bird et al. 2002; de Boer et al. 2002). Women tend to focus food collection on low-risk and nondangerous foods, and many of these same ethnographic accounts document a strong preference and sometimes exclusive use of low spring-tide shellfish collection. My long-term observations of tidal variation and safety of access around Mossel Bay shows that only spring tides on the south coast present prolonged, safe, and easy access to

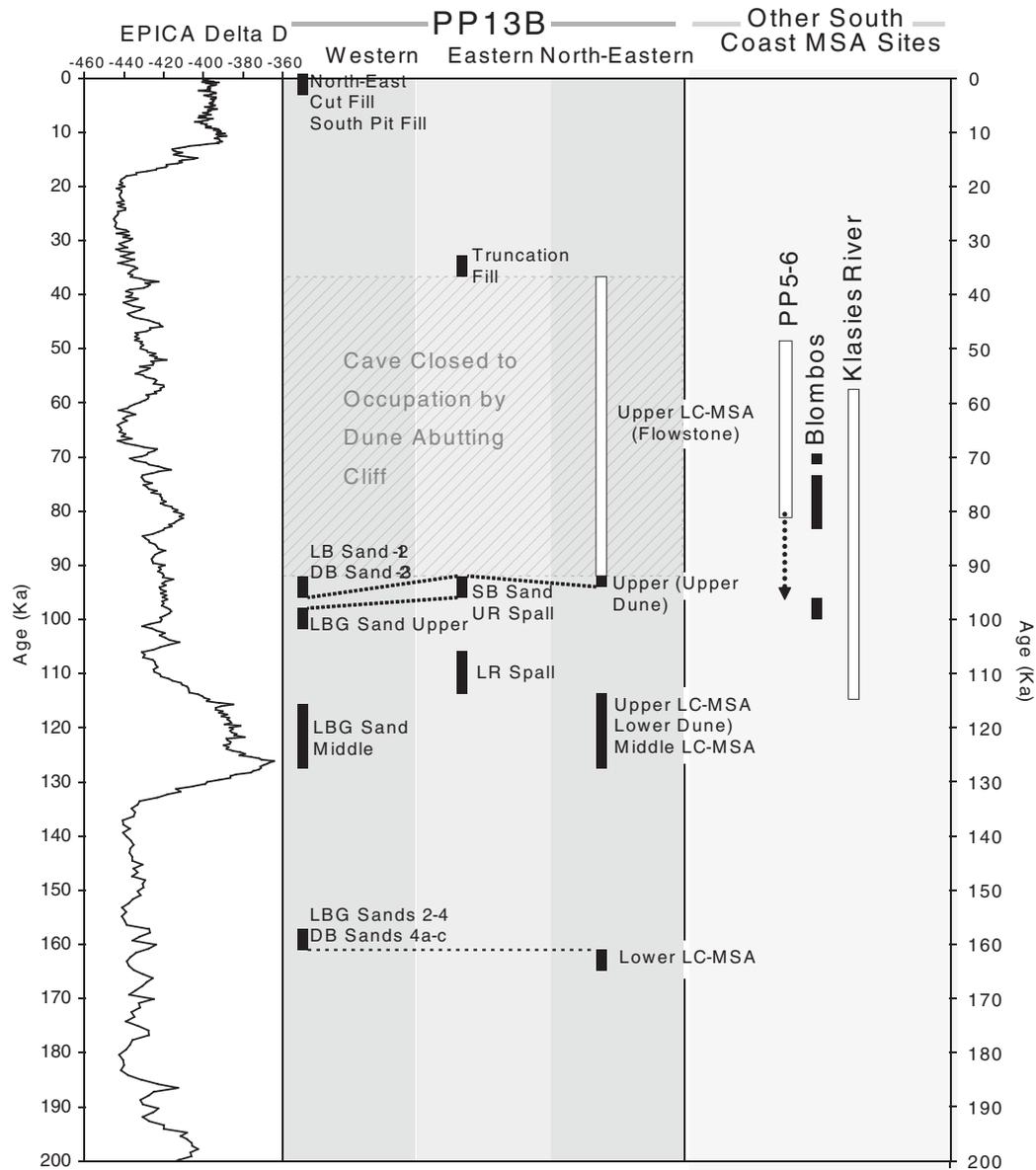


Fig. 18.3 Timescale of the sites where the shellfish characteristics are compared

rocky intertidal taxa, and this is particularly true of the Lower Balanoid zone and below. Figure 18.4 schematizes these observations. This suggests that along the south coast shellfish return rates, and thus the value of a coastal location for a residential site, rises and falls with the moon and tides. The returns of terrestrial resources are seasonally driven and not subject to lunar patterns, so over a lunar month coastal return rates fluctuate by lunar month around seasonally fluctuating terrestrial resources.

Lunar-forced variation in availability and return poses several challenges for a would-be human shellfish collector. Coastal locations inhabited during neap tides will have relatively low return rates, while coastal locations inhabited during spring

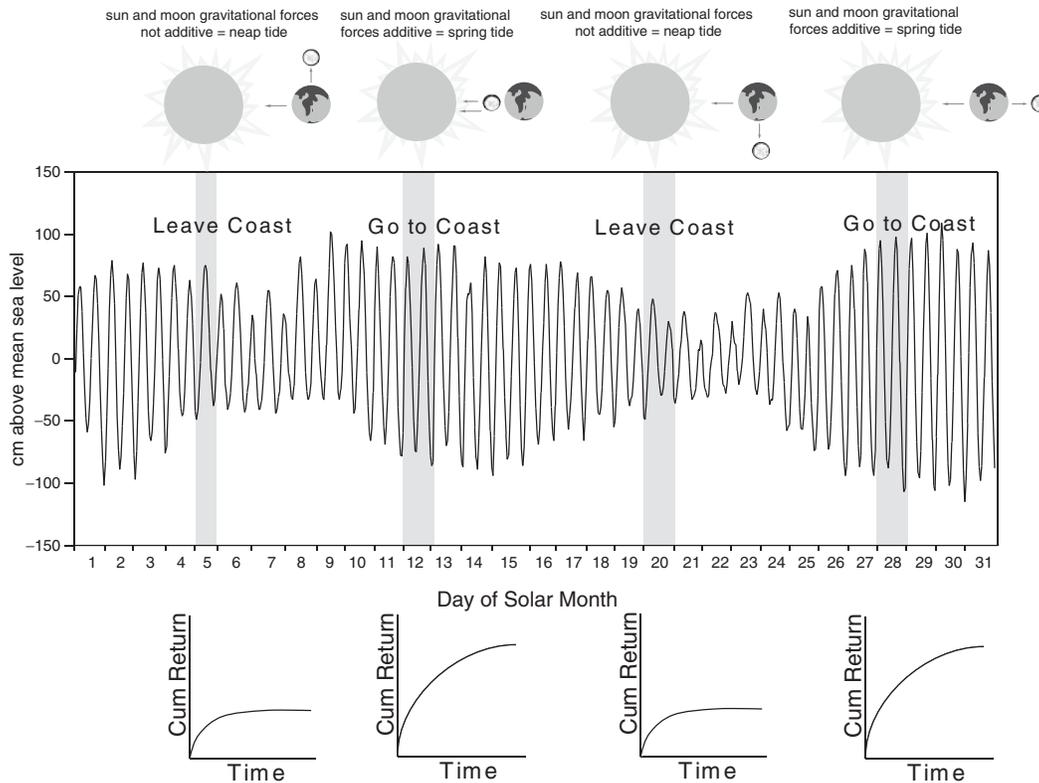


Fig. 18.4 Tidal variation relative to lunar cycle, and estimates of cumulative return rates and movement patterns from it. The tidal variation for January 1998 and its tide gauge data from the Mossel Bay tide gauge supplied by the South African Navy Hydrographic Office

tides will have relatively high return rates. Random use of the coast is highly inefficient, and would be atypical for hunter-gatherers. A human forager should schedule visits to coastal residential sites at times during the lunar month when spring tides are present and then move slightly inland during neaps to broaden the size of the exploitable terrestrial area. The math for calculating spring tides is rather difficult if one relies on solar days. The lunar month is 27.3 solar days; tides advance 25 min per tide, or 50 min per day.

I suggest that this unique lunar forcing of availability and return rates poses a special cognitive challenge to the hominin forager and is doubly difficult, since most of the time the lunar signal occurs at a time when one cannot see the tides (it is nighttime). The complexity of estimating tides is why fisherman and other coastal enthusiasts rely on complex printed tide schedules or programmed watches. If a hominin forager is moving about the landscape, and wants to schedule their visits to the coast so as to intercept the spring tides, they must have a clock of some type, the main candidate being lunar observation.

Once a forager has moved to the coast, and is targeting shellfish, the forager still faces the challenge of hitting the low tide. This may seem as easy as looking down at the water, but this is only true if one has a clear and near view. Tidal conditions are virtually impossible to see if one is not close to the shoreline, and they are very

hard to predict due to the 25 min advance of each tide relative to the solar day. The lunatidal interval (the difference between the time that the moon passes the meridian and the high tide) varies by geographic coordinate (at Mossel Bay it is about 3 h and 16 min), so developing a comprehension of the relation between moon and tidal variation requires recurrent observation. The obvious solution is to place one's residential site right at the water's edge, but that may not always be possible or convenient. Meehan (1982) notes that even expert shellfish collectors regularly made errors in timing the low tide, and once they arrived and found that they have missed the low, they abandoned the foraging foray and walked back to camp, which was typically set several kilometers back from shore.

Being an efficient human shellfish collector requires the novel connection of lunar patterns to tidal variation to shellfish return rates and safety of collection, substantial planning abilities, and communication of complex parameters between group members. All of this is a signal that the enhanced working memory and executive functions (Coolidge and Wynn 2009) of the modern human intellect are in place. Only marine and littoral foods vary by the lunar clock, making the recognition of the lunar to tidal link a clear novel connection, and its multigeneration implementation and refinement a potent example of the ratchet effect. I suggest that coastal settlement became energetically efficient when humans developed the cognitive complexity necessary to understand the relationship between lunar stages and spring tides. The complex lunar-based systems for monitoring and communicating lunar time and tidal variation that are well documented ethnographically (Cordell 1974; Alves et al. 2005; Nishida et al. 2006a, b) would develop to embed this knowledge and facilitate its teaching. Once the settlement is within walking distance of the coast (but not immediately adjacent), timing the visit to intercept the low tide required equally difficult timing and planning.

How do other animals that are not cognitively advanced exploit intertidal resources, and schedule their rhythms around tides and lunar schedules? Among sea animals behaviors that schedule to tidal rhythms are almost all certainly genome-based behavior. The rocky shoreline fish of course have the majority of their behavior embedded in the genome, so natural selection has driven their adaptation. Some seabirds, such as oyster catchers (*Haematopus moquini*), utilize rocky intertidal species (in this case, limpets and mussels). Unlike humans, they can avoid swells through flying straight up and almost certainly like fish have a genome-based behavioral adaptation to tidal patterns. It goes without saying that humans lack this genome-based knowledge – if we had this we would not require tide charts, watches, or cultural systems of lunar-tidal knowledge. I know of no terrestrial mammal that, like humans, has an adaptation that joins terrestriality with persistent and focused use of coastal resources. Some, such as baboons, are known to exploit shellfish occasionally and opportunistically, but these are not coastal adaptations as defined above.

This terrestrial lifeway joined to persistent use of marine resources is another uniquely human adaptation, one that occurs late in the human origins story. I think that the systematic and efficient shellfish collection by early modern humans required the evolution of cognitive complexity that made its first appearance roughly

coincident to when the modern human lineage first appeared (~200–140 ka). This allowed the novel connection between moon and coastal food, and opened an entirely new niche for humans that had many important benefits.

Conclusions

The south coast of South Africa has an unusual confluence of plant diversity, coastline richness, and moderate climate that I think provided the ideal conditions for a refuge for the bottlenecked modern human lineage during the long cold MIS6. The expansion of this population's diet to shellfish was likely crucial to their survival and provided the ideal conditions for the development of the complexities in behavior expressed in the archaeological record from this region. The earliest evidence for shellfish exploitation comes from this region at ~164 ka, but I suspect that early modern humans were exploiting shellfish out on the now submerged continental shelf before this date. I have proposed that their ability to expand their diet to this new resource was a benefit of the development of the modern human cognition that appeared coincident with the origin of the modern human lineage. A complex cognition characterized by fully modern working memory and executive functions allowed them to link lunar phases to tidal rhythms and, thus, develop an effective way to schedule visits to the coast in a manner that maximized returns from the coastal resources. Once this was done, this set in motion a progressive increase in the complexity of the marine adaptation along with an increasing emphasis on coastal resources that culminated by 90 ka with dense shell midden accumulations with collection at the Lower Balanoid Zone and Cochlear Zone, and the use of both rocky and sandy beach contexts. Throughout this time, there is regular, but rare, use of marine mammals such as Cape fur seal and whales, probably through scavenging. By 70 ka, there is the first rare evidence for fishing (Henshilwood et al. 2001b). Upon entering the Holocene, the full range of coastal prey, short of deep-sea fishing and diving, is common in South African sites (Jerardino et al. 2008).

The expansion of the diet to marine foods must have had major, cascading impacts on human diet, nutrition, technology, and mobility. Omega-3 fatty acids are critical to healthy brain growth and placental development, and while marine foods are not the only source (Langdon 2007), they are the best source and their addition to the diet can have substantial fitness benefits (Broadhurst et al. 2002). Unlike the latter authors (see also (Parkington 2003; Parkington et al. 2009)), I do not think that the addition of marine foods stimulated the development of the modern human cognition. Rather, this dietary expansion was a *consequence of that cognition*. I do agree though that a coastal niche provided excellent incubation conditions for the *material cultural expression* of behavioral complexity and may explain the rather singular material cultural complexity evident in the South African archaeological record during this crucial phase in the origins of modern humans.

Coastal adaptations facilitate larger group size and reduced mobility (Erlandson 2001). These larger group sizes place added selective pressure on more effective mechanisms for mediation of social relationships. The typical economic contract between men and women, where men provide the protein, is challenged by the coastal adaptation, with possible widespread effects on intersex relations. We can possibly expect social structures with greater evenness if protein is supplied by women (Hawkes 1996; Hawkes and Bliege-Bird 2002) but also by women collecting shellfish in relatively unthreatening circumstances with their children. With further fieldwork, high-quality methods, and highly resolved chronology, we may be able to investigate these interesting possibilities with this rich coastal archaeological record.

Acknowledgements I thank SAHRA and Heritage Western Cape for providing permits to conduct excavations at Pinnacle Point and export of specimens for analysis. I also thank the Mossel Bay community, Mossel Bay municipality, the staff of the Dias museum, and the Cape Nature Conservation. Our project, SACP4, is funded by the National Science Foundation (US) (grants # BCS-9912465, BCS-0130713, and BCS-0524087 to Marean), the Hyde Family Foundation, the Institute of Human Origins at Arizona State University, and Arizona State University. Thanks to Jocelyn Bernatchez, Hope Williams, and Erich Fisher for the production of the figures. Additionally, I thank Kim Hill and Antonieta Jerardino for stimulating discussions over issues discussed in this chapter and offering many useful counterpoints, some that I have ceded to.

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