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Water alone did not sustain early humans in the desert

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Water alone did not sustain early humans in the desert

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Models of early human dispersal rely on climate to predict where populations could settle, with freshwater availability governing the timing and geography[1,2], particularly across the Saharo-Arabian arid belt, where humid windows episodically opened corridors into the desert interior[3]. Yet Pleistocene dispersals into 'Green Arabia' were brief and geographically constrained[4,5], a pattern not explained by water availability alone. A 1,300 km geoarchaeological survey through Arabia's Rub' al Khali, the world's largest sand sea, found no artefacts or knappable raw materials at palaeolake deposits, despite abundant freshwater and contemporary occupation at the desert margins. Here we show that the accessibility of stone for tool manufacture operated as an independent factor on early human settlement. Spatial modelling confirms that settlement tracked the co-occurrence of water and lithic raw materials across the Arabian Peninsula, with convergent patterns from Africa, North America, and Asia. Dispersal models that omit raw material geology may systematically overestimate the habitable range of stone-tool-dependent populations.

Predictive models of early human dispersal across Arabia, built primarily on palaeohydrological reconstructions, identify interior basins as high-probability zones for Middle Palaeolithic (MP)

and Middle Stone Age (MSA) occupation[3,6]. The expectation that these palaeolakes attracted human settlement reflects decades of palaeoclimatic research demonstrating that orbital forcing periodically transformed the Arabian Peninsula into landscapes of lakes, wetlands, and grasslands[7-10]. GIS-based models built on this record have shown predictive success at the Rub' al Khali margins, where dated MP/MSA assemblages occur alongside lacustrine deposits in the western basin[11,12]. Yet these models have never been verified against systematic ground survey in the desert interior, nor have they been evaluated against the distribution of knappable raw materials, a resource fundamental to Palaeolithic subsistence[13] and consumed at rates that varied with the technology employed[14,15]. Although it has been recognised that water would not be the sole determining factor in site location[6], no study has evaluated this other variable.

To test these predictions, we conducted the first systematic geoarchaeological reconnaissance of the desert interior, along a ~1,300 km transect through the central Rub' al Khali (Fig. 1). We targeted palaeolake deposits independently dated to ~122–67 ka[16], focusing on the MP/MSA because this period corresponds to both the dated palaeolake chronologies and documented *Homo sapiens* dispersals into Arabia[17-19]. Because the nearest knappable outcrops lie more than 200 km from the surveyed basins, the interior decouples water from stone. If freshwater alone governed settlement, MP/MSA populations occupying the adjacent margins should have expanded into the interior during humid phases. While we found abundant evidence for palaeolakes, there were no knappable raw materials, no lithic artefacts, and no trace of human occupation. An independent spatial model, validated against 278 MSA findspots in adjacent Oman, confirms that settlement was restricted to zones where both water and raw materials co-occurred; a Peninsula-wide analysis reveals the same pattern across 346 documented MP/MSA sites.

Habitable but uninhabited

The expedition investigated 126 localities along the survey transect, of which 55 yielded palaeolake deposits correlated to nearby dated localities (Tables S1-S2). Published OSL ages place these interior palaeolakes in Marine Isotope Stage 5 (MIS 5) between ~122 and ~67 ka[16], overlapping the chronologies of MP/MSA occupations at the Rub' al Khali margins: Mundafan (~96-77 ka)[11,12], Al Kharj (~87-71 ka)[20], Jebel Faya (~134-80 ka)[17,21,22], and the Dhofar Nejd plateau (~109-95 ka)[5,18] (Fig. 1b; Table S4). Freshwater lakes and nearby source populations therefore coexisted across the interval, yet the interior remained unoccupied. At observed palaeolake localities, carbonate lacustrine sediments, freshwater mollusc assemblages dominated by *Melanoides tuberculata*, *Corbicula fluminalis*, and ostrich eggshell fragments were observed (Fig. 2). Sedimentological features, including bioturbated limestones, dolomitic microbial build-ups, gypsum rosettes indicative of terminal desiccation, and trace fossils characteristic of shallow lacustrine environments, confirm prior palaeoenvironmental interpretations. The additional localities recorded by our survey at equivalent elevations to the deposits investigated by Matter et al.[16] represent fragmented remnants of the same palaeolake systems (Extended Data Fig. 1; Supplementary Information Section 3).

The transect started at isolated outcrops of Jurassic Hanifa Formation, which provided lithic raw material for the MP/MSA occupation at nearby Mundafan[11,12]. Approximately 80 km further northeast, our survey documented the last bedrock outcrops (Lower Cretaceous Wasia Formation) that yielded heavily weathered silicified sandstones, of limited suitability for stone tool manufacture (Sites 8-9). East of these outcrops, the chert-bearing Mesozoic–Eocene formations dip beneath a thick sequence of Miocene to Quaternary siliciclastic, carbonatic and evaporitic sediments. In the central Rub' al Khali, only small, isolated remnants of these younger basin-fill deposits are exposed between dune fields, and none contain knappable lithologies (Fig. 3). Despite systematic reconnaissance and high ground visibility, we recovered no lithic artefacts or other cultural materials across all surveyed localities, and found no lithic raw materials throughout the transect, whether as exposed bedrock or transported clasts, except at its westernmost and easternmost ends (Fig. S2; Supplementary Information Section 1).

The archaeological vacancy of the central Rub' al Khali reflects a genuine pattern rather than fieldwork limitations. Ground visibility exceeded 95% across deflationary interdunal surfaces, and the identification of centimetre-scale gastropods and ostrich eggshell fragments confirms that lithic artefacts would have been conspicuous had they been present. The absence reflects the surface geology of the central basin, which is composed exclusively of carbonate and evaporite formations lacking cryptocrystalline silicate lithologies suitable for stone tool manufacture[23,24]. Interior palaeolakes were fed by groundwater rather than surface runoff, as indicated by fine-grained lacustrine sediments lacking coarse clastic input. Permanent lakes persist in the Rub' al Khali interior today, fed exclusively by artesian groundwater[25], and Nefud palaeolakes were similarly groundwater-fed systems without surface connectivity[26]. Unlike river-fed lakes, groundwater-fed systems have no fluvial mechanism to transport knappable stone from distant sources.

A dual resource pattern

While the absence of lithic artefacts in the Rub' al Khali interior suggests that water alone may not have been sufficient for habitation, corroborating evidence from the desert margins in Oman demonstrates that settlement occurred where water and knappable raw materials overlapped. We tested this correlation using spatial data collected from 44 archaeological survey campaigns across all of Oman between 2002 and 2024, in diverse geological and hydrological contexts, providing a comprehensive empirical dataset of both positive and null results (Supplementary Information Section 4). We independently modelled two resource layers: distance to drainage networks, and predicted probability of raw material occurrence derived from a Weights-of-Evidence analysis of geological units (Extended Data Fig. 2a,b; Supplementary Information Section 5). These layers were combined into a single human occupation potential surface and validated against 278 documented MSA findspots using Monte Carlo simulation under a spatially random null distribution (Extended Data Fig. 2c,d).

The model demonstrates that human occupation potential is concentrated in narrow zones where both water and knappable raw materials co-occur, predominantly along the Dhofar Nejd and western Hajar piedmont, while interior regions score low despite their proximity to water (Extended Data Fig. 2c). Known MSA sites cluster overwhelmingly in these highest-potential zones, whereas surveyed localities that yielded no artefacts fall within the lowest-potential areas (Extended Data Fig. 2d). Collectively, these results indicate that the central basin of the Rub' al Khali remained uninhabited throughout the MP/MSA, despite (1) the abundance of freshwater lakes, (2) the presence of contemporary human occupations around the desert margins (Fig. 1b), and (3) the demonstrated capacity of MP/MSA populations for long-distance lithic transport[27-29]. The spatial model for Oman independently corroborates this pattern, showing that settlement consistently tracks the co-occurrence of water and knappable stone, rather than water alone. The Oman MSA distribution was not used to train the Peninsula-wide model, yet the same pattern emerges at the continental scale (Fig. 4). Thus, freshwater by itself was insufficient to sustain MP occupation across 'Green' Arabia.

Occupation around the Jubbah palaeolake in northern Saudi Arabia provides the positive mirror example. Like the Rub' al Khali basins, Jubbah is an interior palaeolake system isolated from regional drainage. Unlike the Rub' al Khali, however, it sits on Saq Sandstone that supplied locally abundant quartzite, and MP populations occupied its shorelines[32,33]. The Duqm region of central Oman provides the inverse: chert is abundant and of comparable quality to the Dhofar Nejd, yet MSA sites are rare[30], a pattern attributed to the scarcity of freshwater[31]. Where the Rub' al Khali has water without stone, Duqm has stone with little water, and settlement is effectively absent in both cases. On the Dhofar Nejd, MSA populations occupied chert-rich landscapes during MIS 5c but collapsed when freshwater failed during MIS 5b, despite continued access to raw material[5]. In each case, settlement tracks the co-occurrence of water and knappable stone; where either resource is absent, the probability of occupation decreases significantly.

Tethered to stone

The dual-resource pattern documented here is not unique to Arabia. On Libya's Messak Plateau, 91% of MSA occurrences concentrate near quartzarenite outcrops despite abundant water across adjacent lowlands[34]. On the Tibetan Plateau, Terminal Pleistocene occupation was governed by the localised availability of gneissic pebbles at glacial meltwater confluences, the only knappable material in a granite-dominated landscape[35]. In Egypt's Eastern Desert, MSA sites are associated strictly with specific sandstone formations and are absent from water-rich but lithic-poor areas[36]. At Taramsa in the Egyptian Nile Valley and Jojosi in South Africa, MSA groups made repeated, specialised visits to single raw material outcrops, ignoring other locally available lithologies to export prepared blanks across the wider landscape[37,38]. In North America, Paleoindian settlement systems were bound to stone quarries, with raw material sources functioning as the hubs around which subsistence strategies were organised[39]. These convergent patterns, across different geological substrates, hydrological regimes, and chronological contexts, illustrate the 'tethering'

effect whereby stone-tool-dependent populations become tied to raw material sources[40]. The effect was amplified in Arabia, as MP/MSA prepared-core technologies consumed substantial raw material in core preparation[11,12,22,41], intensifying their dependence on proximity to knappable stone.

We propose that the Arabian Peninsula comprised a patchwork of discrete zones where water and lithic raw materials co-occurred, attracting and sustaining MP/MSA settlement. Existing dispersal models prioritise topographic variables, climate, and water availability[1-3,42,43] but do not incorporate lithic resource distributions. While MP/MSA populations could transport stone over long distances[27-29], such transfers represent occasional long-range acquisition, not the sustained provisioning required to support permanent settlement. Hunter-gatherers navigating >200 km between disconnected groundwater-fed lakes in the Rub' al Khali would need to import all lithic raw materials, a strategy inconsistent with transport costs observed in MP/MSA contexts globally[44-46]. Whether the interior vacancy additionally reflects low colonising population size or the landscape knowledge that foragers accumulate over millennia of occupation (Supplementary Information Section 7), the consequence is the same: populations occupying northern/central versus southern Arabia would have experienced limited demographic exchange across the uninhabited interior. Across the total area of the Arabian Peninsula falling within water-proximity thresholds, 57% overlies geological formations that lack knappable lithologies. Thus, when raw material geology is factored into existing climate-based models, more than half the area conventionally classified as habitable was unsuitable for sustained MP/MSA occupation. This correction extends beyond Arabia to any arid landscape on which early humans settled.

Our results suggest that 'Green Arabia' was an archipelago whose islands were defined as much by geology as by climate; dispersal models that omit lithic raw material distributions may systematically overestimate the habitable area available to stone-tool-dependent populations. For Pleistocene arid landscapes, the viable territory was not merely where water occurred, but the fraction of those areas where water and knappable stone coincided. This constraint was not fixed, however, but would have scaled with how much raw material a given tool technology consumed[14,15]. The prepared core technologies that dominated Arabian MP/MSA assemblages required substantial volumes of stone[11,12,22,41], and the settlement patterns documented here are consistent with a tethering effect that bound populations tightly to outcrops. Subsequent shifts toward more efficient reduction systems may have loosened this dependence.

Methods

Expedition design and logistics

The Rub’ al Khali crossing expedition team conducted systematic geoarchaeological reconnaissance along a ~1,300 km transect through the central Rub' al Khali between 15 November and 20 December 2023 (35 days). The expedition comprised eight team members utilising three purpose-built expedition vehicles equipped with fuel, water (~1,700 litres), and supplies enabling

six weeks of autonomous operation. Route planning involved analysing satellite imagery to chart a passage through the dune fields (Google Earth, Sentinel-2), targeting palaeolake basins that contained previously dated deposits[18].

Site identification and survey methodology

Localities were identified through satellite imagery analysis, searching for visible lacustrine deposits and published palaeolake locations. Survey strategy comprised systematic pedestrian reconnaissance within ~500 m radius corridors centred on exposed lacustrine sediments. Time allocated per locality varied from 10 minutes to 5 hours depending on exposure extent and accessibility. Survey corridors totalled ~43 km^2 of systematically reconnoitred area (calculated as $\pi \times 0.5^2$ km per locality × 55 palaeolake localities). Combined with >95% ground surface visibility, this represents survey intensity comparable to published regional investigations.

Survey targets included: (1) lithic artefacts or manufacturing debris, (2) mollusc shells, (3) ostrich eggshell fragments, (4) sedimentary features characteristic of lacustrine environments, (5) trace fossils, and (6) lithic raw materials suitable for stone tool manufacture.

Chronological control through independently dated localities

Our strategy of targeting palaeolake deposits within the study area of Matter et al.[16] provides chronological control through spatial and stratigraphic correlation with independently dated sections. Of 55 surveyed palaeolake localities, 25 occur within 75 km of Matter et al.'s OSL-dated sections, and five localities (Sites 61–65) lie within 20 km of dated deposits yielding ages of ~122-67 ka. Survey localities at equivalent elevations (within ±15-20 m, accounting for SRTM vertical accuracy and post-depositional deflation) and exhibiting identical lacustrine facies such as grey marls, carbonate platforms, and freshwater mollusc assemblages are interpreted as erosionally fragmented remnants of the same palaeolake systems (Extended Data Fig. 1; Supplementary Information Section 3). The conclusion that freshwater was present but occupation was absent is robust, given the same result obtained across all 55 palaeolake localities spanning the full extent of the transect.

Spatial modelling of human occupation potential for the Arabian Peninsula

To evaluate whether dual-resource availability predicts MP/MSA settlement, we developed a spatial model of human occupation potential for the Arabian Peninsula, integrating water proximity and lithic raw material occurrence.

Water source locations were reconstructed by combining the HydroRIVERS global drainage network[47], filtered to rivers with upstream catchment areas ≥1,000 km^2. We further filtered to eliminate modelled drainage networks in areas with Quaternary aeolian geology[6]. Rivers were buffered by Strahler order to approximate channel width[48].

Raw material presence is defined by a geological map (Supplementary Information Section 5.5) where each geological unit is associated with the presence or absence of various raw material types known to be used to make stone tools. Lithic raw material suitability was assessed based on conchoidal fracture properties characteristic of cryptocrystalline silicates, namely chert, quartzite, quartz, chalcedony, rhyolite, and quartzitic/silicified limestone or sandstone.

Human occupation potential was classified for each resource layer independently. Water-based potential was defined by distance thresholds corresponding to the 50th, 75th, and 95th percentiles of observed site-to-water distances (high = 3, medium = 2, and low = 1 potential, respectively). All raw material types were treated as equal; geological units with at least one of these raw materials were assigned a value of 1 and units without any raw materials were assigned a value of 0. These layers were combined into a single human occupation potential surface that is effectively limited to where raw materials are present and scaled by proximity to water resources (Supplementary Information Section 5).

The combined model was validated against the observed distribution of MSA sites using Monte Carlo simulation. For each of 999 iterations, random point sets equal in number to known sites were generated within the study area, and modelled human occupation potential values were extracted. A 95% confidence envelope was calculated from the ensemble of simulated distributions and compared to the observed distribution to test whether sites are preferentially associated with zones of high modelled potential.

Techno-cultural attribution of surface assemblages

The majority of MP/MSA findspots used in the spatial analyses are surface occurrences lacking stratigraphic or chronometric control. Techno-cultural attribution relies on the presence of prepared core technology diagnostic of the MP/MSA: Levallois reduction systems (preferential, recurrent centripetal, and convergent), Nubian Levallois Types 1 and 2, together with characteristic flake and point products (Levallois flakes, Levallois points, and retouched points on Levallois blanks). Assemblages dominated by bifacial reduction (Lower Palaeolithic) or by blade technology on single-platform cores (Upper Palaeolithic) were excluded. Sites with mixed assemblages spanning multiple periods were included only where MP/MSA components were demonstrably present as discrete spatial concentrations, or where diagnostic MP/MSA core technology was distinguishable from other temporal components. The same typological criteria were applied consistently to the Oman dataset (n = 278) and to the Peninsula-wide compilation (n = 346), following the techno-cultural attributions of the original publications.

Documentation protocols

Geographic coordinates were recorded using GPS (±5–10 m accuracy). All features were photographed with GPS geotagging. Aerial documentation employed drone photography. No physical samples were collected.

Ethics and inclusion statement

Fieldwork in the Rub' al Khali, Saudi Arabia, consisted strictly of non-invasive, non-collecting surface reconnaissance. Prior to the expedition, the research team engaged with the Saudi Ministry of Culture to coordinate activities. Because the proposed 1,300 km continuous transect was unprecedented in scale and designed purely as an observational survey, the Ministry advised that site-specific archaeological research permits were not applicable. Consequently, no excavation was undertaken, and no artefacts, sediments, rock samples, or biological specimens were collected or removed from Saudi Arabia. All observations were recorded *in situ* using photography and GPS logging, with malacological identifications made exclusively from field photographs. Fieldwork in Oman was conducted under permits issued by the Ministry of Heritage and Tourism, within the framework of collaborative research programmes initiated in 2002. A subset of the Omani site data was derived from commercial Environmental Impact Assessments conducted by J.I.R., undertaken in compliance with Omani heritage legislation (RD 2019-35) and IFC Performance Standard 8. All data and analytical code have been made public in an online repository.

Data and code availability

GPS coordinates, field photographs, and survey documentation from the Rub' al Khali crossing expedition are archived in an OSF repository at https://osf.io/4mw23/. The georeferenced MP/MSA site database for the Arabian Peninsula (n = 346), the Oman survey database (n = 278 MSA findspots from 44 campaigns), geological raw material classifications, and modelled human occupation potential surfaces are also archived in the repository under a CC-BY 4.0 licence. The complete analytical workflow for spatial modelling of human occupation potential (Weights-of-Evidence raw material modelling, palaeodrainage proximity classification, combined model generation, and Monte Carlo validation) is provided as a documented, executable R notebook in the repository. The workflow is modular and transferable: users can substitute regional geological maps and drainage networks to assess human occupation potential for stone-tool-dependent populations in any study area with published geological and hydrological data.

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and comments on the manuscript. AI tools (Claude, Gemini) were used to assist with manuscript preparation, including editing for clarity and style. AI was also used to assist with development of R code for spatial analysis and figure generation. All scientific content, analytical design, interpretation, and conclusions are the sole responsibility of the authors.

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Author contributions

R.W.D. and J.I.R. conceived the study, designed the research, and interpreted the results. R.W.D. conducted geoarchaeological investigation during the Rub' al Khali crossing. J.I.R. directed the Oman research campaigns (2002-2025). R.G. co-directed Oman research campaigns and coordinated logistics (2022–2025). E.C. developed the spatial model and performed spatial analyses. J.I.R. and E.C. drafted the figures. M.H. identified and interpreted mollusc assemblages. O.S. produced GIS basemaps and compiled spatial data. M.A.K. validated the geological framework, revised the Rub' al Khali stratigraphic cross-section, and contributed to raw material analysis. A.A.M. facilitated engagement with the Oman Ministry of Heritage and Tourism and approved the final manuscript. J.I.R., E.C., R.W.D., M.I.E., M.R.B., and R.G. wrote and edited the manuscript. All authors reviewed and approved the final manuscript.

Competing interests

The authors declare no competing interests.

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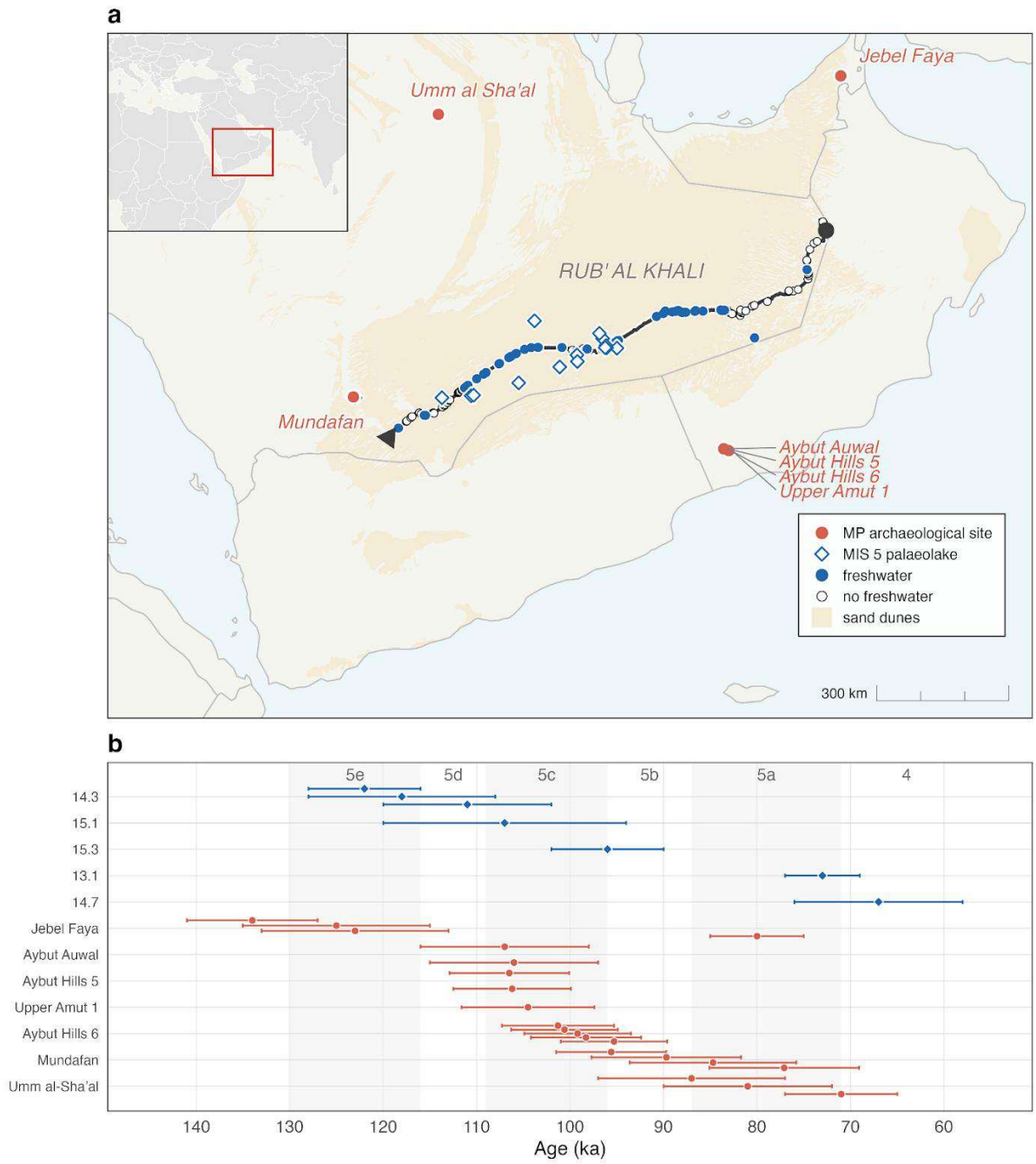


Fig. 1 | Palaeolake evidence and chronological context across the Rub' al Khali. (**a**) Rub' al Khali crossing expedition track (black line) shows the survey transect. Orange filled circles indicate dated MP/MSA sites surrounding the study area. Blue filled circles indicate surveyed localities where palaeolake evidence was recorded (n = 55); black open circles indicate localities lacking palaeolake indicators (n = 71). Blue open diamonds mark published palaeolake localities[8,16]. Sand dune extent defined by Quaternary aeolian deposit boundaries[49]. (**b**) Published OSL chronologies for central interior palaeolakes[16] (blue, ±1σ) and dated MP/MSA sites at the basin margins (red, ±1σ). Numeric ages for archaeological sites presented in Table S4.

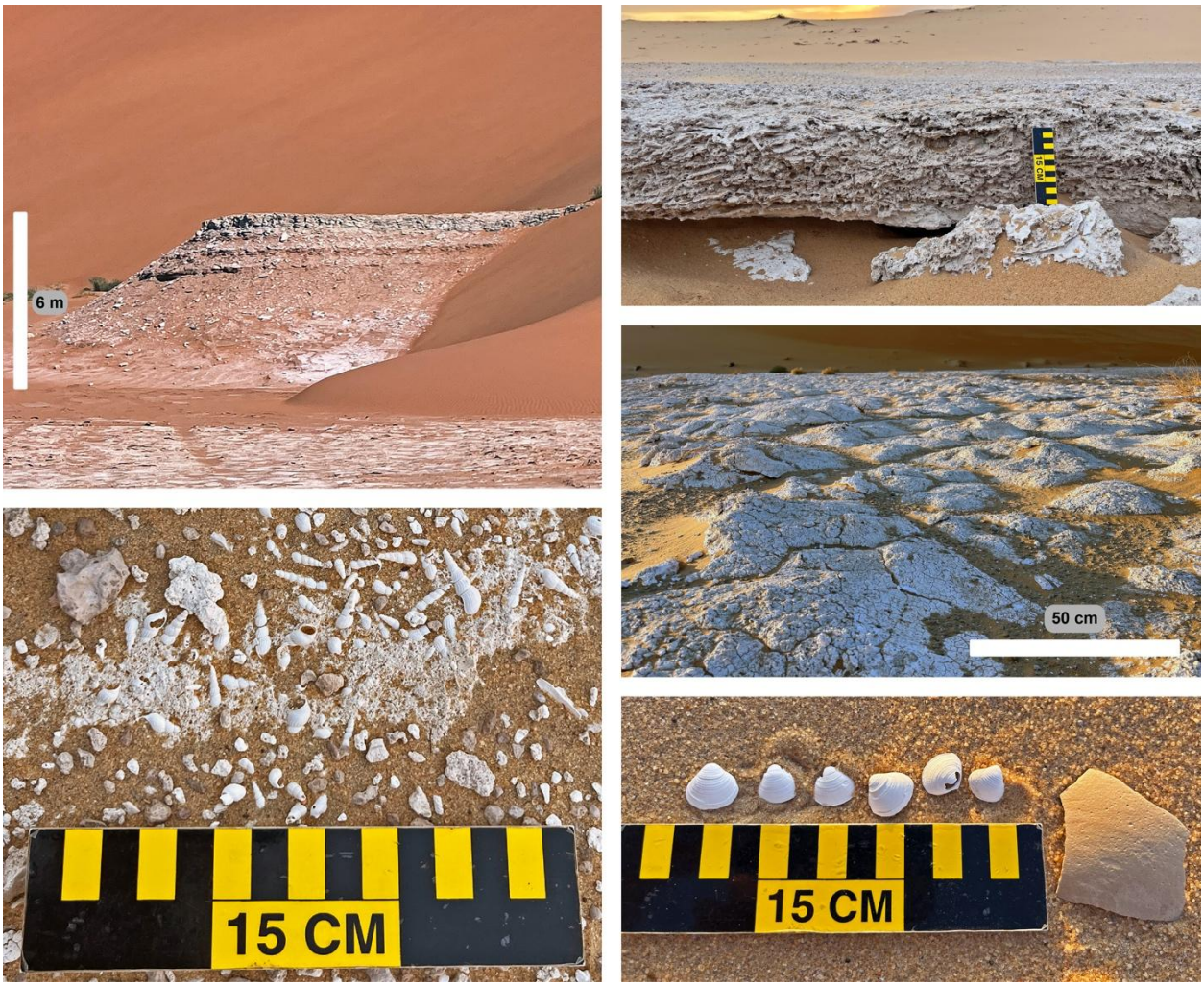


Fig. 2 | Palaeoenvironmental evidence for persistent freshwater at interior Rub' al Khali localities. **Top left**: Partly exposed stratified relict palaeolake deposit in the foreground sabkha evaporites mixed with aeolian sands. **Bottom left**: *Melanoides tuberculata* molluscs in situ. **Top right**: Massive carbonate platform (⌀ >20 cm), strongly bioturbated and with abundant *Melanoides tuberculata* gastropods. **Middle right**: Polygonal gypsiferous laminated dolomitic microbial build-ups (palaeolake). **Bottom right**: *Corbicula fluminalis* bivalves and ostrich eggshell fragment.

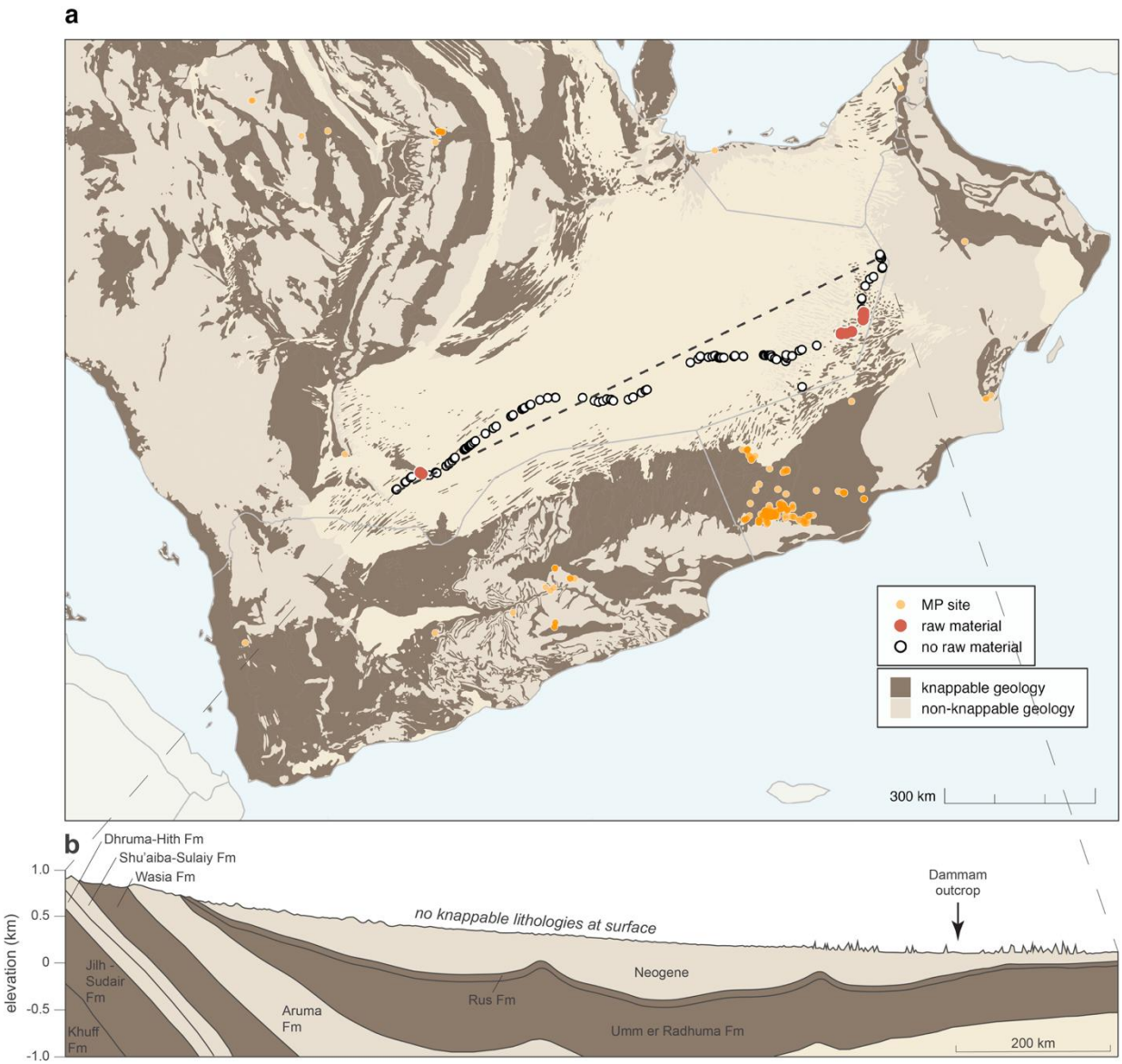


Fig. 3 | Geological constraints on lithic raw material availability across southern Arabia. (a) Surface geology classified by the presence or absence of knappable lithologies (chert, quartzite, quartz, chalcedony, silicified limestone/sandstone, rhyolite), based on the USGS geological map of the Arabian Peninsula[49] with raw material classifications from published formation descriptions[50]. White open circles show survey localities from the Rub' al Khali crossing expedition where no lithic raw material was observed (n = 116); red filled circles show localities where knappable raw material was present (n = 10), all restricted to the western and eastern basin margins. Small gold dots indicate published MP/MSA sites. Dashed line approximates the transect shown in Panel b. **(b)** Schematic geological cross-section along the survey transect, illustrating the burial of Palaeocene–Eocene chert-bearing formations beneath Neogene–Quaternary basin fill across the Rub' al Khali interior. Structural and stratigraphic relationships modified after Stewart[23] and expedition field observations.

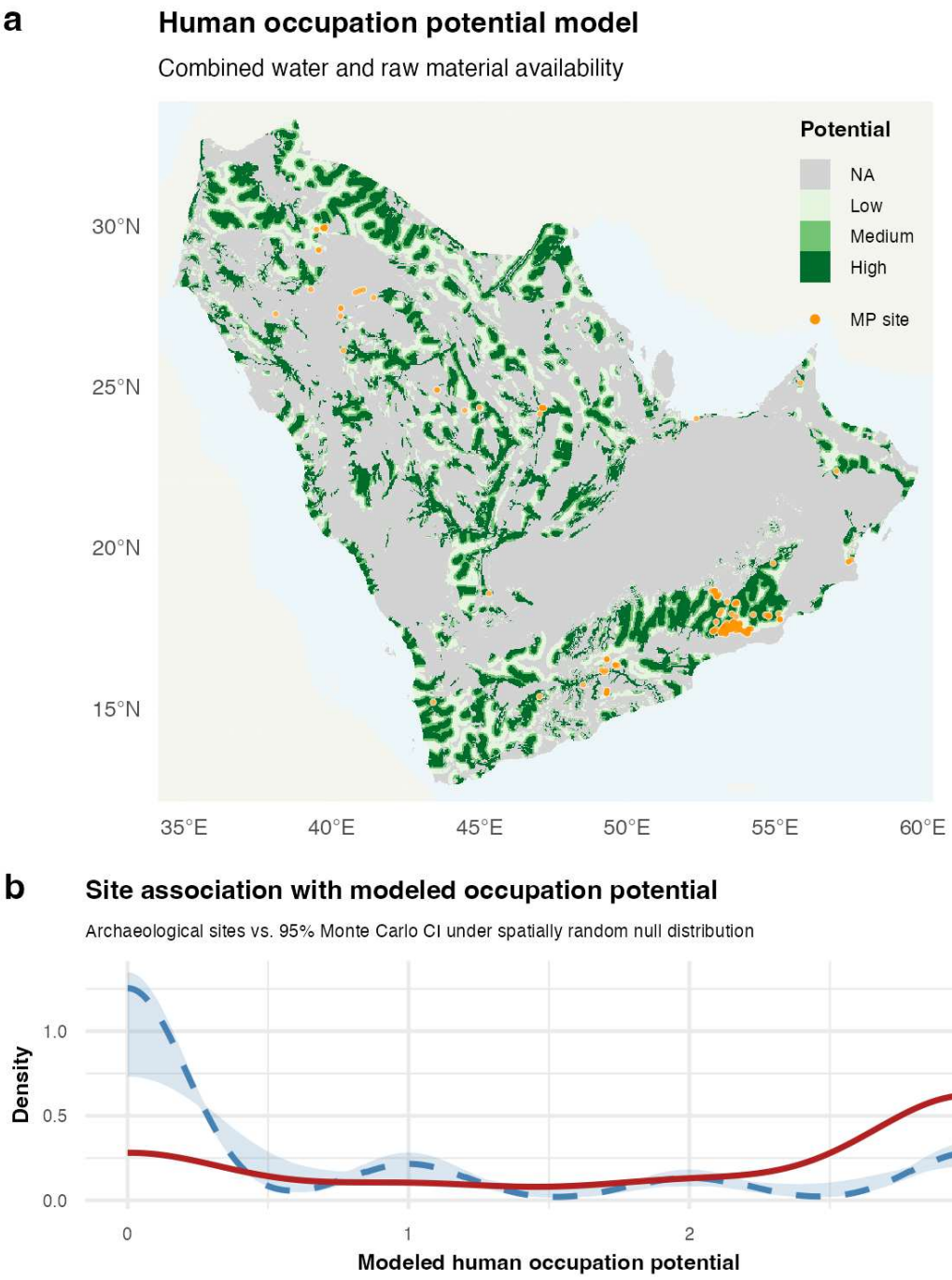
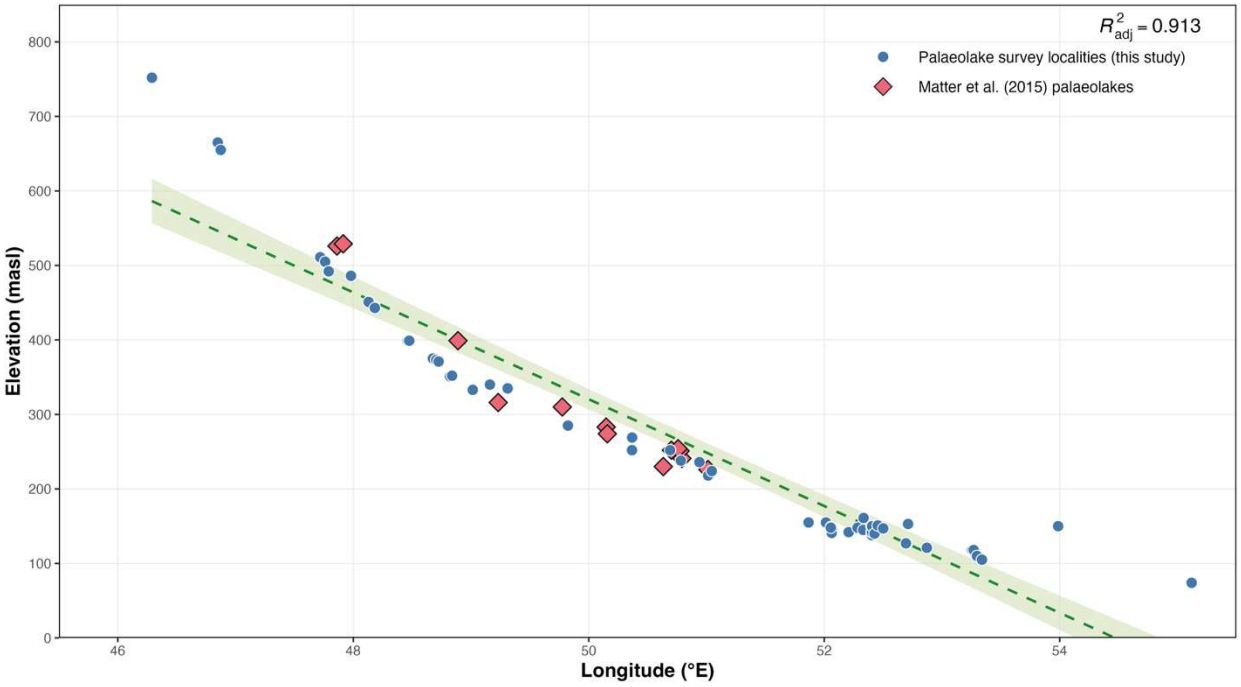


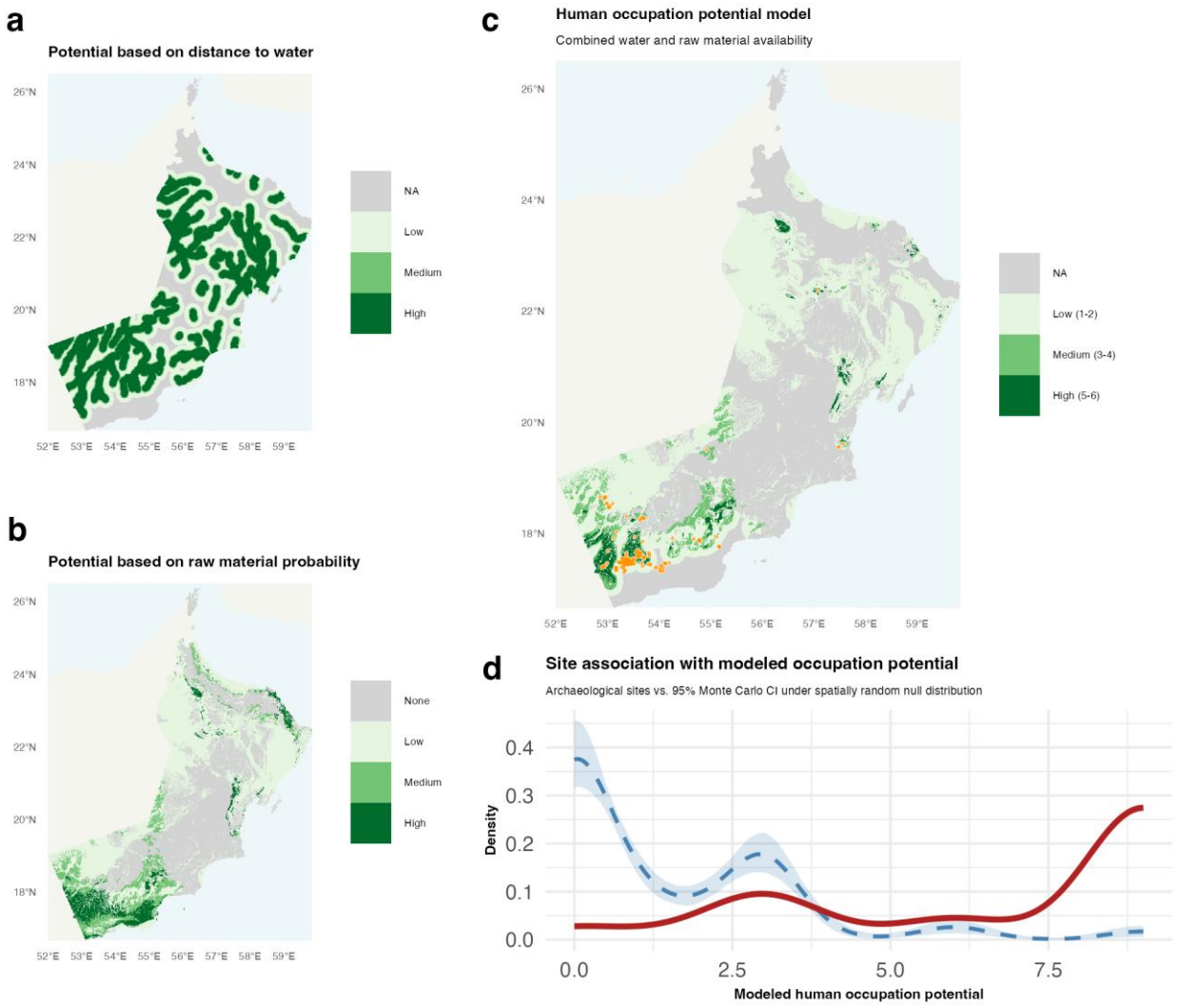
Fig. 4 | Human occupation potential model incorporating dual-resource pattern. (a) Dual-resource model for the Arabian Peninsula. 57% of the area classified as water accessible lacks knappable raw material and is excluded from the dual-resource model. Small orange dots indicate MP/MSA sites. (b) Statistical validation: density distribution of published MP/MSA sites (n = 346; solid red line) plotted against modelled human occupation potential, compared with 95% Monte Carlo confidence interval (blue dashed line and shading) expected under a spatially random null distribution. Sites are significantly over-

represented in zones of highest modelled potential and significantly underrepresented in zones where neither resource occurs.

Extended Data



Extended Data Fig. 1 | Elevation-longitude profile of palaeolake localities across the central Rub' al Khali, reflecting regional piezometric surface. Blue circles show palaeolake deposits documented during the Rub' al Khali crossing expedition (n = 55); red diamonds show Matter et al.[16] sampling localities (n = 24). The dashed line indicates linear regression through survey localities (Adjusted R^2 = 0.913, F = 583.4, p < .0001), with light green shading showing the 95% confidence envelope. The consistent east-directed decline in elevation (~71.4 m per degree longitude) reflects the regional topographic gradient from the Arabian Shield toward the Persian Gulf. Matter et al.[16] palaeolake sites show a mean absolute deviation of 28.8 m from the regression model, supporting the spatial continuity of these lacustrine systems across the central Rub' al Khali.



Extended Data Fig. 2 | Predictive model of human occupation potential incorporating dual-resource patterns in Oman. (**a**) Human occupation potential based on distance to reconstructed palaeodrainage networks (total upstream area ≥ 1,000 km^2). Proximity to water classified as high (dark green), medium (green), or low (light green) probability. (**b**) Human occupation potential based on probability of knappable raw material occurrence, derived from 1:250,000 geological mapping of chert-bearing formations. (**c**) Combined dual-resource model integrating water proximity and raw material availability. High-potential zones (dark green) are restricted to areas where both resources co-occur at their highest human occupation potential, predominantly on the Dhofar Nejd plateau and western Hajar mountain piedmont. Interior regions register as low potential despite high water availability scores. Small orange dots indicate MSA sites. (**d**) Statistical validation: density distributions of modelled human occupation potential at known MSA sites (*n* = 278) compared with the 95% Monte Carlo confidence interval expected under a spatially random null distribution (blue dashed line and shading).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryData1.xlsx
- RAKCrossing2026.04.17SI.docx
- RAKCrossing2026.04.17SI.docx