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Five Global Mass Extinctions in The Geological History and Their Traces in the Hong Kong Region

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Introduction

This paper integrates geological and environmental sciences in probing five of the Earth's mass extinctions and some of their traces left in the Hong Kong region. The implications from these global mass events on the future survival of humanity are also discussed in the concluding remarks.

These global mass extinctions events have been linked to the earth's extreme environmental changes. The causes and effects of these catastrophic events provide valuable ancient analogues to the modern research in climate change and global warming, and they have significant implications to the future survival of humanity. In addition, this paper also attempts to relate some of the specific geological and palaeontological evidence observed in the 'Greater Hong Kong Region' to the overall perspective of the global mass extinctions, in order to better understand the geological impacts and imprints associated with the global mass extinctions in this part of the world.

The Big Bang theory has been used to explain the origin of the Universe (e.g. Peebles *et al*, 2009). It suggests that the Universe began to form about 13.8 billion years ago (Ga) (ESA, 2013) and led to the birth of the Solar System, in which the Earth formed as an integral part, about 4.6 Ga. The first live forms on Earth started shortly after its formation as basic single cells bacteria about 4.3 to 3.8 billion years ago, based on the oldest fossils (single cells bacteria) found recently in Quebec, Canada, as reported in Dodd *et al* (*2017*). They are the World's oldest fossils discovered to date which provide the 'direct evidence' of life on Earth when our planet was still at its infancy. According to a summary by BBC (2014; Fig. 1), the single-celled marine live forms multiplied rapidly, initiated photosynthesis and evolved rapidly into multi-cellular microorganisms, then evolved into land plants and animals, flourished and prospered. For the past 450 million years, these organisms, long before the birth of humanity, had gone through many cycles of mass extinctions and recoveries as dictated by the changes in the Earth's natural environments, cosmic and solar systems' natural processes. These organisms evolved according to the prevailing environment to better adapt to, survive, reproduce and propagate in the natural environment. Through

natural selection, the stronger, well-adapted species survived the calamities and thrive while the weaker, ill-adapted ones perished naturally. These are the basic concepts of Darwin's theory of evolution with a famous motto of 'survival for the fittest'.

In this paper, the 'Greater Hong Kong Region' broadly refers to the Hong Kong Special Administrative Region and its adjacent Southeast China areas, unless otherwise stated.

Five Global Mass Extinctions in the Geological History

Geological and palaeontological evidence suggests that mass extinction has occurred at least five times over the past 450 million years (Ma) (Fig. 2), each of which has eliminated more than half of living organisms on Earth. These catastrophic events coincide with the various 'reef gaps', extended periods (>4 million years) of missing coral reefs records (Veron, 2008). Coral reefs have been used as an indicator of environmental changes due to their high environmental sensitivity; their missing records in the geological history could be linked to global environmental disasters or changes associated with events that caused global mass extinction.

Mass extinctions occurred as a result of drastic or sudden environmental changes that upset the dynamic balance of the Earth's ecosystems. Those species that could not adapt to the new environments and ecosystems became exterminated in massive quantity as shown in fossil records today. These catastrophes of global scale were associated with changes in oceanic chemistry, acidity and salinity, worldwide sea levels, global temperatures, atmospheric concentrations, such as carbon dioxide (CO_2), hydrogen sulphide (H_2S) and methane (CH_4), and precipitation of acid rain. They contributed to our present understanding of consequences of adverse environmental changes, including the trend of global warming due to massive greenhouse gases release related to industrialization and excessive burning of fossil fuels.

The Earth is a dynamic planet constantly changing and evolving due to internal and external factors. These changes could take place from millions of years to instantaneous, triggered by any one or a combination of such processes as plate tectonics and cosmic processes (e.g. asteroid and minor planet impacts).

The following paragraphs introduce in chronological order the five global mass extinctions (Fig. 2), discuss their causes, occurrences and impacts, and examine their geological implications and imprints to the Greater Hong Kong Region (Fig. 3).

1. 1 The End Ordovician Mass Extinction

The first event happened at ca 440 Ma at the end of the Ordovician Period. The tectonic drift of the supercontinent 'Gondwana' to the South Pole caused as much as 85% of sea-life forms to exterminate globally (Veron, 2008). Subsequently in the Silurian, extensive areas of sea formed, massive reef began to build up in shallow seas, first fish evolved and plants began to colonize land. In the Greater Hong Kong areas, no rock older than

400 Ma was found but from regional geological evidence this region was probably covered under deeper sea conditions (Sewell *et al*, 2009).

2 The Late Devonian Mass Extinction

The second event happened at ca 360 Ma in the late Devonian Period. Around 75% of life forms were exterminated and all (100%) living reefs were wiped out globally (Veron, 2008). The oldest rocks found in Hong Kong, the conglomerates of the Devonian Bluff Head Formation, were deposited at ca 400 Ma when a fluvial deltaic environment prevailed in this region. These Devonian rocks crop out at two main locations in Hong Kong: on the northern shore of Tolo Channel and at Ma On Shan (Sewell *et al*, 2009). As described in Sewell *et al* (2009), fragments of fossil fish *placoderm*, the oldest life form, dated at 370 Ma, ever found in Hong Kong, were discovered in 1980 in the sedimentary rock layers in Harbour Island, Plover Cover by a fossil expert, Mr Lee Cho-min of the Hong Kong Polytechnic (now the Polytechnic University of Hong Kong). *Placodermi* is an extinct class of armoured prehistoric fish, whose earliest known fossils were found in China. It evolved and later became extinct during the late Devonian mass extinction at ca 360 Ma. The areas that cover the north and south shores of the Tolo Channel, including the oldest rocks in the Bluff Head Formation, are now part of The Hong Kong UNESCO Global Geopark of international significance.

Following the Late Devonian mass extinction, Hong Kong area was submerged beneath a warm shallow sea during the Carboniferous Period in which calcareous muds were deposited and preserved as marble in the Yuen Long Formation (Sewell *et al*, 2009). The Carboniferous Lok Ma Chau Formation comprises mainly metamorphosed sedimentary rocks deposited on a tidal flat or as a deltaic fan. Later in the Permian, the region became a deep continental sea in rising sea levels due to global warming as the early 'Pangaea' continental fragments began moving northward through different climatic zones and merging together.

3 3 The End Permian Mass Extinction

The third event happened at ca 250 Ma at the end of the Permian Period. All continents moving northward finally merged into one giant supercontinent 'Pangaea', ended with the Earth's biggest Mass Extinction also known as 'The Great Dying' (Veron, 2008). The calamity caused a staggering 96% of all life forms on earth to exterminate. Numerous theories have been proposed as the cause(s) for this catastrophic event: asteroid impacts, flood basalt eruptions, catastrophic methane release, oxygen level drop, sea level fluctuations or some combination of these catastrophes.

In Hong Kong, sedimentary rocks of Permian age are found in Tolo Harbour, mainly in Ma Shi Chau. Several marine fossils have been identified in the Permian siltstones and mudstones that formed in a near-shore tidal flat environment. The marine life forms in the Greater Hong Kong Region suffered almost total extermination during this global catastrophe. The Great Dying of marine species in the Hong Kong Region could be inferred from Veron (2008) on global scale and Sewell *et al* (2009) at regional levels. These species extinction included the fusilinid identified at Tung Chung limestone, brachiopods, most of the bivalves bryozoa, crinoid and 100% of the rugose corals

Prior to the end Permian Mass Extinction, there was a major tectonic event in China accompanied by the intrusion of granitic magmas. Marble and skarn rocks, now strongly deformed (Sewell *et al*, 2009), were formed in contact metamorphic rocks adjacent to the igneous intrusions. The famous Ma On Shan iron deposit is hosted in skarn rocks and contains iron- and magnesium-bearing ore minerals, such as magnetite and haematite.

4 The End Triassic Mass Extinction

The fourth event happened at ca 205 Ma at the end of the Triassic Period (Veron, 2008). Pangaea began to break apart which caused half of marine life and around 80% of land life forms on earth to exterminate (Veron, 2008). Located in the in the eastern part of Pangaea, a convergent margin developed along the southeastern coast of China. The convergent plate tectonic activities caused uplifting and non-deposition in the Greater Hong Kong Region during the Triassic Period, hence initiated extensive volcanism in the Early Jurassic. The evidence for the oldest volcanoes in Hong Kong occurs in the Tuen Mun area, where ca 180 Ma volcanic ash and lavas were found (Sewell *et al*, 2009).

Elsewhere globally, the first dinosaurs, mammals and flowers, which appeared during the Triassic Period, survived through the end Triassic mass extinction and evolved afterwards. During the Early Jurassic, the marine molluscs ammonites were widespread in the ancient shallow sea of Hong Kong.

5 The 'K/T' Mass Extinction

The fifth event happened at ca 65 Ma at Cretaceous/Tertiary Boundary, also known as the 'K/T' boundary. This event, known to have associated with the extinction of dinosaurs, was attributed to a huge asteroid impact that struck the seabed near the Yucatan Peninsula in Mexico (e.g. Alvarez *et al*, 1980). During this disaster, global temperature was 6°C to 14°C warmer and the sea levels were 300m higher than present. At this time the oceans inundated over 40% of the Earth's continents including the driest Sahara Desert, and no ice caps were retained in the polar regions. During this time of global sea-level maximum, the ancient Hong Kong landscape could be portrayed by clusters of islands as represented by the remnants of volcanic and granitic mountains, while most parts of the present city areas and valleys were submerged in waters.

It is likely that before the K/T mass extinction, dinosaurs were present in the Greater Hong Kong Region landmass. In the nearby Guangdong Heyuan County, tens' of thousands of dinosaur egg fossils have been found and the place has been named as Home of Dinosaurs (Lü, 2002).

After the K/T mass extinction, the Greater Hong Kong Region remained as part of a tectonically stable landmass without volcanic activities; the climate was tropical, hot and dry. The Eocene Ping Chau siltstones, ca 50 Ma, were deposited as the youngest rock formation in Hong Kong (Sewell *et al*, 2009). Fossil insects as well as bituminized plant fragments have been discovered in the sedimentary rocks deposited within a lake that periodically dried up allowing salt crystal (gypsum) to form (Sewell *et al*, 2009).

The extinction of dinosaurs that had dominated the Earth for almost 200 million years however has had positive impact on the evolution of other surviving species. Their demise paved the way for the rise of

the mammals, our precursors, in the Tertiary Period. Elsewhere in the world, the first birds probably carried the lineage of dinosaur heritage emerged in the Mesozoic and evolved thereafter.

Geologically Vibrant Periods of the 'Pre-K/T' Greater Hong Kong Region

Geologically, before the K/T event, the Jurassic and Cretaceous Periods (199 Ma – 65 Ma) are the most vibrant periods of the Greater Hong Kong Region, with remarkable geological footprints in the rock records. Fossil evidence shows that during these turbulent periods, booming life forms were recurrently terminated by active and explosive activities, but they quickly recovered and flourished again thereafter. During this time, convergent plate tectonics operating in the Greater Hong Kong Region (Eastern Pangaea) initiated active volcanism and igneous intrusion. Throughout the Jurassic and Early Cretaceous Periods, the igneous activities shaped Hong Kong into its unique landscapes we see today — a territory covered by over 80% of granite and volcanic rock outcrops, hills and mountains. Volcanism started in the Early Jurassic at ca 180 Ma and peaked between 165 Ma and 140 Ma. The last episode of the volcanism ended with a gigantic volcanic explosion, known as the Hong Kong High Island supervolcano eruption at ca 140 Ma, associated with a huge caldera collapse (Sewell *et al*, 2012). Sewell *et al* (2012) further suggested that the eruption of the supervolcano on the southeastern China seaboard would have produced a global environmental impact and could be related to the extinction of dinosaurs.

In Sewell *et al* (2012), the authors estimated that the High Island supervolcano exploded some 1,300 km^3 of volcanic ash (dense rock equivalent of 570 km^3) and crystal and rock fragments (here the term 'supervolcano' is defined as a volcanic centre that has had an eruption of magnitude 8 on the Volcano Explosivity Index (VEI), meaning the measured tephra deposits for that eruption is greater than 1,000 km^3; Newhall & Self, 1982). The Hong Kong Island and Kowloon areas are sitting on the 18-km-wide caldera (large volcanic crater), the remnants of an extinct supervolcano. The High Island supervolcano is about half of the size of the well-studied 74,000 year-old Toba supervolcano eruption and has an estimated TNT equivalent destructive forces comparable to about 30,000 Hiroshima nuclear bombs exploding at the same time. From here, one could speculate that this super eruption could have produced a global environmental impact and caused extinction of many life forms in the Greater Hong Kong Region. It is speculated that the more vulnerable giant-sized dinosaurs in the region could have been exterminated during the catastrophe while the small-sized dinosaurs could have survived through the Cretaceous Period until 65 Ma. This, however, was not the case. In the neighbouring Kwangtung Province, Heyuan County, about 175 km NNE of Hong Kong, a small-sized dinosaur called 'Heyuannia', about 1.5m–2m in length, estimated 20 kg in weight, was discovered and dated at 89 Ma–65 Ma (Lü, 2002). Since the first discovery in 1996, over 17,000 fragments of fossilized dinosaur eggs, 8 fossilized dinosaur skeletons and 168 dinosaur footprints have been found in Heyuan, thus the name 'Home of Dinosaurs'. The Guinness Book of World Records, 2004, registered that the Heyuan Museum, Guangdong Province, China held the world's largest collection of dinosaur eggs, having a total of 10,008 individual samples as of November 2004. All of the eggs come from the late Cretaceous Period (89-65 Ma) and include eggs *from oviraptorid and duck-billed dinosaurs.*

Despite the eruption of the Hong Kong's High Island supervolcano, life continued to thrive. Dinosaurs probably flourished together with other diverse life forms in the Mesozoic Hong Kong landmass and shallow sea. Land plants flourished as shown by the Middle Jurassic plant fossils found in the rocks of the Tai O Formation, probably deposited on an alluvial plain (Sewell *et al*, 2009).

Discovered in 1924, the first fossil in Hong Kong was an ammonite (*Hongkongites hongkongensis*), which now becomes the logo of the Geological Society of Hong Kong, found embedded in the mudstone on the northern shore of Tolo Channel. Plenty of ancient sea creatures were probably widespread in the warm shallow sea in Sham Chung, Fung Wong Wat and Tai Tong areas where many Jurassic fossils were found. In 2013, a Late Jurassic fish fossil *Paralycoptera*, supposedly collected from Lai Chi Chong, was discovered in the collections of the Stephen Hui Geological Museum at The University of Hong Kong (Tse *et al*, 2015). The discovery is an extinct species of basal *osteoglossoid* from freshwater environments dated at ca 147 Ma. *Paralycoptera* and the other ammonites found in Hong Kong became extinct during the K/T mass extinction.

One could now visualize from these diverse fossil findings that the ancient Hong Kong landmass and shallow sea were teeming with terrestrial plants and marine creatures during the Jurassic and Cretaceous Periods, probably also with the dinosaurs. To date, no dinosaur fossil has been found in the Hong Kong territory probably due to scarcity of sedimentary rocks and deep weathering conditions which are less favorable for the preservation of fossils. It certainly warrants greater efforts, research and field work to find the first dinosaur fossil of Hong Kong. The trophy of its first discovery should be very rewarding and fulfilling for the Hong Kong geosciences community and general public alike.

Would the Sixth Global Mass Extinction be forthcoming?

After the five well documented mass extinctions in the Earth's geological history, one would ask if the sixth global mass extinction event would be forthcoming. It is a question of utmost significance to the future survival of humanity.

The occurrence of mass extinctions in the past is well proven by fossil records, but their frequency and pattern of happening is a matter of debate. One school of thought considers, as discussed in (Rampino, 2015), that mass extinctions could occur from time to time roughly in a 30-million-year cycle associated with the cyclical movement of our solar system within the periphery of the galaxy. Likewise, Lafrance (2015) summarized that a regularity of mass extinctions of a 26-million-year cycle citing the researchers Michael Rampino and Ken Caldeira whose scientific work was accepted by the Monthly Notices of the Royal Astronomical Society in September, 2015. Another school of thought considers that plate tectonic processes, which are the fundamental geological forces that constantly reshape and recycle the Earth's crust, may have been the driving force that led to the occurrence of mass extinctions in the past.

Regardless of the relative importance of these natural cosmic and geological processes in determining the occurrence of a mass extinction, these natural processes do result in varying magnitudes of severity and impact on Earth's living

species, and perhaps even drive biological evolutionary changes. The five massive extinctions explored earlier in this paper are of global scales while there are also smaller extinctions of regional extent as observed in fossil records. Similar natural forces that drove the past mass extinctions may be recurrent in nature, although not necessarily cyclic, and therefore potential threats to the living organisms including humanity in the future.

There are other non-natural processes or threats that have a great amplifying potential to initiate a mass extinction within a short period of time or even instantly in geological time scale. Current human activities have already resulted in global warming, which cause mountain glaciers, sea ice and ice caps to diminish, as well as in desertification, acid rains and catastrophic methane release. These warning signs, if remained unchecked, may eventually lead to an anthropogenic catastrophe or even the sixth global mass extinction which threaten human generations. A recent study (Ceballos *et al*, 2015) finds that the Earth is entering a new period of extinction, and humans could be among the first casualties. The report suggests that modern extinction rates for vertebrates varied from 8 to 100 times higher than the background rate. Although another study (Pimm *et al*, 2014) finds a higher extinction rate at 1,000 times the background extinction rate based on a broader variety of species, an increased rate of extinction appears to be compelling. Human activity is certainly responsible for the extinctions of many vulnerable species (Pimm *et al*, 2014).

The greatest threat to humanity comes from humans' own self make destruction through the acts of war, judging from the current global political situations and conflicts. The present global population of 7.7 billion is still growing rapidly, competing for limited essential earth resources, food and water. The threat of going into major destructive wars is looming. Humans could easily trigger the potential sixth global mass extinction almost instantly if the current nuclear stockpiles were to be unleashed in global nuclear wars. The chance of the sixth global mass extinction occurring within this 21st century is much higher than any other causes of mass extinction. Any acts of triggering a nuclear war by irrational rival parties could immediately set off a 'nuclear winter' leading to global mass extinction instantly. This is a real threat to humanity which has become imminent as seen from the current North Korea tensions.

Eruption of Mount Toba Supervolcano: A "Near Miss" of the Sixth Global Mass Extinction

When discussing the adverse impacts of global mass extinctions on living species, we need a modern analogue in order to better appreciate their colossal destructive consequences. Mount Toba super eruption occurred some 74,000 years ago in Northern Sumatra, Indonesia, had resulted in Lake Toba (100 km x 30 km), the world's largest active volcanic caldera. This is known to have been by far the biggest super eruption of the last 2 million years (Oppenheimer, 2008). This catastrophe is also considered as one of the most severe events close to the scale of the previous global mass extinctions. It was one of the 50 supervolcanoes to have erupted since man walked the planet, and the first ever experienced by modern humankinds, and all of them occurred well before any recorded human history. This super eruption created a crater, now known as Lake Toba, 90 km in diameter. It exploded an excessive amount of 2,800 km^3 volcanic ash and tuff, and is classified as a

magnitude 8 or 'mega-colossal' eruption on the VEI (Newhall & Self, 1982).

Understanding the prehistoric eruption of the Toba supervolcano is very crucial to the survival of humanity in the future. The aftermath of the super eruption was considered by some as the greatest ever faced by modern humans. It almost drove the population to the brink of extinction. Genetic evidence suggests that global human population size fell to about 10,000 adults between 50,000 and 100,000 years ago, mainly in around the tropical areas (Oppenheimer, 2008). Only this small population managed to survive the super eruption alongside with gigantic tsunami waves and the enormous amount of tephra that spread throughout the planet, which triggered the onset of 'volcanic winter' almost instantly and exacerbated the 'chill factor' of the Late Pleistocene Ice Age that had already been underway (Rampino & Ambrose, 2000). The global average temperature dropped to 5°C, the living organisms were unable to adapt to the sudden onset of severe cold. It has been suggested that today's humans originated from these survivors (Oppenheimer, 2008). From this handful of survivors, our human species has demonstrated the strong resilience and ability to survive, rebound and propagate through the recent history of the Earth to the population of 7.7 billion today, a number that is still growing rapidly.

In Malaysia, remains of Palaeolithic tradition known as the Kota Tampan Culture in the Lenggong Valley, now declared as the UN World Heritage site, include stone pebble tools that are found embedded in the 74,000-year-old Toba volcanic ash (Oppenheimer, 2008). This means that modern humans had reached Southeast Asia well before the Toba supereruption. These artefacts are some of the oldest well-dated evidence for modern humans outside Africa. Based on the absence of human remains found in the Toba ash, archaeologists tend to believe that the Kota Tampan Culture were wiped out during the Toba eruption, despite there were also speculation that they persisted right up until 7,000 or even only 4,000 years ago.

Mount Toba supereruption, which is considered as a 'near-miss' of a global mass extinction, has demonstrated that human species have the strong resilience and ability to survive through mega-colossal calamities and rejuvenate quickly (Foo, 2017).

Implications to the future Survival of Humanity

The Earth experienced five major mass extinctions of global scales which also left some of their imprints in the Hong Kong area. It is inferred that in the Hong Kong region, the High Island supervolcano erupted ca 140 Ma is considered to be the closest in magnitude to these mass extinctions in terms of destructive forces. By comparing with the well-studied modern analogue Toba supervolcano erupted 74,000 years ago, we could better appreciate the colossal destructive forces of the eruption of Hong Kong High Island supervolcano which likely produced a global environmental impact and probably caused extinctions of many life forms then flourishing in the Greater Hong Kong Region. It is possible that the High Island super eruption wiped out some large-sized dinosaur species, but not the small-sized ones which managed to live through the calamity,

although solid evidence in the Hong Kong territory is yet to be discovered.

The five global mass extinctions in the past occurred as a result of drastic or sudden environmental changes that upset the dynamic balance of the Earth's ecosystems. Those species that could not adapt to the new environments and ecosystems became exterminated in massive quantity. The fundamental mechanism that caused these mass extinctions is similar to the anthropogenic destructive effects of present day environmental pollution and global warming, and therefore these mass extinctions provide us with the actual ancient analogues of the aftermath as valuable lessons learnt. The rapid industrialization for the past 200 years have brought in significant wealth and convenience to humans, but at the same time, it caused alarming environmental destruction of global scale. In the process of rapid population growth and development, the rate of extinction has increased and will continue to do so if the population growth and development remain unchecked. In particular, the cold war styled massive nuclear armaments and build-ups by rival parties could trigger man-made global mass extinction instantly, simply by irrational acts of distrusts and misjudgements.

For the future survival of humanity, the immediate and top priority of the global communities should work towards embracing the 2015 Paris Climate Agreement and total global nuclear disarmament and eradication, jointly and responsibly, in the true spirit of shared humanity, keeping our planet earth safe, clean and habitable for the next few millenniums. These objectives are consistent with the United Nations' Sustainable Development Goals, a universal call to action to drive the betterment of our planet and us human beings.

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The "Hong Kong Geology – A 400-Million Year Journey" published in the Hong Kong Geological Survey Website (2009: last review: 22 May 2013) is a fantastic and handy reference for professionals and novices alike to gain insights into the interesting geology of Hong Kong. Its simplicity has inspired me to find out more about the geology of Hong Kong, and therefore it has become one of the key references to this paper. I would like to take the opportunity to congratulate and commend the authors R.J. Sewell, L.K. Tang & R. Shaw, for their job well done and invaluable contributions in promoting geosciences of Hong Kong. I am also looking forwards to reading the authors follow up research on the Hong Kong High Island supervolcano which could had left global geological imprints ca 140 million years ago.

This paper is also dedicated to the great people of Malaysia, my beloved country, in commemoration of her 60th Year's Anniversary of Independence on the 31st August, 2017. God bless Malaysia and her wonderful people.

References

Alvarez, L.W., Alvarez, W., Asaro, F. & Michel, H.V. 1980. Extraterrestrial cause for the Cretaceous–Tertiary extinction. *Science*, 208, 1095–1108.

BBC 2014, October. *Nature: prehistoric life*. Retrieved from: http://www.bbc.co.uk/nature/prehistoric

Ceballos, C., Ehrlich, P.R., Barnosky, A.D., García, A., Pringle, R.M., & Palmer, T.M. 2015. Accelerated modern human–induced species losses: Entering the sixth mass extinction. *Science Advances*, 1, https://doi.org/10.1126/sciadv.1400253

European Space Agency (ESA) 2013, March 21. Planck reveals an almost perfect Universe. *European Space Agency*. Retrieved from http://www.esa.int/Our_Activities/Space_Science/Planck/Planck_reveals_an_almost_perfect_Universe

Foo, W.Y. 2017. From The Origin Of The Earth To The Rise Of Humanity: Its Geological Imprints In the Hong Kong Region and Impacts to Global Environment. *The Management Journal (32nd Anniversary Edition), The International Institute of Management (IIM).*

Dodd, M.S., Papineau, D., Grenne, T., Slack, J.F., Rittner, M., Pirajno, F., O'Neil, J. & Little, C.T.S. 2017. Evidence for early life in Earth's oldest hydrothermal vent precipitates, *Nature* 543, 60–64.

Lafrance, A. 2015, Nov 3. The Chilling regularity of Mass Extinctions. *The Atlantic*. Retrieved from: https://www.theatlantic.com/science/archive/2015/11/the-next-mass-extinction/413884/

Lü, J. 2002. A new oviraptorosaurid (Theropoda: Oviraptorosauria) from the Late Cretaceous of southern China. *Journal of Vertebrate Paleontology*, 22, 871–875.

Newhall, C.G. & Self, S. 1982. The volcanic explosivity index (VEI) an estimate of explosive magnitude for historical volcanism. *Journal of Geophysical Research – Oceans*, 87 (C2), https://doi.org/10.1029/JC087iC02p01231

Oppenheimer, S. 2008, March 15. The Mount Toba Event. Mathilda's Anthropology Blog. Retrieved from: https://mathildasanthropologyblog.wordpress.com/2008/03/15/92/

Peebles, P.J.E., Page, L.A., Jr., & Partridge, R.B. 2009. *Finding the Big Bang*. Cambridge University Press, Cambridge, UK, 571 pp

Pimm, S.L., Jenkins, C.N. *et al*. 2014. The biodiversity of species and their rates of extinction, distribution, and protection. *Science, 344*, https://doi.org/10.1126/science.1246752

Rampino, M.R. & Ambrose, S.H. 2000. Volcanic winter in the Garden of Eden: the Toba supereruption and the late Pleistocene human population crash. *In*: McCoy, R.W. & Heiken, G. (eds), *Volcanic Hazards and Disasters in Human Antiquity*, Geological Society of America Special Papers, 345, 71–82.

Rampino, M.R. 2015. The 30-Million Year Mass Extinction Cycle—"A Coincidence, or a Dark-Matter Event?", The Daily Galaxy, May 25, 2015. URL: http://www.dailygalaxy.com/my_weblog/2015/05/the-30-million-year-mass-extinction-cycle-a-coincidence-or-a-dark-matter-event-holiday-feature-in-1980-walter-alvarez.html

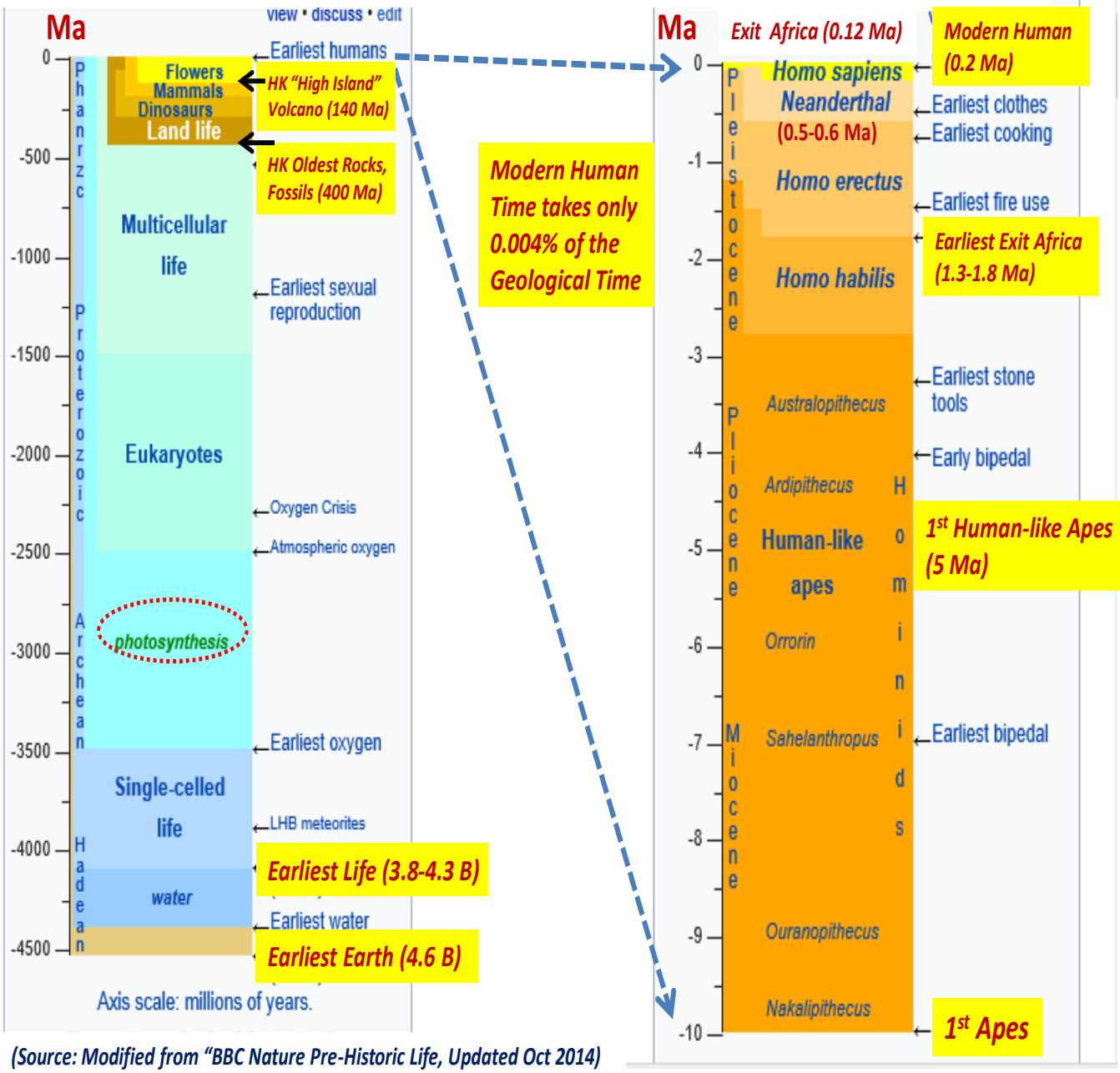
Sewell, R.J., Tang, D.L.K. & Campbell, S.D.G. 2012. Volcanic–plutonic connections in a tilted nested caldera complex in Hong Kong. *Geochemistry, Geophysics, Geosystems*, **13**, Q01006, https:// doi.org/10.1029/2011gc003865. Sewell, R.J. & Tang, L.K., 31 August, 2012, Hong Kong formed by rare supervolcano eruption (handout from Hong Kong's Geotechnical Engineering Office at the Civil Engineering and Development Department).

Sewell, R.J., Tang L.K. & Shaw, R. 2009. *Hong Kong Geology – A 400-Million Year Journey.* Retrieved from http://hkss.cedd.gov.hk/hkss/eng/education/GS/eng/hkg/indexe.htm

Tse, T., Pittman, M. & Chang, M. 2015. A specimen of *Paralycoptera* Chang & Chou 1977 (Teleostei: Osteoglossoidei) from Hong Kong (China) with a potential Late Jurassic age that extends the temporal and geographical range of the genus. *PeerJ*, **3**, https://doi.org/10.7717/peerj.865

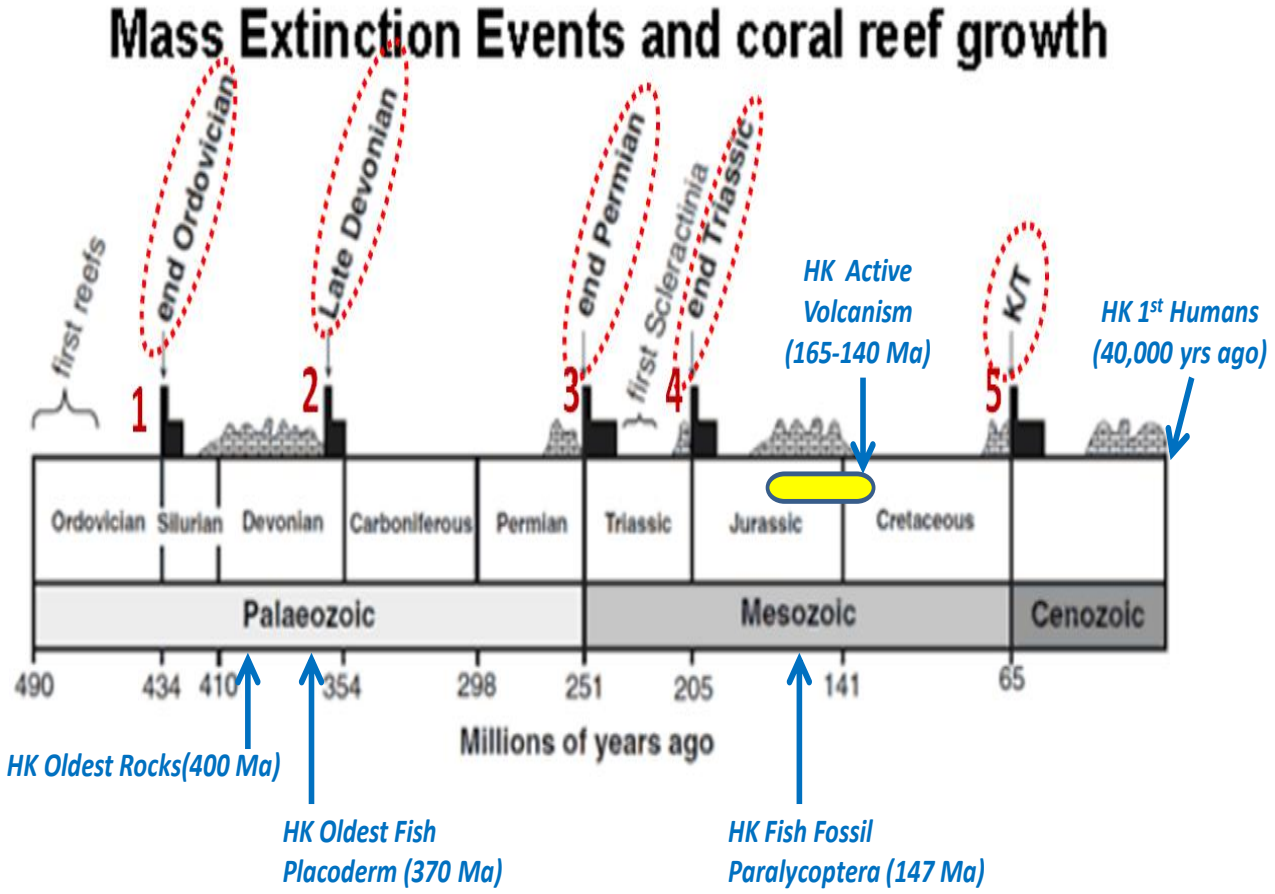
Veron, J.E.N. 2008. Mass extinctions and ocean acidification: biological constraints on geological dilemmas. *Coral Reefs*, 27, 459–472.

Fig. 1 Geological Time Scale & Human Time Scale



(Source: Modified from "BBC Nature Pre-Historic Life, Updated Oct 2014)

Fig. 2 Five (5) Mass Extinction Events in Geologic History



Timelines coincided with 100% Reef Extinction creating "Reef Gaps" on the Earth > 4 million years

- **Black rectangles represent global "Reef Gaps"**
- **Brick-pattern shapes show times of prolific reef growth**
- **Blue arrows show Geological Events in the Greater Hong Kong Region** *(Modified After Veron ,2008)*

Five (5) Global Mass Extinction Events

- *1st Humans, Sai Kung Paleolithic culture (40,000 ya)*
- *Youngest Rocks (50 Ma), Siltstones in Ping Chau*
- *Mammals thrived*
  - ♦*ALL dinosaurs died out* **K/T Boundary** **5**
- *"High Island Super Volcano" Eruption (140 Ma)*
  - ➢*Small-sized dinosaurs "Heyuannia" (80-65 Ma) survived*
  - ➢*Large-sized dinosaurs and many living species wiped out*
- *Active Volcanism with Granitic Intrusions (165-140 Ma)*
- *Dinosaurs roaming on HK Landmass*
- *Ammonites & Fish Paralycoptera (147 Ma)*

End Triassic **4**

- *Tectonic uplifting and non-deposition*

End Permian **3**

- *Deep Continental Sea, "Pangaea" forming*
- *Warm Shallow Sea, calc muds (marble) in Yuen Long*

Late Devonian **2**

- *Fish "Placoderm" (Fossil 380 Ma), extinct end of Devonian*
- *Coral Reefs flourished in Warm Shallow Sea*
- *Oldest Rocks (400 Ma): Conglomerates of Bluff Head Fm.*

End Ordovician **1**

- *No older Rocks/Fossils found in HK Geological Records*

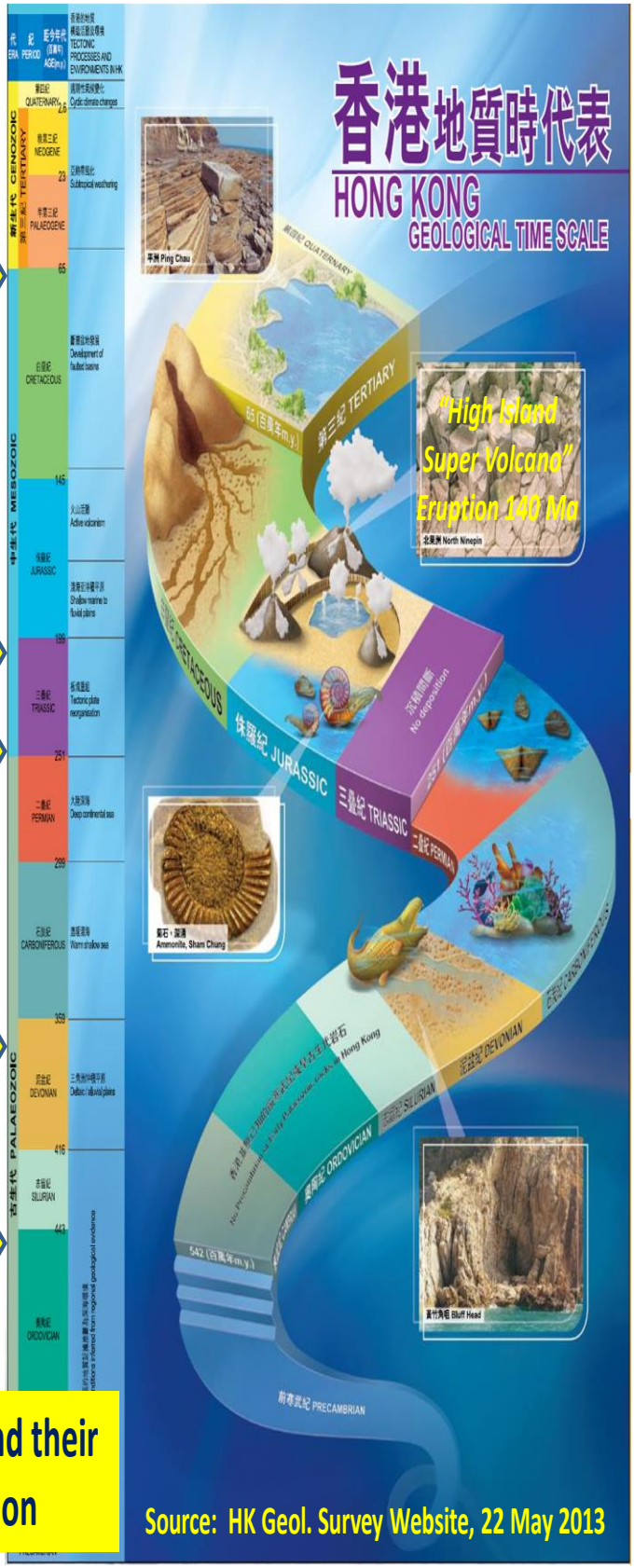


Fig. 3: Global Mass Extinction Events and their Imprints in the Greater Hong Kong Region