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News and Views

Fine-tuning paleoanthropological reconnaissance with high-resolution satellite imagery: the discovery of 28 new sites in Tanzania

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Introduction

Fossils, artifacts, and their geological settings are the raw data of human evolution—they evince what actually happened when and where, and its ecological context. As such, field research represents the essential foundation upon which the discipline of paleoanthropology rests. Many discoveries are made from large outcrops of sedimentary rock in the East African Rift Valley, and researchers have thus concentrated explorations on these extensive exposures (e.g., Omo, Koobi Fora, Olduvai). However, smaller outcrops, where human evolution may also be documented, have received little attention. Due to fast infrastructure development and rapid population growth in East Africa there is an urgent need to implement a research strategy that will increase our ability to identify smaller exposures.

We have incorporated high resolution satellite imagery (HRSI) into our survey methodology, greatly improving our ability to systematically locate and efficiently identify smaller outcrops (e.g., <10 km^2). Here we demonstrate its successful application during the first three field seasons (2006–2008) of a country-wide reconnaissance for new sites in Tanzania. We have identified 28 previously unknown archaeological and/or fossil-bearing localities in nine administrative districts. We describe our field work in the Hanang district in more detail to exemplify how HRSI can be incorporated into reconnaissance work at scales not previously accessible.

Background

Tanzania has long been recognized for its rich archaeological and paleontological record of human evolution. Much of the country is situated between the Albertine and Gregory rifts as they wrap around the margins of the Tanzanian Craton (McConnell, 1972; Dawson, 1992). The well known hominid paleontology sites are primarily located in the northern part of the country where the Gregory Rift and its associated volcanism are quite active (Dawson et al., 1994). These include Laetoli, Olduvai Gorge, and other late Neogene and Quaternary sites in proximity (Kent, 1941; Kohl-Larsen, 1943; Isaac, 1965; Keller et al., 1975).

Relatively few paleoanthropological sites have been recorded outside of the northern volcanic sector. These include Wembere-Manonga (Harrison, 1997), Isimila (Howell et al., 1962), and a number of archaeological sites in southwestern Tanzania (Clark, 1970), central Tanzania (Masao, 1992), and in the western Lake Victoria region (Wayland, 1954; Reid and Njau, 1994). Mesozoic and early Cenozoic fossil sites are also found in Tanzania, but not typically in the northern sector (Maier, 2003; Rauhut, 2005; Stevens et al., 2005).

It is unlikely that the northern geographic cluster of late Neogene-Quaternary sites (Fig. 1) reflects the geographic range of early hominids. Indeed, even early taxa such as *Australopithecus afarensis* are found in a variety of environmental settings across a wide geographic range (Reed, 2008). Given the adaptive plasticity of even early hominids, the cluster of sites in Northern Tanzania more likely represents an artifact of geological circumstance and survey intensity than a real biogeographic signal. We undertook our broad survey in the anticipation that the absence of evidence of human evolution in other parts of the country might be due to a lack of intensive survey.

In order to test this hypothesis, we developed the Tanzania International Paleoanthropological Research Project (TIPRP). Co-directed by the authors, this multi-year project is conducting a systematic country-wide reconnaissance for previously unknown sediments of paleoanthropological interest. We employed a HRSI-based approach that led to the identification of 28 previously unknown localities. The localities were discovered within relatively

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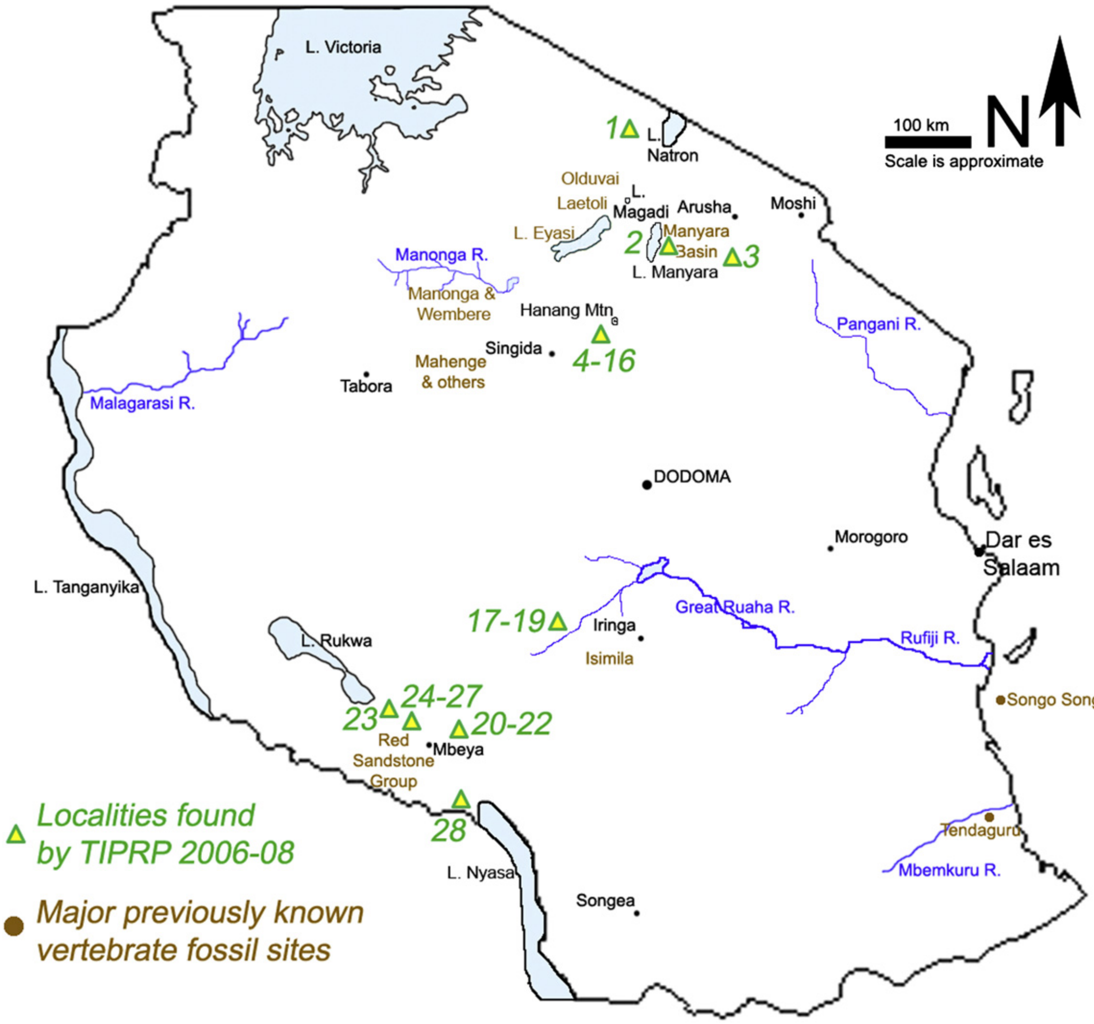

Fig. 1. Schematic map of Tanzania showing the distribution of known paleontological and paleoanthropological sites, TIPRP found localities, and major geographic features.

small sedimentary packages and were often obscured by steep topography and/or vegetation (Table 1).

Although HRSI is commonly used in archaeology to detect landscape archaeological features (e.g., settlements, monuments; e.g., De Laet et al., 2007; Garrison et al., 2008; Saturno et al., 2007; Siart et al., 2008), reports of HRSI application to field paleoanthropology are rare. Our approach follows the precedent set by Asfaw et al. (1990) who conducted an imagery-based systematic survey of paleoanthropological resources in Ethiopia, resulting in the discovery of sites such as Konso Gardula (Asfaw et al., 1992), Kesem-Kebena (WoldeGabriel et al., 1992), and Fejej (Asfaw et al., 1991). Their project relied on imagery with much lower resolution than what is currently available. That work employed Landsat Thematic mapper (TM) mosaics with resolution of ~30 m, Space Shuttle Large Format Camera (LFC) photographs that provided a scale of ~1:50,000, and 1:30,000 aerial photo coverage (much of it dating to the 1960s). With the advent of GoogleEarth© and access to significantly higher resolution imagery (~1 m, some freely available and some purchased), we were able to employ a much finer-resolution approach, targeting smaller sedimentary packages with less visible outcrop.

While TIPRP is not the first survey project conducted distal to the concentration of rich paleoanthropological sites in northern Tanzania (McBrearty et al., 1984; Lim, 1985; Willoughby and Sipe, 2002; Kafumu and Paepe, 2003), we expand on these other projects by including a wider geographic range and by employing newly available technologies.

Methodology

Identifying target areas with high-resolution satellite imagery

While Landsat TM, LFC imagery, and aerial photographs have proven useful for many paleontological and archaeological projects over the years, recently released high-resolution satellite imagery (HRSI) and GoogleEarth© have facilitated a level and ease of remote survey never before possible within paleoanthropology.

TIPRP initially worked from freely available satellite imagery (http://earth.google.com). The quality and resolution of these images vary and are continuously updated. Some areas of Tanzania have ~1 m resolution for many square kilometers, while other areas have 30–76 m resolution for vast tracks.

Working within the constraints of these various levels of image quality we initially targeted areas for ground assessment. Additional information for identifying target areas came from geological and historical accounts (e.g., Spurr, 1953; Quennell et al., 1956; Pickering, 1958; Schluter, 1997).

During our first field season in 2006, we briefly visited a number of these targets, identifying and bounding several sedimentary packages worthy of more study. For these areas, we pursued the

Table 1
New localities identified by TIPRP (2006–2008) listed by numbers 1–28 shown in Figure 1 [a,b]

Map No.	Locality name	Location/Village	Area/District	Region	Latitude	Longitude	Abundant fossil taxon	Industry	Discovery date
1	OLL-ARC 1	Oloololo	Ngorongoro	Arusha	S2°23′	E35°24′	BOV, EQU, SUI, CAR	MSA	23-Nov-07
2	MWJ-VP 1	Mswakini Juu	Monduli	Arusha	S3°36′	E36°02′	SUI, BOV, EQU	MSA, LSA	18-Nov-07
3	NAM-VP 1	Namba Mbili	Simanjiro	Manyara	S3°39′	E36°41′	BOV	MSA	13-Jul-06
4	GDM-VP 1	Gidagamodi	Hanang	Manyara	S4°28′	E35°14′	BOV, EQU	–	15-Sep-07
5	GDM-VP 2	Gidagamodi	Hanang	Manyara	S4°28′	E35°13′	BOV, MAM	–	15-Sep-07
6	GDM-VP 3	Gidagamodi	Hanang	Manyara	S4°27′	E35°13′	BOV	–	20-Sep-07
7	GSG-VP 1	Ghalusaygaje	Hanang	Manyara	S4°29′	E35°14′	BOV, EQU, CAR, ROD	–	14-Sep-07
8	GUJ-VP 1	Gujaw Hill	Hanang	Manyara	S4°29′	E35°16′	BOV	–	23-Jun-08
9	HEW-VP 1	Hewari	Hanang	Manyara	S4°29′	E35°14′	BOV, EQU, ROD, REP	–	12-Sep-07
10	HEW-VP 2	Hewari	Hanang	Manyara	S4°51′	E35°14′	BOV, EQU, REP, ROD	–	13-Jun-08
11	JVA-VP 1	Javda scarp	Hanang	Manyara	S4°25′	E35°14′	GIR, BOV	–	21-Jun-08
12	KHA-VP 1	Khambalinda	Hanang	Manyara	S4°29′	E35°16′	BOV	–	23-Jun-08
13	KLA-VP 1	Kigchela	Hanang	Manyara	S4°30′	E35°11′	BOV, EQU	–	20-Jun-08
14	MUL-VP 1	Mulbadaw	Hanang	Manyara	S4°23′	E35°16′	BOV, EQU	–	21-Jun-08
15	MUL-VP 2	Mulbadaw	Hanang	Manyara	S4°25′	E35°14′	BOV	–	21-Jun-08
16	MUL-VP 3	Mulbadaw	Hanang	Manyara	S4°25′	E35°14′	BOV	–	22-Jun-08
17	MWG-ARC1	Mwagusi Sand River	Ruaha NP	Iringa	S7°36′	E34°52′	–	LSA	27-Jul-06
18	MWG-ARC2	Mwagusi Sand River	Ruaha NP	Iringa	S7°36′	E34°53′	–	LSA	27-Jul-06
19	MWG-ARC3	Mwagusi Sand River	Ruaha NP	Iringa	S7°34′	E34°53′	–	LSA	27-Jul-06
20	MAH-ARC2	Mahalalela	Mbeya	Mbeya	S8°47′	E33°58′	–	MSA; bifaces	30-Jul-06
21	MAH-ARC1	Mahalalela	Mbeya	Mbeya	S8°47′	E33°58′	–	MSA	30-Jul-06
22	MAL-ARC 1	Malamba	Mbeya	Mbeya	S8°47′	E33°37′	–	MSA	29-Jul-06
23	ITD-VP 1	Itindi, Galula	Chunya	Mbeya	S8°39′	E33°00′	BOV, PISC	–	2-Nov-07
24	ITB-VP 1	Itimba, Mshewe	Mbeya	Mbeya	S8°53′	E33°14′	TUR	–	4-Nov-07
25	ILM-ARC 1	Ilota Mshewe	Mbeya	Mbeya	S8°53′	E33°14′	–	MSA; diminutive bifaces	21-Oct-07
26	ILO-ARC 1	Ilota	Mbeya	Mbeya	S°53′	E33°13′	–	Iron Age pottery	23-Oct-07
27	MAD-ARC 1	Madibila	Mbozi	Mbeya	S8°54′	E33°11′	–	MSA & Iron Age pottery	26-Oct-07
28	LAN-ARC 1	Landani	Ileje	Mbeya	S9°31′	E33°40′	–	LSA-OBS	8-Aug-06

[a] Abbreviations: ARC = Archaeological Locality; VP = Vertebrate Paleontology Locality; BOV = Bovid; EQU = Equidae; SUI = Suidae; CAR = Carnivore; ROD = Rodent; GIR = Giraffe; TUR = Turtle; REP = unidentifiable reptile; MSA = Middle Stone Age artifacts; LSA = Late Stone Age artifacts; OBS = Obsidian; NP = National Park.
[b] Both paleontological and archaeological localities were named after a village or local landscape feature; GPS coordinates have been down-graded to ~5 km resolution in order to protect Tanzanian antiquities.

acquisition of HRSI. GoogleEarth© is constantly updating their data set. Fortuitously, some of the areas, such as east of Mbeya, had ~1 m resolution imagery freely available by the time we conducted our second field season in 2007. HRSI was not available through GoogleEarth© for the Hanang district. Consequently, we tasked IKONOS satellites to procure HRSI (~1 m), working through eMap International (http://www.emap-int.com/), for our 2008 field season.

Our imagery-driven survey is an iterative process. We first identify an area of interest based on erosional patterns and spectral reflectance predictive of sedimentary rock, combined with a structural geological interpretation. The imagery is also important in estimating the degree of vegetation cover and facility of access. Typically, in color-corrected images sediments reflect as white/very-bright and we used this signature to predict our targets (see Supplementary Online Material [SOM]). Because the satellite imagery is geo-referenced, we immediately know the exact latitude and longitude for the targets. We then drive and hike to the locations guided by hand-held GPS. The ground survey immediately rules out any exposures that are not sedimentary rock such as basement rock and grassy areas that are found in some cases to falsely reflect brightly on imagery (see SOM and SOM Fig. 1). This ground truth then informs additional imagery interpretation by ruling out such targets given their specific geomorphological characteristics, reflectance, and/or other visual subtleties. The SOM Table 1 shows which predicted targets yielded positive and negative results.

We use large poster-sized print-outs of the imagery with an overlain latitude and longitude grid to assist on-the-ground. With 1 m resolution imagery small dirt roads and even animal tracks can be seen and easily followed. This dramatically improved our ability to move across the landscape efficiently, especially in areas with significant vegetation cover and steep topography, such as in Hanang and Mbeya. As such, we could constantly re assess, going back and forth between imagery and ground truth to refine and adjust the strategy on a real-time field basis (see Fig. 2a–d).

Locality definition

We named new paleontological localities on the basis of their fossil content and distribution, density, and composition. A locality is defined as a geomorphologically restricted area within a site that may have fossils from multiple horizons but that, for example, encompasses a hillside bounded by the hilltop, valley floor, and streams. A locality designation constrains the fossil assemblage such that identifying associated elements and/or conjoinable fragments would be reasonable. Fossiliferous sediments with only bone fragments identifiable to Class were not given a locality designation. Archaeological localities were defined by artifact concentration, density, and whether or not it represented primary deposition. We define a site as a cluster of localities, such as Olduvai Gorge or Hanang.

Mt. Hanang: case study

The history of our discovery and extensive survey of the Mt. Hanang localities demonstrate the power of the application of HRSI to paleoanthropological field work. At the southern-most extent of the Gregory Rift (Foster et al., 1997) there are two faults associated with a small volcano (Mt. Hanang) and rift lakes (Balangida and Balangida Lelu). The imagery available on GoogleEarth© provided ~30 m resolution (Fig. 2a) and showed a white reflective horizon that appeared to be banked up on top of the two escarpments. Our two-day stop over in this area in 2006 confirmed that these were sediments and that they were fossiliferous. While there had been some limited field geology done in the area previously (Dawson,

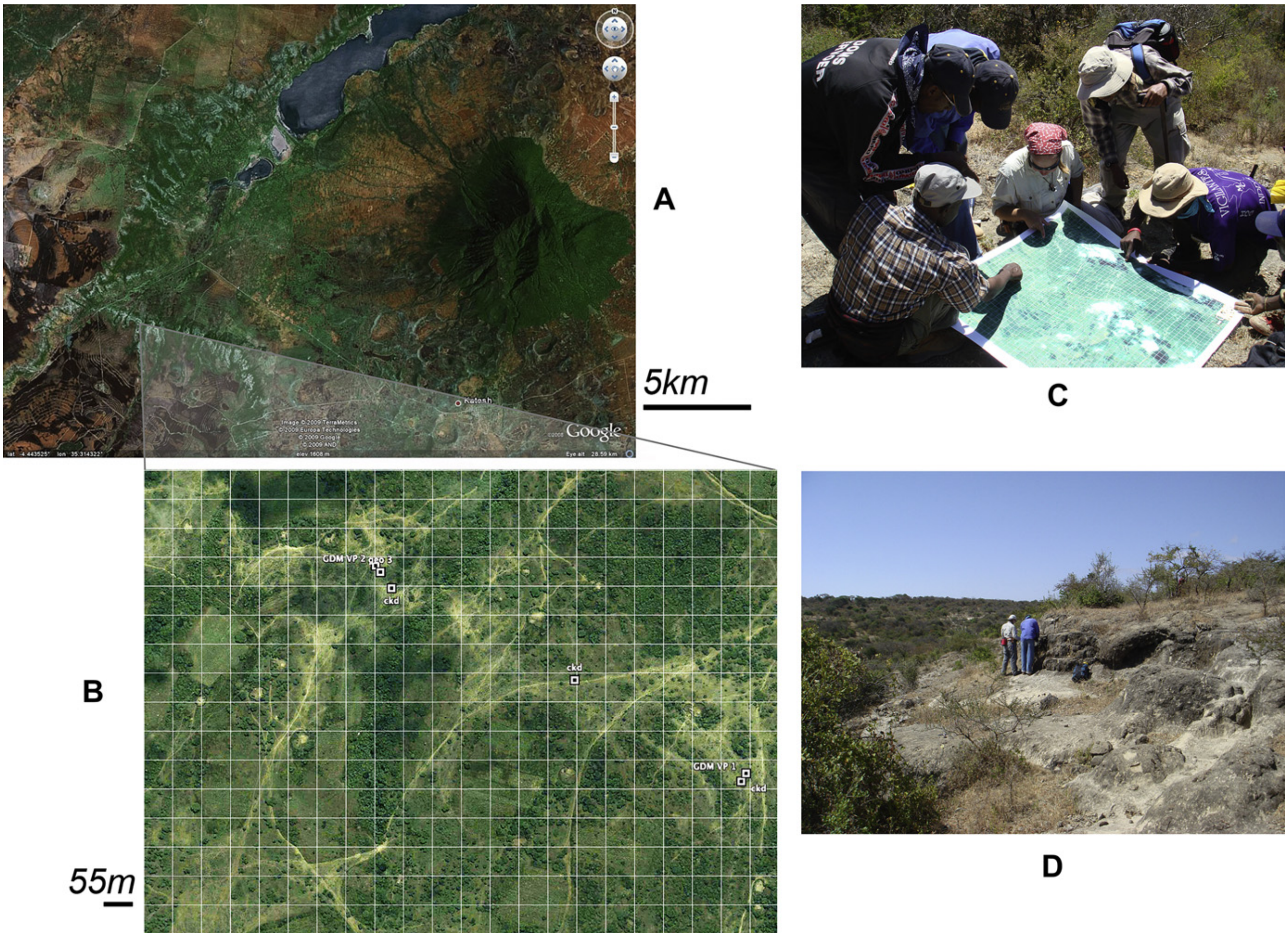

Fig. 2. An aerial view of the Hanang paleontological study area showing various stages of image resolutions and survey work. A. Approximately 30 m resolution image available freely on GoogleEarth© showing white reflective horizon (sediments) banked up on top of two escarpments, with Mt. Hanang to the northeast and Lake Balangida. B. High resolution image ~1 m) obtained from IKONOS, with fossil localities and checked outcrops from 2007 field season plotted. C. Field crew working with imagery in the field. D. Geologic marker horizon above HEW VP 2. Photograph shows the typical terrain and vegetation cover for this area.

1964; Ebinger et al., 1997), this was the first notation of the sediments or presence of fossils.

As part of our 2007 field season we returned to Mt. Hanang for two weeks to conduct a more extensive survey using the ~30 m resolution imagery. We followed the outcrop along the edge of the escarpments but found that the soft sediments banked on top of metamorphic basement rock had produced very steep ravines, deeply incising the area. There is also significant vegetation cover, as can easily be seen in Figure 2a–d. Despite these hurdles we were able to identify five localities.

While aerial photographs can provide essential information on a fairly fine-scale, for most parts of East Africa these photographs were taken more than 50 years ago. We have found from past experience that foot paths, vegetation cover, horticulture, access roads, and erosional patterns change rapidly enough that these air photos have limited usefulness for on-the-ground survey strategy. Additionally, the lack of geo-referencing makes interpolation of exact location from air photos difficult, especially using 50 year old photographs. Topographic sheets at 1:50,000 can be helpful, but again, these are often based on the old aerial photographs so roads and paths are similarly outdated. Recent HRSI provides a level of modern detail that is unsurpassed by other forms of imagery.

For the 2008 field season we tasked and purchased ~1 m IKONOS imagery for this area. Figure 2b provides an example of the improved resolution. We spent another two weeks in this area but were significantly more efficient, covering virtually every exposure >500 m^2. The HRSI enabled us to identify survey routes exploiting animal tracks that would otherwise have been impossible to predict as good thoroughfares (Fig. 2c,d). We identified eight more localities. We also conducted extensive geological work, compiling detailed stratigraphic sections and samples for our geochronological efforts. We recovered over 100 fossil specimens identifiable at least to Family. The associated laboratory analyses are in process and will be reported in detail elsewhere.

Hanang represents a relatively small fossiliferous outcrop that is not easily seen from nearby roads. Given that Hanang is not along a route to known paleoanthropological sites (save for Kondoa [Leakey, 1983]), without the aid of satellite imagery it probably would have taken many more years to come to the attention of the paleontology community.

Conclusion

Survey for new fossil and archaeological sites is an extremely high-risk research endeavor. As our discipline operates on faster and faster measures of productivity and project success, field projects that do not promise immediate returns on investment become more difficult to undertake and fund.

However, fossils and artifacts are the fundamental evidence of human evolution, documenting how, when, and where our ancestors and close relatives lived and evolved. As Tanzania and other African countries undergo population expansion and urbanization, the discovery and recovery of paleoanthropological sites are of urgent concern (White, 2004). Consequently, methodological approaches that can make reconnaissance work as time- and cost-efficient as possible, and also improve our discovery success, need to be developed and fostered.

GIS, satellite imaging, and GoogleEarth© have had an incredible impact on the life sciences and we are now seeing this technology begin to play a larger role in paleontological and anthropological research. For example, the power of geospatial imaging has been noted for recording specimen distribution within localities (Conroy et al., 2008). Here, we show the power of the technology for exploring small sedimentary exposures and discovering new paleoanthropological sites. While drone technology will undoubtedly revolutionize paleontological field reconnaissance one day, the remotely sensed imagery available today is already making significant impacts on the identification and exploration of new paleoanthropological sites, such as the 28 new localities we found in Tanzania.

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Appendix. Supplementary material

Supplementary material associated with this article can be found in the online version, at doi:10.1016/j.jhevol.2010.07.014.

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