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Ozymandias in the Anthropocene: The city as an emerging landform

Abstract

The extent of urban areas is rapidly expanding across the globe, both horizontally and vertically. Whilst natural and social scientists have examined the impacts of this urbanisation upon earth system and social processes, to date researchers have largely overlooked how in turn earth system processes can act upon this urban fabric to produce hybrid landforms. Unique pseudokarst landforms are found within the urban fabric, including urban stalactites and urban sinkholes. Additionally, both the chronic and acute degradation of urban buildings can form rubble and dust which if left in situ will be shaped by fluvial and aeolian processes. For many of these urban geomorphological processes the neglect or abandonment of parts of the urban network will facilitate or accelerate their influence. If there are economic, climatic or social reasons for abandonment or neglect these processes are likely to reshape parts of the urban fabric into unique landforms at a range of scales. We contend that researchers need to explicitly consider the urban fabric as an Anthropocene landform and that by doing so important insights can be gained into urban hazards and geomorphological processes. Shelley’s Ozymandias, in which the eponymous king failed to account for the effects of earth system processes acting on “mighty” urban structures over time, serves as an important reminder of the impermanence of our urban works and the need to recognize and understand the processes acting upon them.

Ozymandias

I met a traveller from an antique land
Who said: Two vast and trunkless legs of stone
Stand in the desert. Near them, on the sand,
Half sunk, a shattered visage lies, whose frown
And wrinkled lip, and sneer of cold command
Tell that its sculptor well those passions read
Which yet survive, stamped on these lifeless things,
The hand that mocked them and the heart that fed.
And on the pedestal these words appear:
"My name is Ozymandias, king of kings:
Look on my works, ye Mighty, and despair!"
Nothing beside remains. Round the decay
Of that colossal wreck, boundless and bare
The lone and level sands stretch far away. (Percy Bysshe Shelley, 1818)

The number of people living in cities now exceeds those who do not. It is estimated that 54 percent of the world's population reside in urban areas and this is expected to rise to 66 percent by 2050 (United Nations, 2015). Coincident with a rise in urban population is an increase in rate of expansion of densely populated areas, with an expected tripling of urban areas between 2000 and 2030 from 0.5% to 1.5% of the planet's land area (Angel et al., 2011, Seto et al., 2012). Turning attention from horizontal to vertical sprawl, researchers have also considered how cities are expanding into new strata where technologies allow for deeper excavation (Graham, 2016). Researchers working in both physical and human geography have sought to understand the effects of this urbanisation on both the planet and on human society (e.g. Chin, 2006, Dye, 2008, Gong et al., 2012, Hamel et al., 2013, Pile and Thrift, 2000, Singh et al., 2002, Tatem et al., 2013). Less research has given consideration to how the fundamental physical processes which shape landforms in nature interact with the built urban environment.

The Anthropocene is an interesting frame for this line of enquiry precisely because it is a concept that straddles the line between physical and human geography where particular attention is levelled at anthropogenic effects on environmental processes (e.g. Brown et al., 2017, Brown, 1970, Goudie and Viles, 2016, Graham and Marvin, 2001, McCann and Ward, 2011, Pacione, 2009, Steffen et al., 2007, Tarolli and Sofia, 2016, Thomas, 1956). Within geographical and earth sciences the focus on exploring the Anthropocene as a theoretical framework has so far been largely restricted to humans as agents of environmental change either developing new landforms, or altering earth surface processes (e.g. Brown et al., 2017, Price et al., 2011, Tarolli and Sofia, 2016). Examples of Anthropocene geomorphological forms include the large scale excavations associated with mining operations, agricultural terracing and the change in land cover associated with development of cities (Price et al., 2011, Tarolli et al., 2014, Tarolli and Sofia, 2016). In addition to direct changes to landscapes, other researchers have looked at the effects of humans upon processes, exploring ways in which land use can change hydrological (Syvitski et al., 2005, Tooth et al., 2009) and aeolian (Li et al., 2009, Mauz et al., 2005, Wang et al., 2013) processes for example. Taken one step further however, we might then consider a less anthropocentric approach where environmental process go to work on human-built structures to create hybrid landforms (Whatmore, 2002). Weisman (2008), for instance, considers how cities may change should humans vanish, however his focus was largely on the effects of plants and animals in recolonizing urban space with little explicit consideration of the reshaping of the urban landscape by geomorphological processes. At much longer timescales both Weisman (2008) and Zalasiewicz (2008) consider how the remains of the urban infrastructure might be preserved in the geological record. We suggest here more explicit consideration of cities and other urban infrastructure as alternative landforms upon which geomorphological processes are acting is needed. If we frame geomorphological processes as fundamentally erosional or depositional in nature, then it follows that hybrid urban geomorphology would consider the removal of material from the urban environment and the deposition of material upon the urban fabric as a substrate. In both cases we can ask whether, given sufficient time, this would yield unique hybrid ‘landforms’ which have not previously existed prior to the Anthropocene.

Urban weathering and formation of Anthropocene regolith

Researchers have long studied the effects of weathering processes on man-made structures, and how these processes differ within urban, as opposed to non-urban environments (e.g. Inkpen and Jackson, 2000, Searle and Mitchell, 2006, Smith et al., 2005, Török et al., 2011). However, typically this research has been in the context of the effects upon material surfaces over management timescales on the order of 10^1 years. Weathering is a fundamental geomorphological process which renders rock into sediment particles (regolith) and reshapes rock surfaces, typically at very slow rates. The current focus of research on urban weathering has been on the mechanisms involved and the small scale landforms that result from this ‘reshaping’ (e.g. alveolar weathering, surface crusting and pitting). However, if the stone fabric of the urban landscape is considered as an Anthropocene geological formation, then over decadal timescales weathering processes will develop Anthropocene urban regoliths as well as more intensively reshaped surfaces. The move towards urban greening, where infrastructure is designed, or revised, to incorporate green spaces upon and within structures shows the urban fabric already acts as an alternative surficial geology hosting biogeomorphological processes. In addition to weathering, other more acute erosional processes can act upon the urban fabric to generate regolith through structural collapse, for example through earthquakes.

Although it has rarely been conceived in such a way, destructive urban warfare can be seen as a form of Anthropocene geomorphological process; as the use of high explosives in the urban environment causes the destruction of buildings and creation of rubble with a range of particle sizes (Graham, 2011, Weizman, 2012). For example warfare in the Syrian city of Aleppo between 2011 and 2014 is estimated to have caused damage or destruction to 302,000 housing units, 52% of the pre-war housing in the city, the majority of which is multi-storey apartment blocks (United Nations, 2014). A UN report observed that piles of rubble and debris are accumulating in Aleppo (United Nations, 2014, 11). Typically, this material, whether formed by chronic or acute processes, will be cleared during maintenance or reconstruction of the urban infrastructure. However, if there are social conditions such as abandonment (McLeman, 2011) or neglect, which precludes removal of this urban regolith, then it would then be expected to be shaped by other fundamental aeolian, fluvial and biogeomorphological processes. The timescales over which these processes operate, the morphology of the resultant landforms and their persistence or transience in the landscape over decadal timescales are entirely unknown, yet much information could be gleaned from cities like London, where abandoned tube stations were isolated and persevered by Luftwaffe bombing runs which destroyed surface structures during the Second World War (Dobraszczyk et al., 2016, Garrett, 2015). Additionally, urban areas which have been abandoned due to disaster such as at Chernobyl or Fukushima, or neglected due to economic downturns and/or social unrest such as Detroit (Dobraszczyk, 2010, Moore and Levine, 2010) would be useful case studies. Although building materials and styles have changed extensively throughout history, an effective understanding of these processes could also aid archaeological research; shedding light on how abandoned and destroyed urban areas are reshaped by earth surface processes and thus help interpret the forms which may be preserved in the archaeological record (DeSilvey, 2006). Such an approach, of forecasting archaeology, has many parallels with the work of Virilio (1994) on Atlantic coastal bunkers from the Second World War, where much of the monolithic concrete architecture created by Hitler's architect Albert Speer is beginning to fold into the landscape and shape, for instance, dune formation. In turn, further geomorphological insights could be gained by considering ancient abandoned cities as landforms which could potentially be used cautiously as a space-for-time substitution. Over even longer timescales, an understanding of how urban forms are reshaped by earth processes, coupled with tectonic setting (Zalasiewicz, 2008), could help to forecast their sedimentological characteristics and potential for preservation in the geological record.

Urban Stalactites

Concrete has been used as a building material since at least the time of the Roman Empire, but became ubiquitous in the 20th century; first through World War II defensive structures (again, see Virilio, 1994), and then in urban developments, particularly in association with the Brutalist architectural movement (Mould, In Press). If we consider cement as a form of sedimentary rock, its high calcium oxide content of around 66% (Kosmatka et al., 2011) means it is broadly analogous to limestone and would be subject to similar geomorphological processes and could thus potentially form pseudokarst (see Eberhard and Sharples, 2013, Halliday, 2007 for discussions of 'pseudokarst' formations). Specifically, it has been documented that concrete and lime mortar can be weathered by dissolution processes, leaching calcium from the concrete; these dissolved ions can then precipitate out as stalactite and stalagmite formations as shown in Figure 1A-E (Allison, 1923, Smith, 2016, Ver Steeg, 1932). The process of stalactite formation from concrete leachate differs to that in natural limestone caves, as it proceeds via dissolution of calcium hydroxide and absorption of CO_2 from the atmosphere to produce the precipitate, whereas in limestone caverns CO_2 is degassed from dissolved calcite (Smith, 2016). Furthermore, the dominance of near-vertical surfaces in the urban environment will act as weathering-limited slopes and discourage the build-up of regolith and weathering products upon buildings. At the same time this will favor the vertical drainage and percolation of water and encourage pseudo-karst processes including formation of evaporites on overhanging surfaces.

To date, calcium carbonate formations; referred to as urban stalactites or calthemite (Smith, 2016), have been studied from a geochemical perspective (Smith, 2016, Sundqvist et al., 2005) and the morphology of stalactites has been described at two sites (Smith, 2016, Ver Steeg, 1932), but there is almost nothing documented about how these formations differ in morphology to stalactites in natural karst systems. Stalactites of “soda straw” type have been most commonly described (Allison, 1923, Smith, 2016, Ver Steeg, 1932), but Smith (2016) also documents flowstone and coralloid type formations. The only quantitative measurements of urban stalactite growth rates we are aware of give a typical range of 3-29 mm/yr (Smith, 2016, Sundqvist et al., 2005, Ver Steeg, 1932), however Smith (2016) found one example with an equivalent growth rate of 160 mm/yr. The chemistry of concrete leachate precipitation favors more rapid formation, with calcium hydroxide around 200 times more soluble in water than calcite which forms limestone cave formations (Sefton, 1988 in Smith, 2016).

We can consider whether differences in processes, rates and controls on dripstone formation in urban environments are likely to result in differences in morphologies compared to natural cave systems. In human built tunnels for example, there is a prevalence of straight lines and sharp angles, which do not exist in natural karst systems (Macfarlane, 2013). and wide seasonal ranges of temperate and thus seasonal variations in evaporation and resulting stalactite growth rates (Ver Steeg, 1932), compared to near constant temperatures in natural caves. Lastly, the caves of karst systems are typically sheltered and have little or no moving air, whereas in urban environment there may be prevailing, strong air currents (Kanda, 2007). These currents could influence the formation of stalactites, particularly in subterranean tunnels, such that they form at an angle non-normal to gravity (Figure 1B), potentially readily forming dendrite; stalactites which are rare in natural systems. Alison (1923) postulates that faster drip rates would favor the formation of thinner stalactites, and that asymmetry in morphology, including the formation of stalactite curtains, could be a result of changes in growing conditions, including seasonality.

It is possible, given sufficient time that pseudo-karst systems could form upon an anthropogenic substrate, where abundant depositional formations create entire systems which resemble natural limestone caves. The early onset of such a phenomenon has been documented in the book *Explore Everything: Place-hacking the City* by Bradley Garrett, where he recounts an ethnographic vignette relayed to him by a recreation trespasser in London who had gained access to the ‘Mail Rail’, a 6.5-mile subterranean railway that had been mothballed by the Post Office for almost a decade:

The stories emerging from the trip were like something out of the Royal Geographical Society archives: miles of tunnels running right underneath central London that almost no one knew about. The crew made multiple trips into the Mail Rail that June, walking from Paddington to Whitechapel. As 'Gary' explained:

The tunnels become tighter approaching the stations, meaning stooping was required at regular intervals throughout the trip. Towards the eastern end of the line, calcium stalactites were more abundant, hanging from the tunnel ceilings, and gleaming under the fluorescent light. This produced a very real feeling of adventure, like we were in an Indiana Jones movie, in some kind of mine or cave system with wooden carts and the smell of damp throughout (Garrett, 2014: 153-154).

Abundant urban stalactites have also been documented in a disused railway tunnel (Hartland et al., 2010) (Figure 1A), believed to be formed by hyperalkaline drip water from dissolved carbonate cement or mortar (Hartland et al., 2010), and in an abandoned cellar in Uppsala, Sweden (Sundqvist et al., 2005). In another 150-year old utility tunnel under the (very damp) north embankment in London, Garrett also encounter early straw cone formations (Figure 1D and 1E).

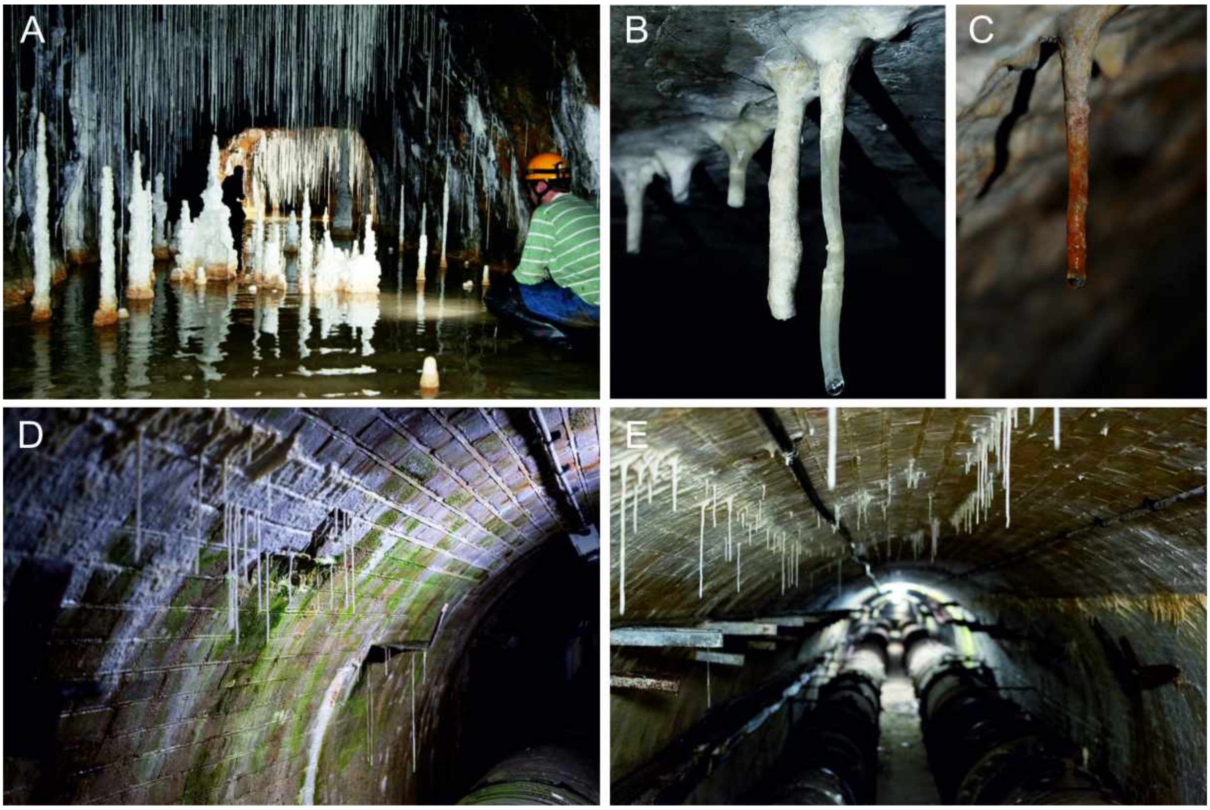

Figure 1 – Subterranean urban stalactite formations; A) Disused railway tunnel in Britain (J.Gunn in Hartland et al, 2010), B) Calthemite formation which has been shaped by air currents (Garry K. Smith), C) an orange stalactite, likely stained by iron oxide, inside the Fort du Salbert, France (Thomas Bresson, wikimedia commons under a cc-by-2.0 license), D & E) utility tunnels under the north embankment, London (Bradley Garrett)

Urban sinkholes – an emerging Anthropocene geohazard

A final example of geomorphological processes acting upon and within the urban fabric is the formation of "urban sinkholes" (Figure 2). Such formations pose a risk to life and infrastructure and occur due to a variety of processes (Banks et al., 2015). Obtaining accurate numbers for the occurrence of urban sinkholes is problematic as there are very few published studies on the phenomenon. The city of Guangzhou in China is built within a karst region and studies report an estimated 17 urban sinkholes formed between 1995-2005 (Liu et al., 2005 in

Zhao et al, 2009) and a further 20 between 2007-2012 (Gao and Lei, 2013), which reflects a general reported increase in sinkhole collapses in Chinese urban areas (Lei et al., 2015). In the absence of academic studies the use of news media reporting of sinkholes can be a useful alternative for recording occurrences and estimating abundance (Banks et al., 2015). In 2016 there were six separate sinkholes reported in roads in the Greater Manchester urban area in news media (ITV, 2017), whilst Japanese media reported transport ministry figures of nearly 3300 sinkholes occurring in Japan during the 2014 financial year, most in urban areas (Nikkei, 2016). In early 2017, a large sinkhole opened in the concrete spillway of Oroville dam in northern California, forcing the evacuation of nearly 200,000 people and causing an estimated $200,000 of damage to the spillway (Chambers, 2017).

Many urban sinkholes have been found to occur via the same processes observed in karst systems for collapse or cap rock sinkholes, namely the collapse of a capping layer of rock over an erosional void (Waltham et al., 2007). Additionally, some occur as a result of the collapse of abandoned mine workings (Pepe et al., 2013) or other man-made subterranean tunnels (Eberhard and Sharples, 2013). An example of this type is the Paris catacombs in the late 18th century where collapses of uncharted limestone quarries swallowed buildings and necessitated the formation of a city inspectorate which still exists to map and maintain them (Garrett, 2011, Shea, 2011). A class of sinkhole which may be almost unique to urban environments is one in which a void space is created by soil piping (Banks et al., 2015, Stafford et al., 2013) and in which the capping layer is formed of asphalt or similar anthropogenic building materials (Figure 2). In effect the urban development has created a new, and unusual surficial geological profile, in which a highly labile earth stratum, is overlain by an impermeable and erosion resistant layer, e.g. asphalt or concrete. Urban development, either through its effects on proximal surficial geology or through the failure of urban drainage systems has created the water flow conditions which directly lead to the soil piping removing the material below the capping layer via flowing water/dissolution, which subsequently leads to collapse of the capping layer into the void.

Figure 2 – Urban sinkholes attributed to soil piping resulting from broken or leaking water pipes removing material with subsequent collapse of asphalt capping layer. A) collapse at corner of Montrose Avenue and Honore Street, Chicago, caused by broken water transfer pipe (TheeErin on Flickr under a cc-by-2.0 licence), B) Large sinkhole in Fukuoka, Japan in November 2016 (Muyo on wikimedia commons under a cc-by-sa 4.0 license), C) Sinkhole in St Mary's Avenue, Omaha, attributed to leaking pipe (Courtney "Coco" Mault on Flickr under a cc-by-2.0 license).

It is debatable whether these 'urban sinkholes' are true sinkholes (c.f. Brinkmann et al., 2008, Eberhard and Sharples, 2013), but their existence is due to anthropogenic changes to geology and hydrology, and their appearance in urban environments is likely to be in contrast to the extreme rarity of piping derived sinkholes in natural systems. Without fully understanding the mechanisms behind the formation of sinkholes in urban environments it is not possible to design effective mitigation measures. Urban sinkholes are hazards with the potential to cause economic losses through direct damage and indirect impacts on service and transport networks as well as loss of life and there is a pressing need to understand their mechanisms, particularly in light of 75% of recorded sinkholes in China being attributed to human activities (Lei et al., 2015). Indeed, in 2014 the UK Government Chief Scientific Adviser called for more information on the hazard susceptibility and processes associated with the formation of urban sinkholes (Banks et al., 2015).

Abandonment and neglect as drivers of change

A key consideration in the theoretical framework of the city as an emerging landform is that society has infrastructure in place to mitigate or arrest these Anthropocene urban geomorphological processes; streets and buildings are cleaned of deposits, sinkholes are filled in and drainage issues causing soil piping are corrected. However, in the event that such support frameworks are absent there will be nothing arresting the development of Anthropocene urban geomorphologies and therefore the occurrence and scale of these features will increase. This idea parallels those of Weisman (2008) who considered the degree to which humanity arrests the effects of nature upon cities, and how nature would recolonize cities should humankind disappear. We therefore need to consider abandonment and neglect of the urban environment as an agent of urban geomorphological change in the Anthropocene. The extensive underground infrastructures of many large cities, many of which are neglected or abandoned (see Garrett 2015) offer ample opportunity to explore these biogeomorphological and hybrid urban geomorphological processes.

In the context of neoliberal policies of infrastructural privatisation and cuts to government budgets for construction and maintenance, the need to understand how material and environmental hybrid landforms develop could not be more pressing. Further, as “smart cities” continue to be constructed with infrastructures networked to a host of domestic and civil functions, understanding urban failure like flooding events and collapses takes on new weight as their impacts ripple through other networks. In a sense, the deeper cities sink and the more complicated their tangles of tunnels and infrastructural threads become, the more important and interesting it is to extrapolate from empirical case studies and speculate at wider geomorphological scales. Further, from the perspective of human geography's drive toward an expanded sense of "GeoHumanities", these new hybrid formations offer an opportunity to rethink the environment around us, both horizontally and vertically, when we stretch thinking about material spatial amalgamations into deeper temporalities where new environmental aesthetics are being formed (Dixon et al., 2012a, Wiles, 2014).

Conclusions

Reimagining the city as an emerging hybrid Anthropocene landform provides opportunities and challenges for natural science research and challenges human geographers to consider less anthropocentric "cultural" landscapes. As outlined above, although the underlying physical processes remain the same, the unique materials and morphologies of the city may require revisions or additions to current geomorphological theories. Therefore, by studying fundamental interactions within the emerging urban landscape new insights may be gained into underlying geomorphological processes. The great opportunity here is to undertaken inter-disciplinary work between natural and social scientists (c.f. Castree, 2014, Castree, 2015, Dixon et al., 2012b), since the morphological and societal drivers and impacts of Anthropocene urban geomorphologies cannot be disentangled or dealt with in isolation.

The application of the Anthropocene as a theoretical framework has so far had a clear focus on how humans shape the natural environment directly and how they interact and change geomorphological processes. However, in doing so the research community has not fully considered how fundamental geomorphological processes will alter, shape and potentially destroy anthropogenic infrastructure and form new hybrid Anthropocene landscapes. To fully investigate the processes, drivers, and implications of these Anthropocene urban geomorphologies will require interdisciplinary teams of earth scientists, social scientists, archaeologists, urban planners and civil engineers. We contend that only by considering the urban landscape as an Anthropocene landform and studying both the processes and social drivers can we avoid falling into the trap of Shelley’s Ozymandias who neglected to consider the effects the twin processes of time and geomorphology would have to reshape the landscape around and upon the urban structures he had created.

Allison, V C *1923 The growth of stalagmites and stalactites. The journal of geology 31 106-25.*
Angel, S, Parent, J, Civco, D L, Blei, A & Potere, D *2011 The dimensions of global urban expansion: Estimates and projections for all countries, 2000–2050. Progress in Planning 75 53-107.*
Banks, V J, Reeves, H J, Ward, E K, Raycraft, E R, Gow, H V, Morgan, D J R & Cameron, D G *2015 Media, Sinkholes and the UK National Karst Database. in* ***Doctor, D H, Land, L & Stephenson, J B*** *eds Sinkholes and the engineering and environmental impacts of karst: Proceedings of the fourteenth multidisciplinary conference. National Cave and Karst Research Institute, Rochester, Minnesota, USA. 223-229.*
Brinkmann, R, Parise, M & Dye, D *2008 Sinkhole distribution in a rapidly developing urban environment: Hillsborough County, Tampa Bay area, Florida. Engineering Geology 99 169-84.*
Brown, A G, Tooth, S, Bullard, J E, Thomas, D S G, Chiverrell, R C, Plater, A J, Murton, J, Thorndycraft, V R, Tarolli, P, Rose, J, Wainwright, J, Downs, P W & Aalto, R E *2017 The Geomorphology of The Anthropocene: Emergence, Status and Implications. Earth Surface Processes and Landforms 42 71-90.*
Brown, E H *1970 Man Shapes the Earth. The Geographical Journal 136 74-85.*
Castree, N *2014 The Anthropocene and Geography III: Future Directions. Geography Compass 8 464-76.*
Castree, N *2015 Unfree Radicals: Geoscientists, the Anthropocene, and Left Politics. Antipode 49 52-74.*
Chambers, D *2017 Huge Sinkhole Opens at Highest Dam in the U.S. National Geographic. [online] Available at: http://news.nationalgeographic.com/2017/02/lake-oroville-dam-drought-dam-flood/ [Accessed 13/02/2017].*
Chin, A *2006 Urban transformation of river landscapes in a global context. Geomorphology 79 460-87.*
DeSilvey, C *2006 Observed decay: telling stories with mutable things. Journal of material culture 11 318-38.*
Dixon, D P, Hawkins, H & Straughan, E R *2012a Of human birds and living rocks Remaking aesthetics for post-human worlds. Dialogues in Human Geography 2 249-70.*
Dixon, D P, Hawkins, H M & Straughan, E R *2012b Wonder-full geomorphology: Sublime aesthetics and the place of art. Progress in Physical Geography 37 227-47.*
Dobraszczyk, P *2010 Petrified ruin: Chernobyl, Pripyat and the death of the city. City 14 370-89.*
Dobraszczyk, P, Galviz, C & Garrett, B L *2016 Global Undergrounds: Exploring Cities Within Reaktion Books, London. pp 280.*
Dye, C *2008 Health and urban living. Science 319 766-69.*
Eberhard, R S & Sharples, C *2013 Appropriate terminology for karst-like phenomena: the problem with 'pseudokarst'. International Journal of Speleology 42 2.*
Gao, Y & Lei, M *2013 Sinkhole Hazard Assessment Based on Real-Time Monitoring of Karst Water Pressure in Guangzhou, China 2013 NGWA Summit - The National and International Conference on Groundwater. NGWA, San Antonio, Texas, USA. [Online] Available at: https://ngwa.confex.com/ngwa/2013gws/webprogram/Paper9158.html [Accessed 15/01/2017].*
Garrett, B L *2011 Cracking the Paris carrières: corporal terror and illicit encounter under the City of Light. ACME: An International E-Journal for Critical Geographies 10 269-77.*
Garrett, B L *2014 Explore Everything: Place Hacking the City Verso Books, London. pp 273.*
Garrett, B L *2015 Subterranean London: cracking the capital Prestel Publishing, London. pp 176.*
Gong, P, Liang, S Y, Carlton, E J, Jiang, Q, Wu, J, Wang, L & Remais, J V *2012 Urbanisation and health in China. The Lancet 379 843-52.*
Goudie, A S & Viles, H A *2016 Geomorphology in the Anthropocene Cambridge University Press, Cambridge, UK. pp 380.*
Graham, S *2011 Cities under siege: The new military urbanism Verso Books, London. pp 402.*
Graham, S *2016 Vertical: The City from Satellites to Bunkers Verso Books, London. pp 416.*

Graham, S & Marvin, S *2001 Splintering urbanism: networked infrastructures, technological mobilities and the urban condition Psychology Press, London. pp 479.*

Halliday, W R *2007 Pseudokarst in the 21st century. Journal of Cave and Karst Studies 69 103-13.*

Hamel, P, Daly, E & Fletcher, T D *2013 Source-control stormwater management for mitigating the impacts of urbanisation on baseflow: A review. Journal of Hydrology 485 201-11.*

Hartland, A, Fairchild, I J, Lead, J R, Dominguez-Villar, D, Baker, A, Gunn, J, Baalousha, M & Ju-Nam, Y *2010 The dripwaters and speleothems of Poole's Cavern: a review of recent and ongoing research. Cave and Karst Science 36 37-46.*

Inkpen, R J & Jackson, J *2000 Contrasting weathering rates in coastal, urban and rural areas in southern Britain: preliminary investigations using gravestones. Earth Surface Processes and Landforms 25 229-38.*

ITV *2017 Manchester was plagued by at least six sinkholes in 2016. ITV plc, London, UK. [online] Available at: http://www.itv.com/news/granada/2017-01-01/manchester-was-plagued-by-at-least-six-sinkholes-in-2016/ [Accessed 25/01/2017].*

Kanda, M *2007 Progress in urban meteorology: A review. Journal of the Meteorological Society of Japan 85B 363-83.*

Kosmatka, S H, Kerkhoff, B & Panarese, W C *2011 Design and control of concrete mixtures Portland Cement Assoc., Skokie, Illinois, USA. pp 370.*

Lei, M, Gao, Y & Jiang, X *2015 Current Status and Strategic Planning of Sinkhole Collapses in China. in* ***Lollino, G, Manconi, A, Guzzetti, F, Culshaw, M, Bobrowsky, P & Luino, F*** *eds Engineering Geology for Society and Territory - Volume 5: Urban Geology, Sustainable Planning and Landscape Exploitation. Springer International Publishing, Cham, Switzerland. pg 529-533.*

Li, G, Chen, J, Ji, J, Yang, J & Conway, T M *2009 Natural and anthropogenic sources of East Asian dust. Geology 37 727-30.*

Liu, H-P, Wang, Y-l, Liu, J-l, Ni, Y-X, Wang, J-J & Liang, H-M *2005 Cause mechanism and spatiotemporal distribution of major geological disasters in Guangzhou. Ziran Zaihai Xuebao/ Journal of Natural Disasters 14 149-53.*

Macfarlane, R *2013 Underland. Granta. Granta Publications, London. [online] Available at: https://granta.com/underland/ [Accessed 03/09/2016].*

Mauz, B, Hilger, W, Müller, M J, Zöller, L & Dikau, R *2005 Aeolian activity in Schleswig-Holstein (Germany): Landscape response to Late Glacial climate change and Holocene human impact. Zeitschrift für Geomorphologie, NF 49 417-31.*

McCann, E & Ward, K *2011 Mobile urbanism: cities and policymaking in the global age University of Minnesota Press, Minnespolis, MN, USA. pp 213.*

McLeman, R A *2011 Settlement abandonment in the context of global environmental change. Global Environmental Change 21, Supplement 1 108-20.*

Moore, A & Levine, P *2010 Detroit Disassembled Damiani, Bologna, Italy. pp 127.*

Mould, O *In Press Brutalism Redux: Relational Monumentality and the Urban Politics of Brutalist Architecture. Antipode 1-20.*

Nikkei *2016 Giant Japanese sinkhole blamed on tunnel work. Nikkei Asian Review. Nikkei Inc, Tokyo, Japan. [online] Available at: http://asia.nikkei.com/Japan-Update/Giant-Japanese-sinkhole-blamed-on-tunnel-work [Accessed: 25/01/2017].*

Pacione, M *2009 Urban geography: A global perspective Routledge, Abingdon, Oxfordshire, UK. pp 736.*

Pepe, P, Pentimone, N, Garziano, G, Martimucci, V & Parise, M *2013 Lessons learned from occurrence of sinkholes related to man-made cavities in a town of southern Italy. in* ***Land, L, Doctor, D H & Stephenson, J B*** *eds Sinkholes and the engineering and environmental impacts of karst: proceedings of the thirteenth multidisciplinary conference. National Cave and Karst Research Institute, Carlsbad, New Mexico, USA. pg 393-401.*

Pile, S & Thrift, N J *2000 City A-Z: Urban Fragments Psychology Press, Abingdon, UK. pp. 322.*

Price, S J, Ford, J R, Cooper, A H & Neal, C *2011 Humans as major geological and geomorphological agents in the Anthropocene: the significance of artificial ground in Great Britain. Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences 369 1056-84.*

Searle, D E & Mitchell, D J *2006 The effect of coal and diesel particulates on the weathering loss of Portland Limestone in an urban environment. Science of the total environment 370 207-23.*

Sefton, M *1988 "Manmade" speleothems. South African Peleological Association Bulletin 28 5-7.*

Seto, K C, Güneralp, B & Hutyra, L R *2012 Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proceedings of the National Academy of Sciences 109 16083-88.*

Shea, N *2011 Under Paris. National Geographic 219 104.*

Singh, M, Müller, G & Singh, I B *2002 Heavy metals in freshly deposited stream sediments of rivers associated with urbanisation of the Ganga Plain, India. Water, Air, and Soil Pollution 141 35-54.*

Smith, B J, Turkington, A V & Curran, J M *2005 Urban stone decay: The great weathering experiment? Geological Society of America Special Papers 390 1-9.*

Smith, G K *2016 Calcite straw stalactites growing from concrete structures. Cave and Karst Science 43 4-10.*

Stafford, K W, Shaw-Faulkner, M G & Brown, W A *2013 Clastic sinkhole and pseudokarst development in East Texas. in* ***Land, L, Doctor, D H & Stephenson, J B*** *eds Sinkholes and the engineering and environmental impacts of karst: proceedings of the thirteenth multidisciplinary conference. National Cave and Karst Research Institute, Carlsbad, New Mexico, USA. pg 393-401.*

Steffen, W, Crutzen, P J & McNeill, J R *2007 The Anthropocene: are humans now overwhelming the great forces of nature. AMBIO: A Journal of the Human Environment 36 614-21.*

Sundqvist, H S, Baker, A & Holmgren, K *2005 Luminescence Variations in Fast-Growing Stalagmites from Uppsala, Sweden. Geografiska Annaler: Series A, Physical Geography 87 539-48.*

Syvitski, J P M, Vörösmarty, C J, Kettner, A J & Green, P *2005 Impact of humans on the flux of terrestrial sediment to the global coastal ocean. Science 308 376-80.*

Tarolli, P, Preti, F & Romano, N *2014 Terraced landscapes: From an old best practice to a potential hazard for soil degradation due to land abandonment. Anthropocene 6 10-25.*

Tarolli, P & Sofia, G *2016 Human topographic signatures and derived geomorphic processes across landscapes. Geomorphology 255 140-61.*

Tatem, A J, Gething, P W, Smith, D L & Hay, S I *2013 Urbanization and the global malaria recession. Malaria journal 12 1-11.*

Thomas, W L *1956 Man's Role in Changing the Face of the Earth The University of Chicago Press, London. pp 1193.*

Tooth, S, Rodnight, H, McCarthy, T S, Duller, G A T & Grundling, A T *2009 Late Quaternary dynamics of a South African floodplain wetland and the implications for assessing recent human impacts. Geomorphology 106 278-91.*

Török, Á, Licha, T, Simon, K & Siegesmund, S *2011 Urban and rural limestone weathering; the contribution of dust to black crust formation. Environmental Earth Sciences 63 675-93.*

United Nations *2014 City Profile of Aleppo: Multi Sector Assessment. UN-Habitat, Nairobi, Kenya. pp 28.*

United Nations *2015 World Urbanization Prospects: The 2014 Revision. Highlights. Department of Economic and Social Affairs, Population Division New York, USA. pp 32.*

Ver Steeg, K *1932 An Unusual Occurrence of Stalactites and Stalagmites. The Ohio Journal of Science 32 69-84.*

Virilio, P *1994 Bunker archeology Princeton Architectural Press, New York. pp. 215.*

Waltham, T, Bell, F G & Culshaw, M *2007 Sinkholes and subsidence: karst and cavernous rocks in engineering and construction Springer Science & Business Media, Chichester, UK. pp 382.*

Wang, T, Yan, C Z, Song, X & Li, S *2013 Landsat images reveal trends in the aeolian desertification in a source area for sand and dust storms in China's Alashan plateau (1975–2007). Land Degradation & Development 24 422-29.*
Weisman, A *2008 The world without us Random House, London. pp 324.*
Weizman, E *2012 Hollow land: Israel's architecture of occupation Verso Books, London. pp 160.*
Whatmore, S *2002 Hybrid geographies: Natures cultures spaces Sage, London. pp 226.*
Wiles, W *2014 The concrete tangle in* ***Lake, E*** *ed aeon. [online] Available at: https://aeon.co/essays/cities-thrive-most-when-they-are-a-tangled-mess [Accessed 13/07/2016].*
Zalasiewicz, J *2008 The Earth after us: what legacy will humans leave in the rocks? Oxford University Press, Oxford, UK. pp 268.*
Zhao, Q, Lin, H, Jiang, L, Chen, F & Cheng, S *2009 A study of ground deformation in the Guangzhou urban area with persistent scatterer interferometry. Sensors 9 503-18.*