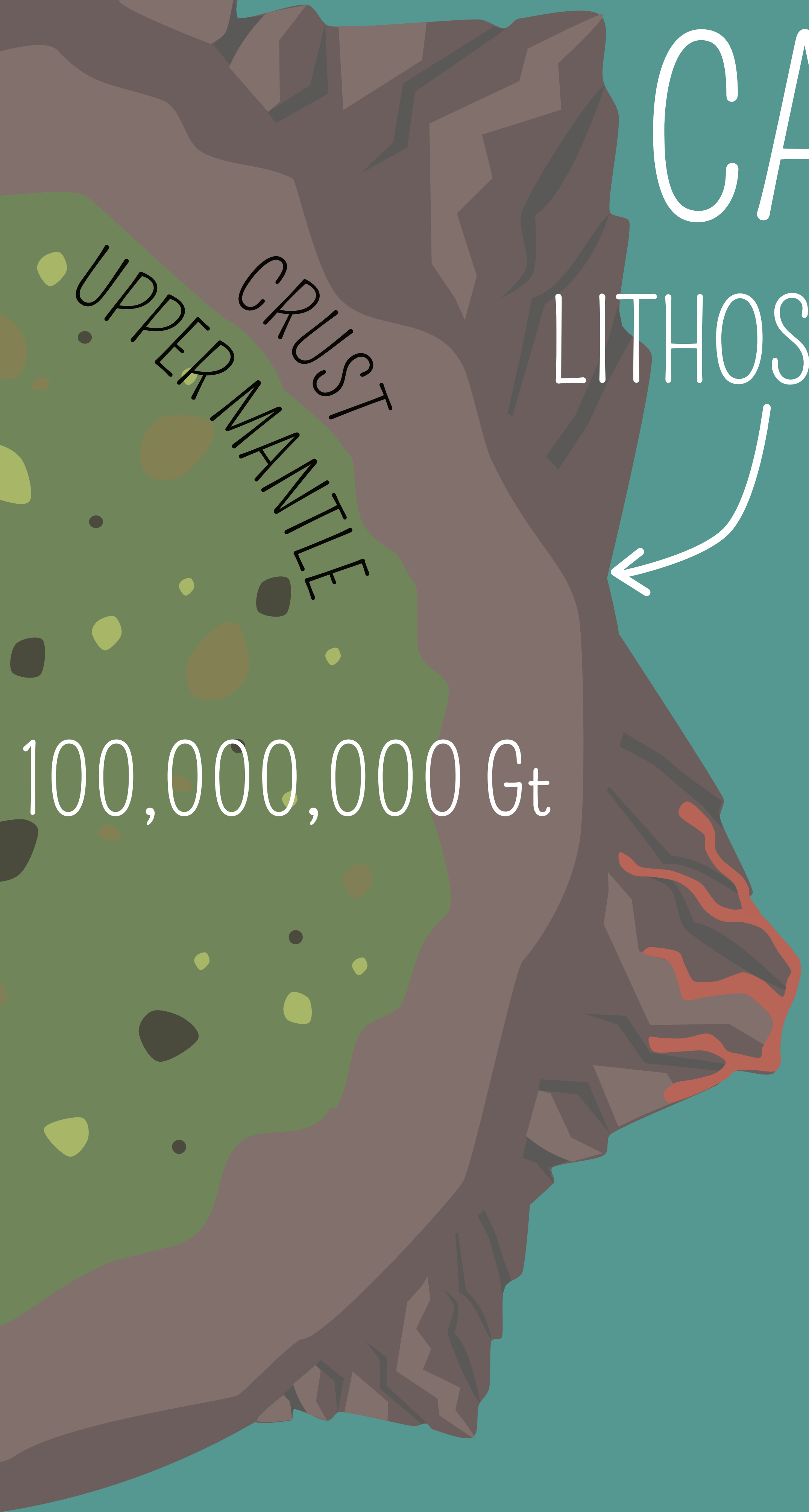
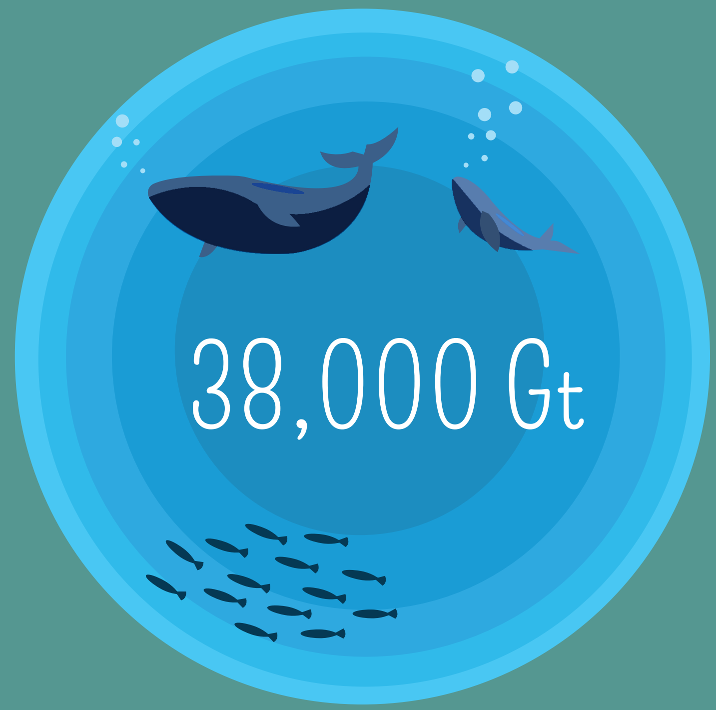
CARBON RESERVOIRS

LITHOSPHERE



OCEANS

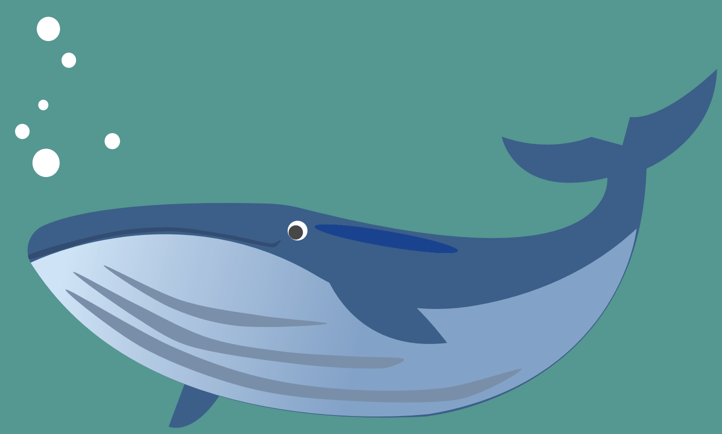


TERRESTRIAL BIOSPHERE & SOIL

ATMOSPHERE

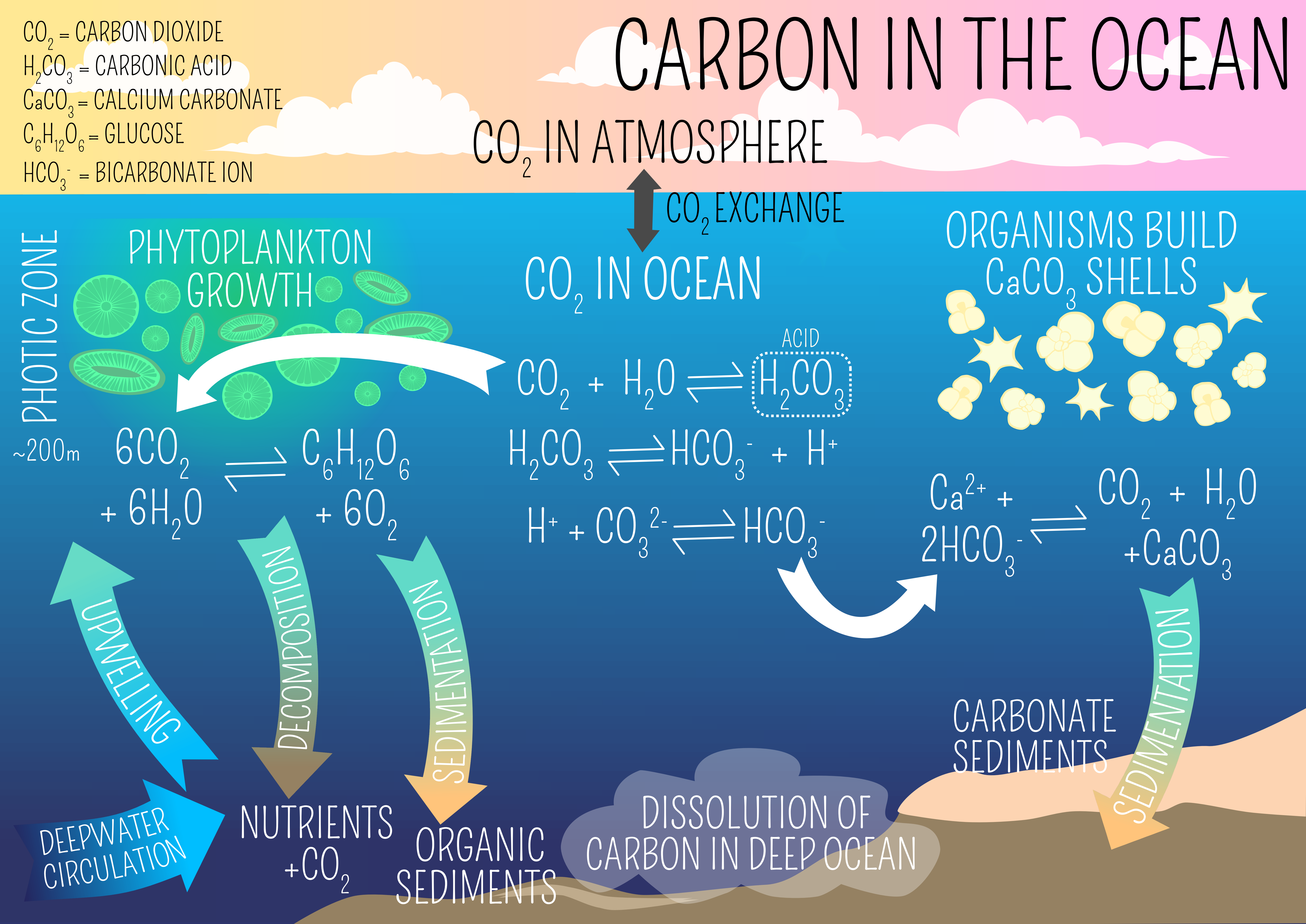
average increase 4 Gt year^{-1}

1 Gt =

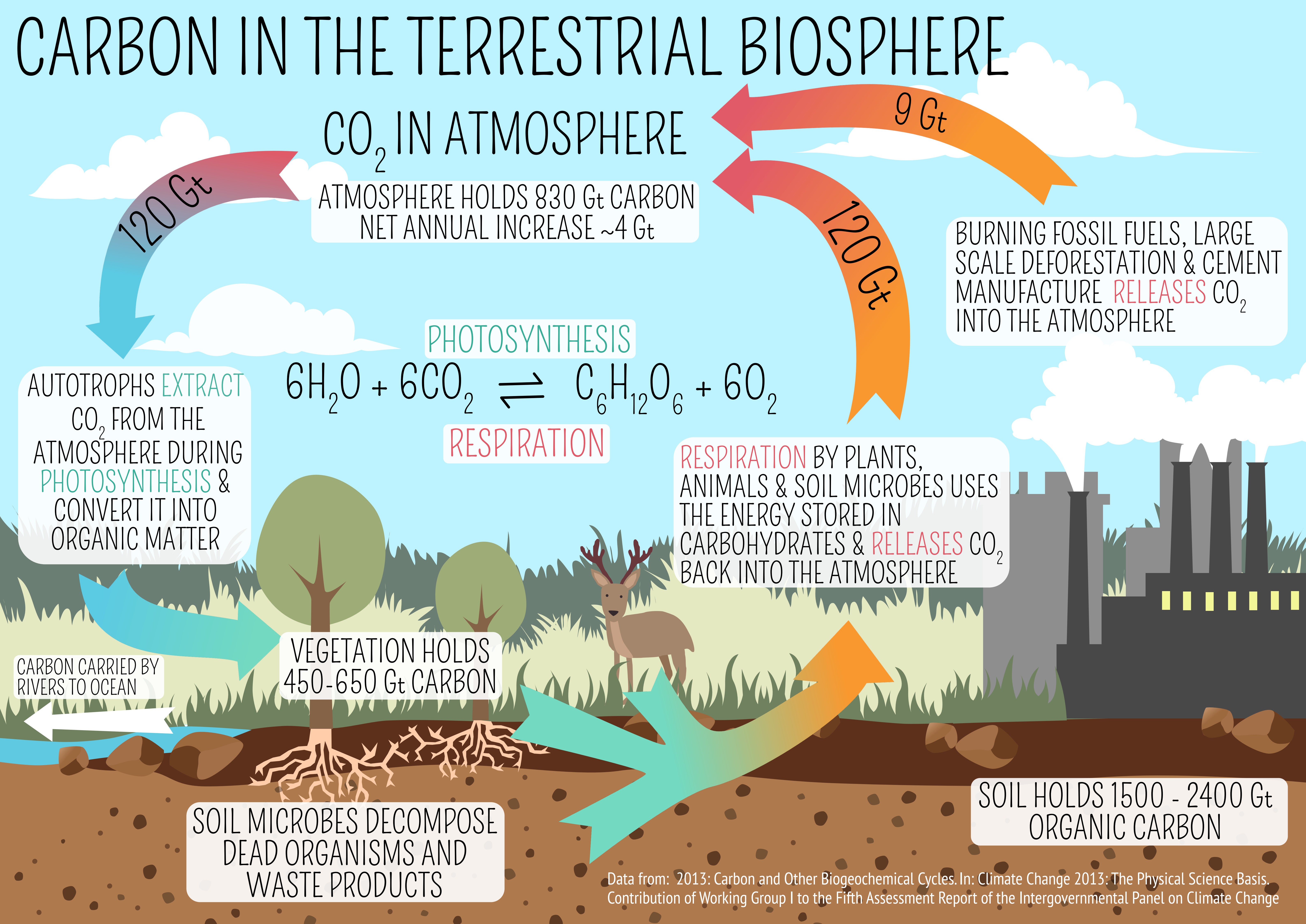


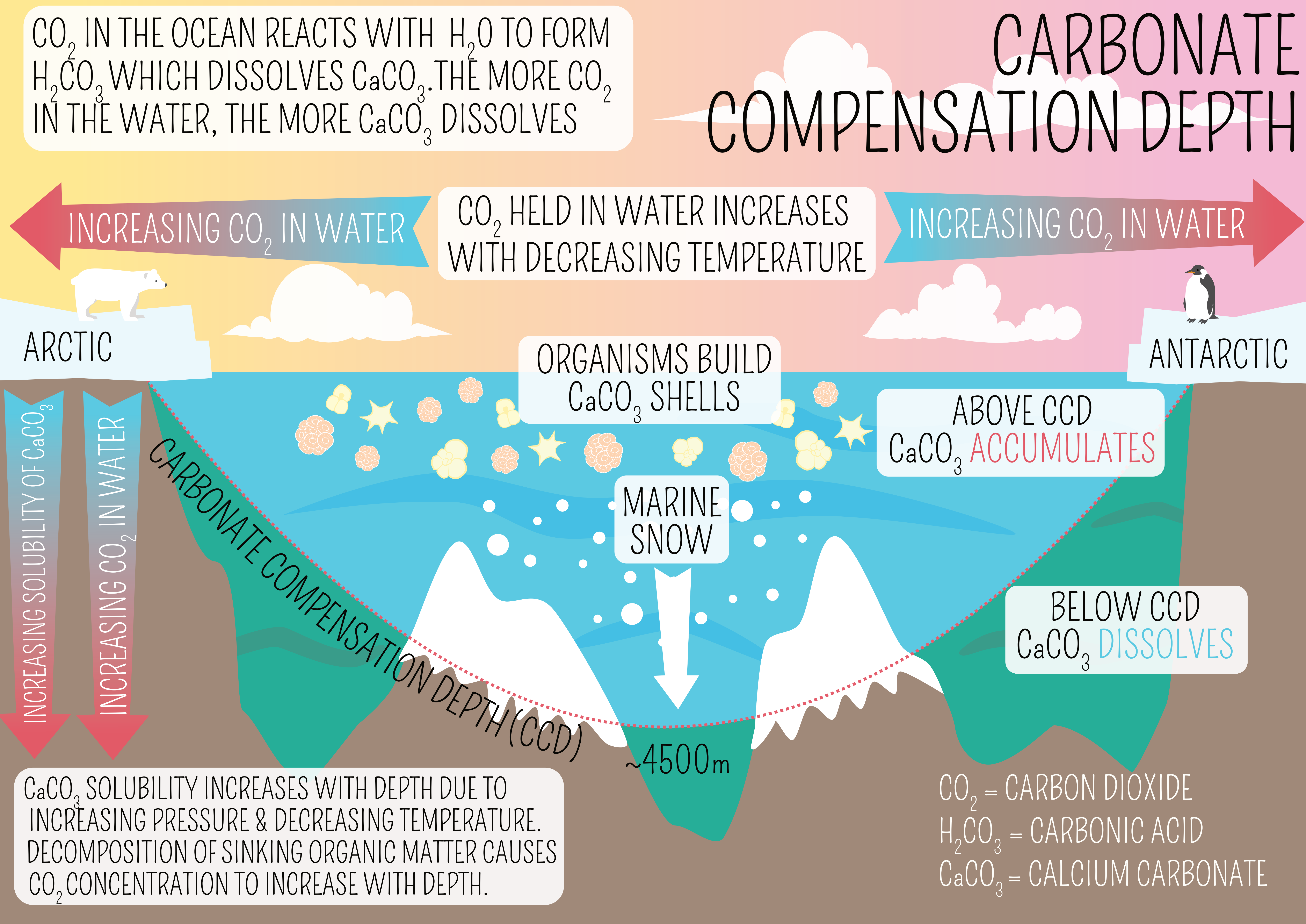
X 6 MILLION

Data from: 2013: Carbon and Other Biogeochemical Cycles. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

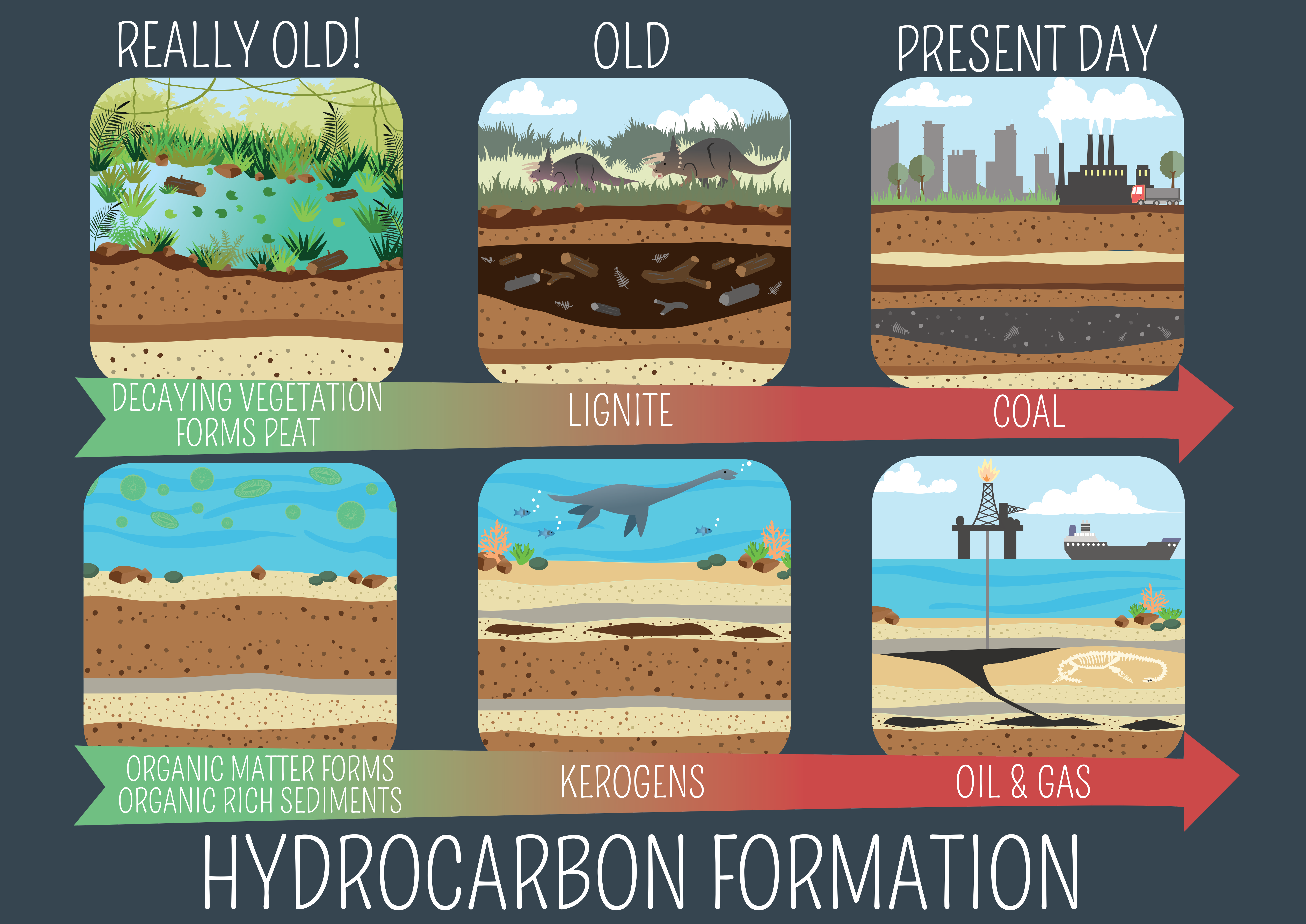


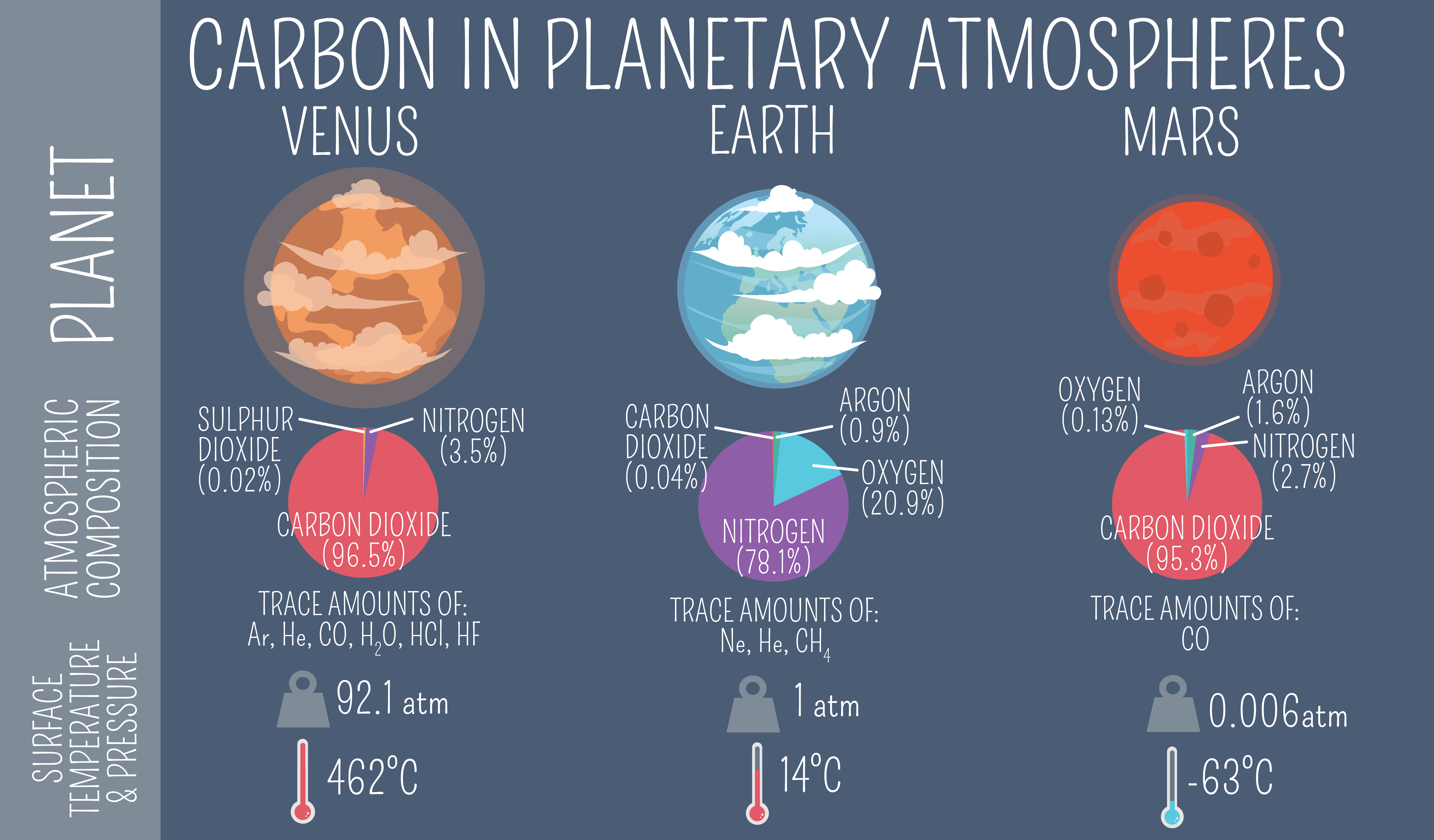
CARBON IN THE OCEAN
CO_2 = CARBON DIOXIDE
H_2CO_3 = CARBONIC ACID
$CaCO_3$ = CALCIUM CARBONATE
$C_6H_{12}O_6$ = GLUCOSE
HCO_3^- = BICARBONATE ION
CO_2 IN ATMOSPHERE
CO_2 EXCHANGE
CO_2 IN OCEAN
PHOTIC ZONE
~200m
PHYTOPLANKTON GROWTH
$6CO_2 + 6H_2O \rightleftharpoons C_6H_{12}O_6 + 6O_2$
ACID
$CO_2 + H_2O \rightleftharpoons H_2CO_3$
$H_2CO_3 \rightleftharpoons HCO_3^- + H^+$
$H^+ + CO_3^{2-} \rightleftharpoons HCO_3^-$
ORGANISMS BUILD $CaCO_3$ SHELLS
$Ca^{2+} + 2HCO_3^- \rightleftharpoons CO_2 + H_2O + CaCO_3$
UPWELLING
DECOMPOSITION
SEDIMENTATION
SEDIMENTATION
DEEPWATER CIRCULATION
NUTRIENTS $+CO_2$
ORGANIC SEDIMENTS
DISSOLUTION OF CARBON IN DEEP OCEAN
CARBONATE SEDIMENTS


CARBON IN THE TERRESTRIAL BIOSPHERE
CO_2 IN ATMOSPHERE
ATMOSPHERE HOLDS 830 Gt CARBON
NET ANNUAL INCREASE ~4 Gt
120 Gt
120 Gt
9 Gt
BURNING FOSSIL FUELS, LARGE SCALE DEFORESTATION & CEMENT MANUFACTURE RELEASES CO_2 INTO THE ATMOSPHERE
PHOTOSYNTHESIS
$6H_2O + 6CO_2 \rightleftharpoons C_6H_{12}O_6 + 6O_2$
RESPIRATION
AUTOTROPHS EXTRACT CO_2 FROM THE ATMOSPHERE DURING PHOTOSYNTHESIS & CONVERT IT INTO ORGANIC MATTER
RESPIRATION BY PLANTS, ANIMALS & SOIL MICROBES USES THE ENERGY STORED IN CARBOHYDRATES & RELEASES CO_2 BACK INTO THE ATMOSPHERE
VEGETATION HOLDS 450-650 Gt CARBON
CARBON CARRIED BY RIVERS TO OCEAN
SOIL MICROBES DECOMPOSE DEAD ORGANISMS AND WASTE PRODUCTS
SOIL HOLDS 1500 - 2400 Gt ORGANIC CARBON
Data from: 2013: Carbon and Other Biogeochemical Cycles. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change



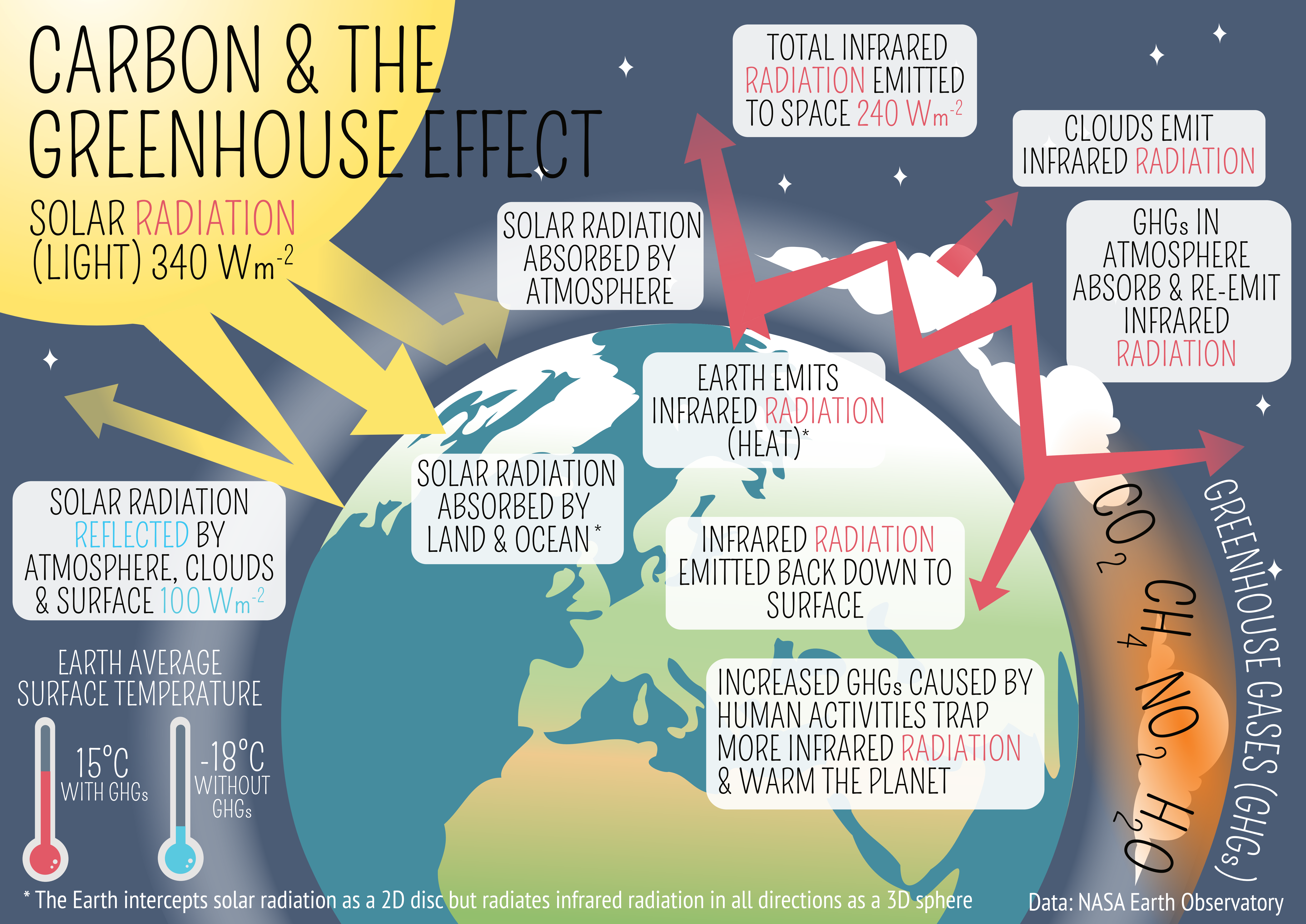
CARBONATE COMPENSATION DEPTH
CO_2 IN THE OCEAN REACTS WITH H_2O TO FORM H_2CO_3 WHICH DISSOLVES $CaCO_3$. THE MORE CO_2 IN THE WATER, THE MORE $CaCO_3$ DISSOLVES
INCREASING CO_2 IN WATER
CO_2 HELD IN WATER INCREASES WITH DECREASING TEMPERATURE
INCREASING CO_2 IN WATER
ARCTIC
ANTARCTIC
ORGANISMS BUILD $CaCO_3$ SHELLS
ABOVE CCD $CaCO_3$ ACCUMULATES
MARINE SNOW
BELOW CCD $CaCO_3$ DISSOLVES
INCREASING SOLUBILITY OF $CaCO_3$
INCREASING CO_2 IN WATER
CARBONATE COMPENSATION DEPTH (CCD)
~4500m
$CaCO_3$ SOLUBILITY INCREASES WITH DEPTH DUE TO INCREASING PRESSURE & DECREASING TEMPERATURE. DECOMPOSITION OF SINKING ORGANIC MATTER CAUSES CO_2 CONCENTRATION TO INCREASE WITH DEPTH.
CO_2 = CARBON DIOXIDE
H_2CO_3 = CARBONIC ACID
$CaCO_3$ = CALCIUM CARBONATE


REALLY OLD!
OLD
PRESENT DAY
DECAYING VEGETATION FORMS PEAT
LIGNITE
COAL
ORGANIC MATTER FORMS ORGANIC RICH SEDIMENTS
KEROGENS
OIL & GAS
HYDROCARBON FORMATION



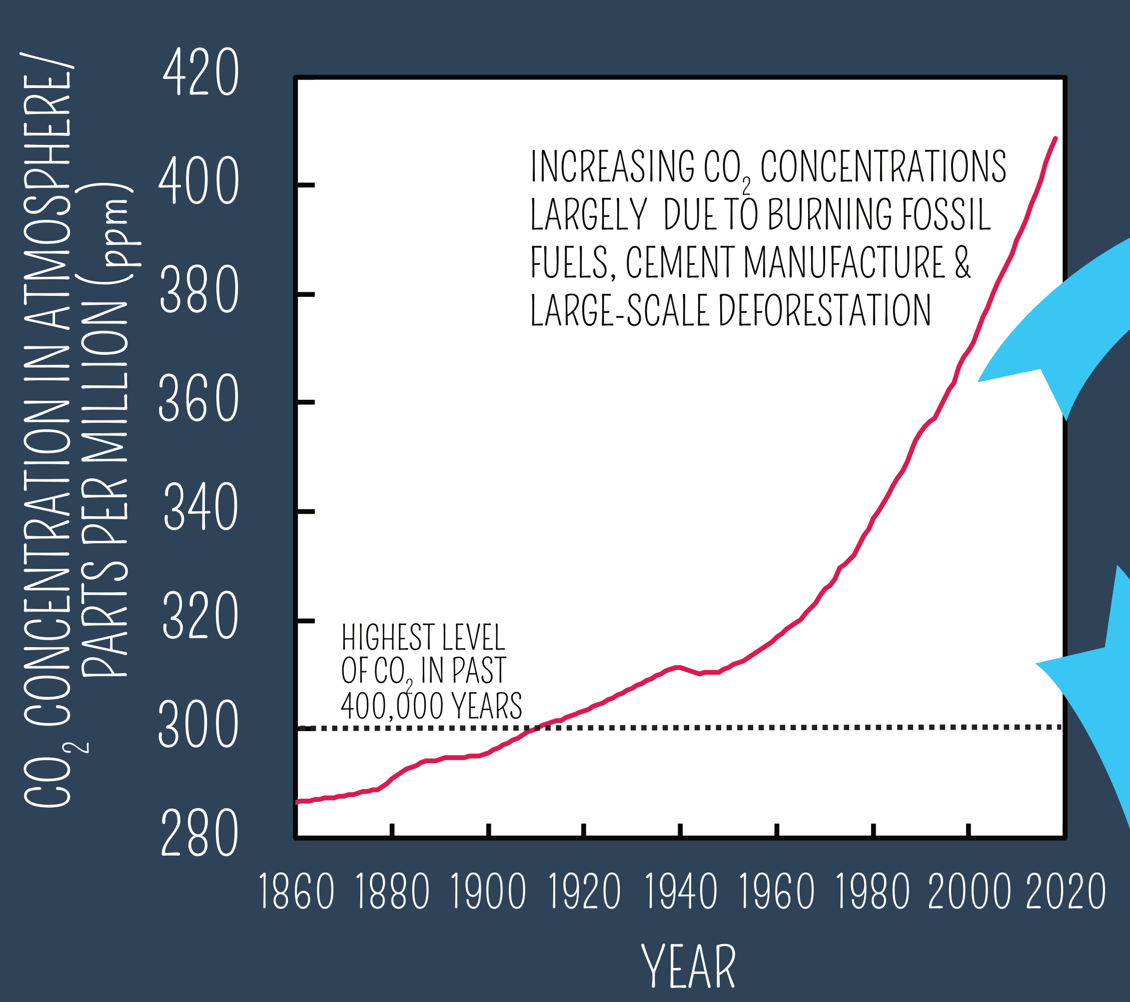
WHY IS VENUS SO HOT?

EARTH AND VENUS ARE SIMILAR SIZED PLANETS AND WHILST VENUS IS CLOSER TO THE SUN, ITS THICK CLOUD COVER REFLECTS MOST OF THE SUNLIGHT THAT HITS IT. VENUS'S ATMOSPHERE HOWEVER IS 96.5% CARBON DIOXIDE (CO_2) AND IT IS MUCH DENSER THAN EARTH'S. THIS AMOUNT OF CO_2 CREATES A STRONG GREENHOUSE EFFECT, RAISING VENUS'S SURFACE TEMPERATURE TO AROUND 462 °C, HOTTER THAN ANY OTHER PLANET IN THE SOLAR SYSTEM.

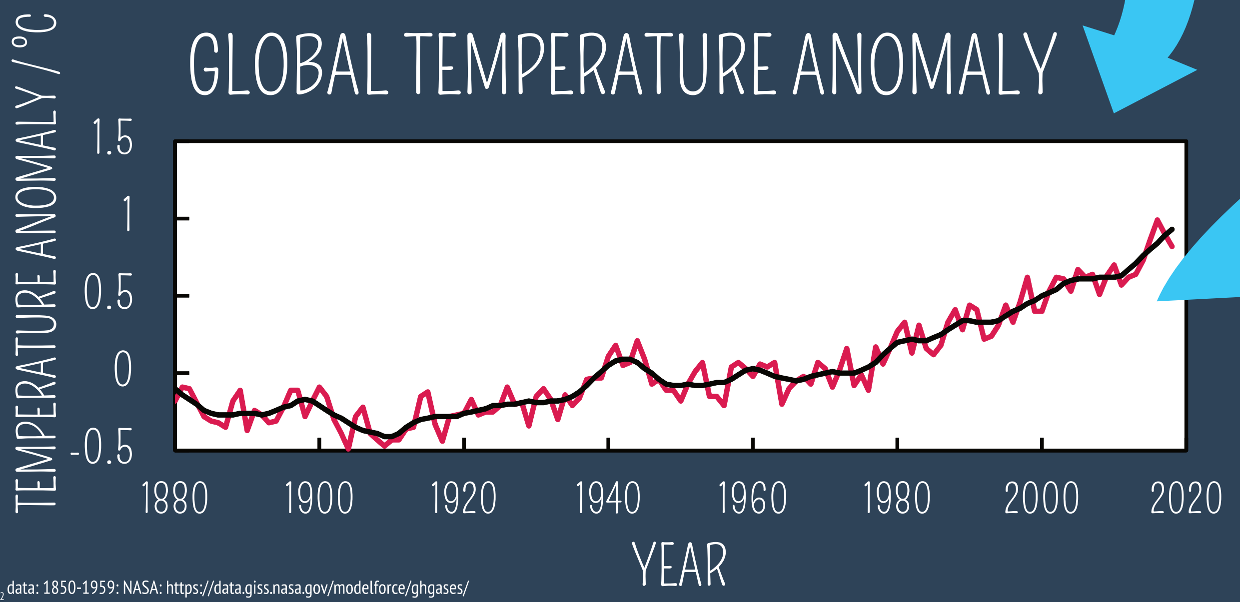

CARBON & THE GREENHOUSE EFFECT
SOLAR RADIATION (LIGHT) 340 Wm^{-2}
SOLAR RADIATION ABSORBED BY ATMOSPHERE
TOTAL INFRARED RADIATION EMITTED TO SPACE 240 Wm^{-2}
CLOUDS EMIT INFRARED RADIATION
GHGs IN ATMOSPHERE ABSORB & RE-EMIT INFRARED RADIATION
EARTH EMITS INFRARED RADIATION (HEAT)*
SOLAR RADIATION ABSORBED BY LAND & OCEAN *
SOLAR RADIATION REFLECTED BY ATMOSPHERE, CLOUDS & SURFACE 100 Wm^{-2}
INFRARED RADIATION EMITTED BACK DOWN TO SURFACE
INCREASED GHGs CAUSED BY HUMAN ACTIVITIES TRAP MORE INFRARED RADIATION & WARM THE PLANET
CO_2 CH_4 NO_2 H_2O
GREENHOUSE GASES (GHGs)
EARTH AVERAGE SURFACE TEMPERATURE
15°C WITH GHGs
-18°C WITHOUT GHGs
* The Earth intercepts solar radiation as a 2D disc but radiates infrared radiation in all directions as a 3D sphere
Data: NASA Earth Observatory

CARBON & CLIMATE CHANGE

INCREASING CO_2 CONCENTRATION IN THE ATMOSPHERE ENHANCES THE GREENHOUSE EFFECT AND HAS A POSITIVE FEEDBACK ON GLOBAL WARMING. THIS HAS SEVERAL SIGNIFICANT AND POTENTIALLY IRREVERSIBLE KNOCK-ON EFFECTS...

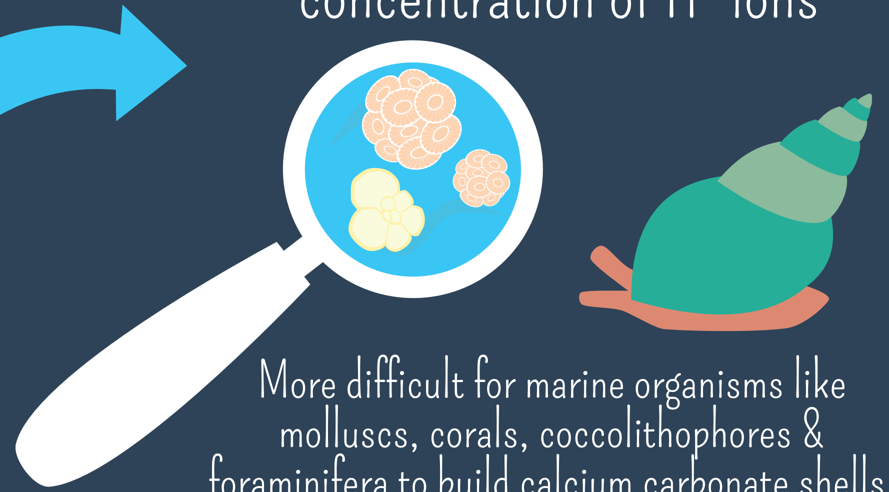


GLOBAL TEMPERATURE ANOMALY



OCEAN pH

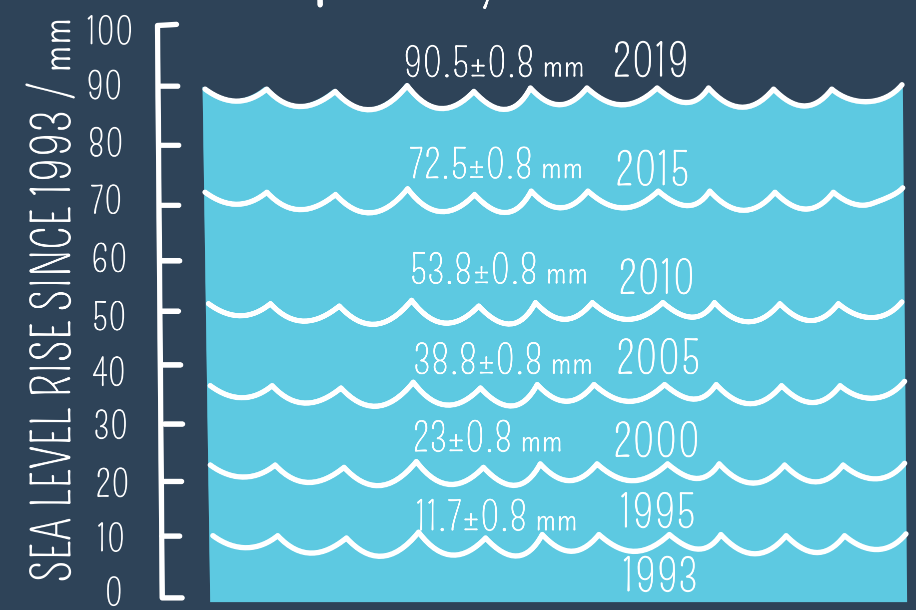
↓0.1 pH in surface water (since 1860) equivalent to 26% increase in concentration of H^+ ions

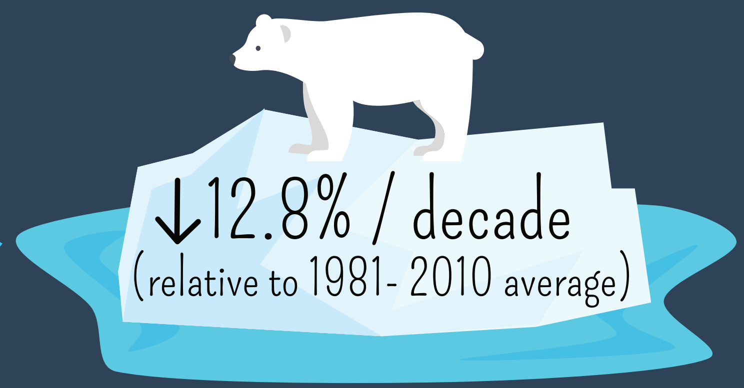


More difficult for marine organisms like molluscs, corals, coccolithophores & foraminifera to build calcium carbonate shells.

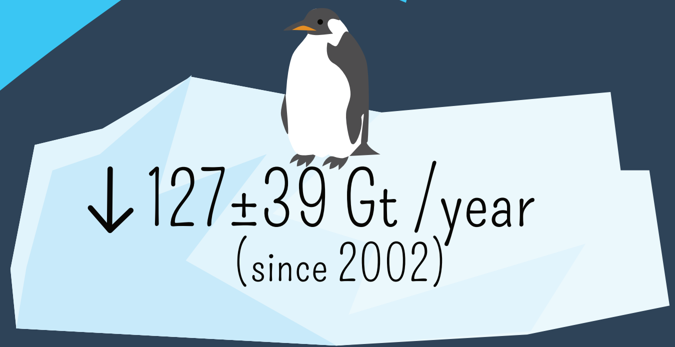
GLOBAL SEA LEVEL

↑3 mm/year (since 1993)

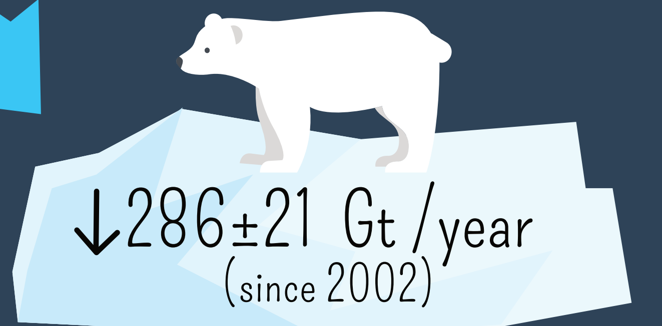




ARCTIC SEA ICE



ANTARCTIC ICE MASS



GREENLAND ICE MASS

CO_2 data: 1850-1959: NASA: https://data.giss.nasa.gov/modelforce/ghgases/

CO_2 data: 1959-2018: National Oceanic and Atmospheric Administration, Earth System Research Laboratory, Global Monitoring Division.Dr. Pieter Tans, NOAA/ESRL (www.esrl.noaa.gov/gmd/ccgg/trends/) and Dr. Ralph Keeling, Scripps Institution of Oceanography (scrippsco2.ucsd.edu/).

Global Temperature Anomaly data: Land-Ocean Temperature Index NASA's Goddard Institute for Space Studies (GISS).

Greenland& Antarctica Ice mass data: Wiese, D. N., D-N. Yuan, C. Boening, F. W. Landerer, and M. M. Watkins (2016) JPL GRACE Mascon Ocean, Ice, and Hydrology Equivalent HDR Water Height RL05M.1 CRI Filtered Version 2., Ver. 2., PO.DAAC, CA, USA. Dataset accessed [2019-04-07] at http://dx.doi.org/10.5067/TEMSC-2LCR5.

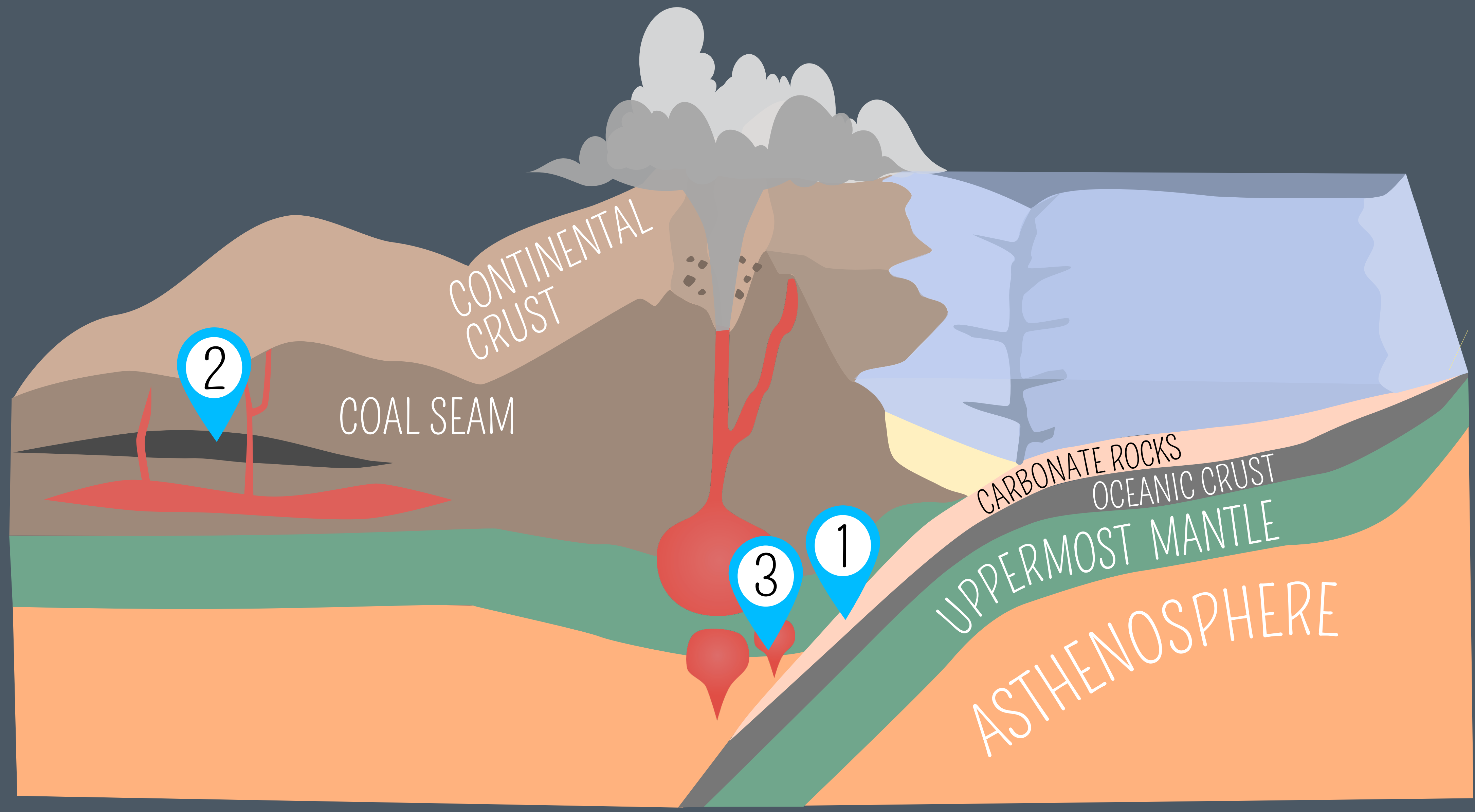
Global sea level data: GSFC. 2017. Global Mean Sea Level Trend from Integrated Multi-Mission Ocean Altimeters TOPEX/Poseidon, Jason-1, OSTM/Jason-2 Version 4.2 Ver. 4.2 PO.DAAC, CA, USA. Dataset accessed [2019-04-07] at http://dx.doi.org/10.5067/GMSLM-TJ42.

Ocean Acidification data: Pörtner, H.-O., D.M. Karl, P.W. Boyd,W.W.L. Cheung, S.E. Lluch-Cota, Y. Nojiri, D.N. Schmidt, and P.O. Zavialov, 2014: Ocean systems. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken,P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 411-484.

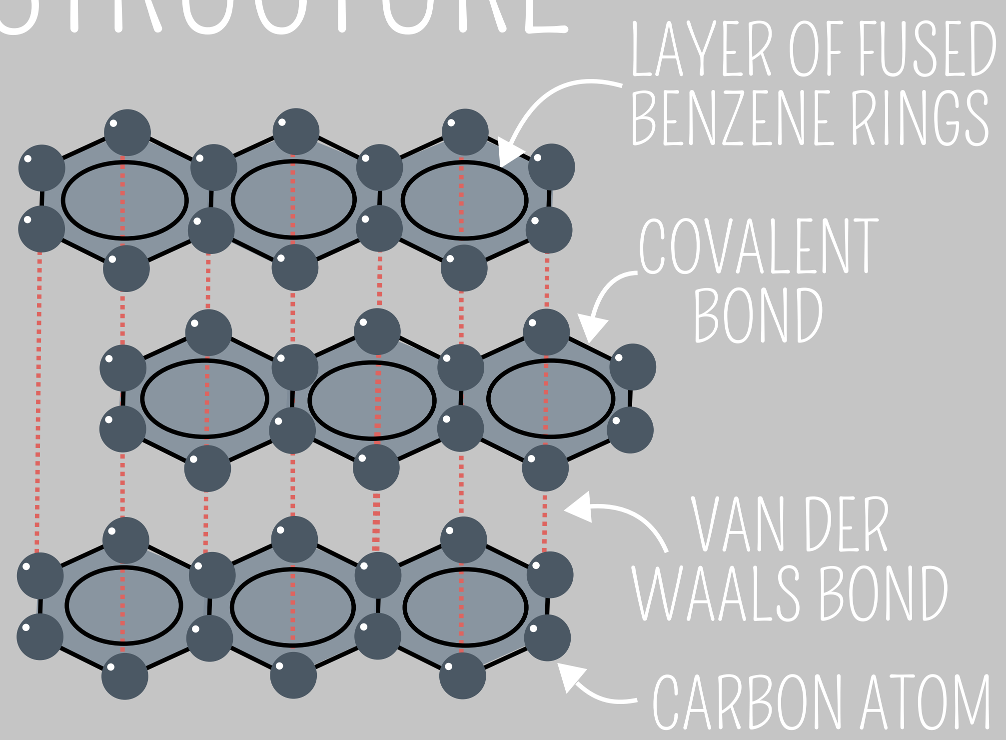
GRAPHITE

FORMATION

1. SUBDUCTION & REGIONAL METAMORPHISM OF CARBON-RICH SEDIMENTARY ROCKS
2. CONTACT METAMORPHISM WITH COAL SEAM
3. IGNEOUS ROCKS ASSOCIATED WITH METAMORPHOSED GRAPHITE-BEARING SEDIMENTARY ROCKS



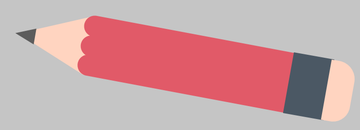
STRUCTURE



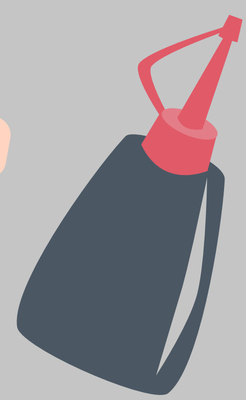
PROPERTIES

- HIGH MELTING POINT
- CONDUCTOR OF HEAT & ELECTRICITY
- LUBRICANT
- OPAQUE
- SOFT

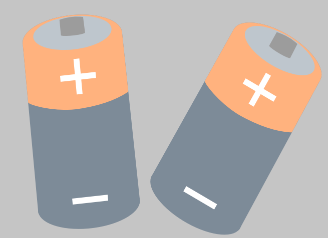
USES



PENCILS

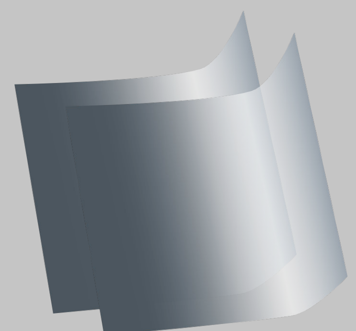


LUBRICANT



ANODE IN LITHIUM ION BATTERIES

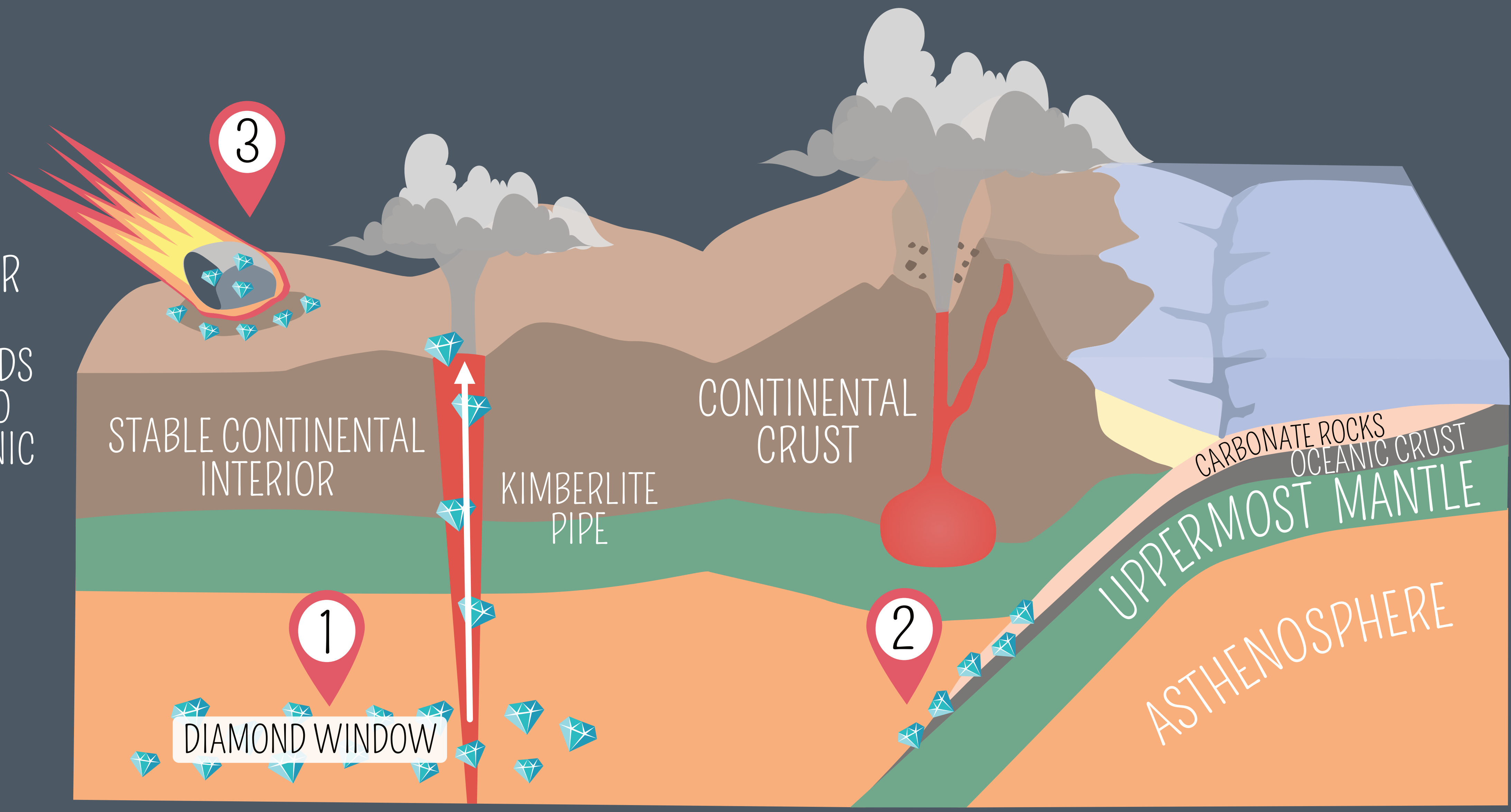
REFRACTORY APPLICATIONS e.g. CRUCIBLE



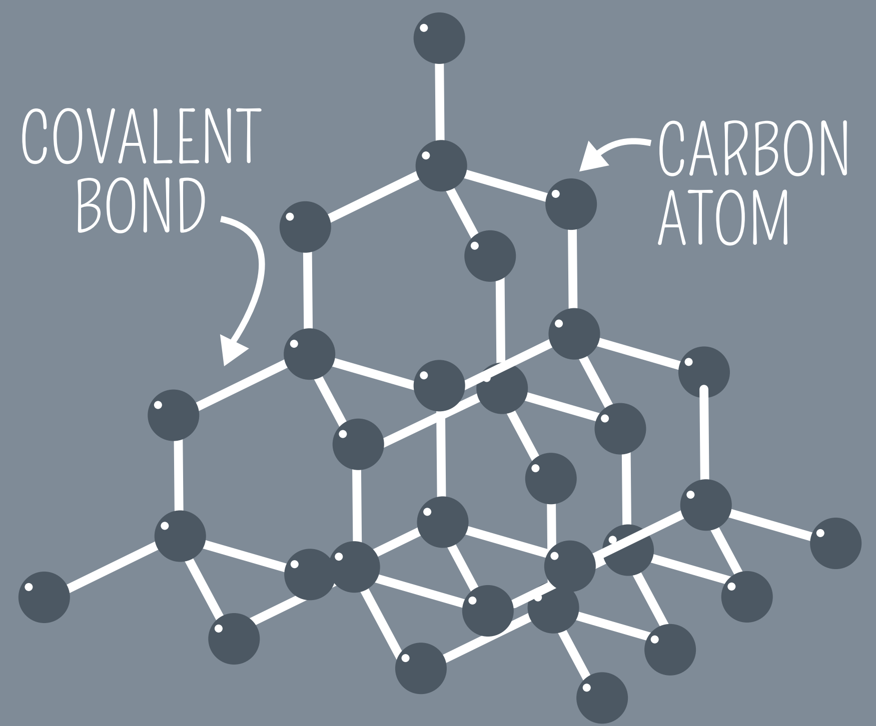
GRAPHENE SHEETS

DIAMOND
FORMATION

1. DIAMOND WINDOW - ZONE UNDER STABLE CONTINENTAL INTERIORS. MAJORITY OF MACROSCOPIC DIAMONDS FORM HERE & CAN BE TRANSPORTED TO THE SURFACE IN DEEP SOURCE VOLCANIC ERUPTIONS
2. ULTRA HIGH PRESSURE METAMORPHISM OF CARBONATE SEDIMENTS
3. METEORITE IMPACT (NANO DIAMONDS)



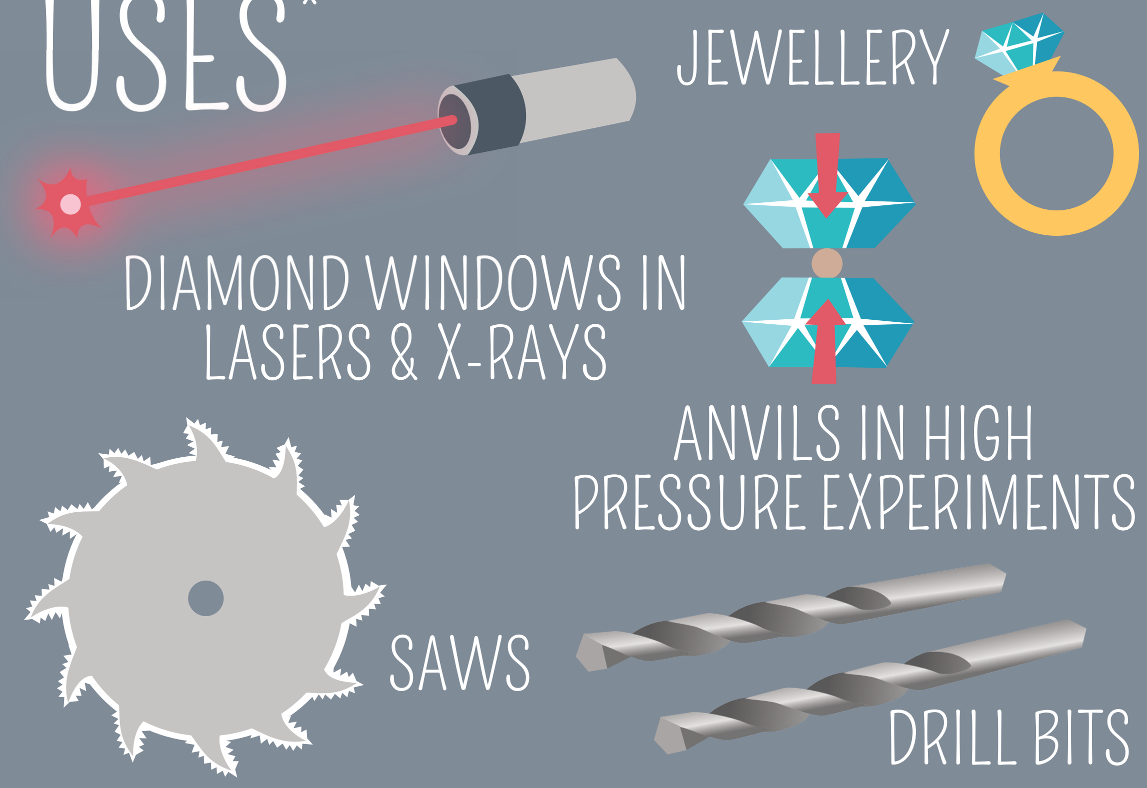
STRUCTURE



PROPERTIES

- HIGH MELTING POINT
- HIGHEST THERMAL CONDUCTIVITY OF ANY NATURAL MATERIAL
- TRANSPARENT
- HARDEST NATURAL MATERIAL

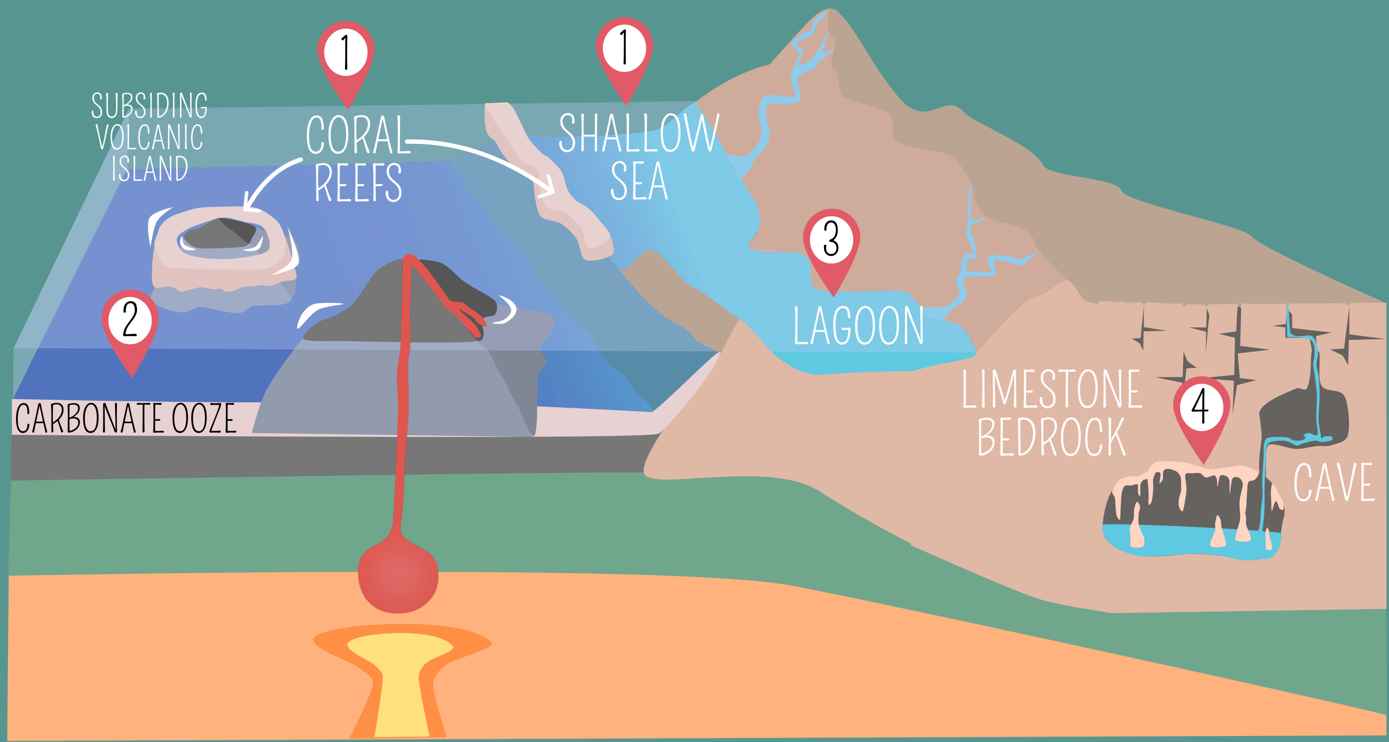
USES*



*high tech applications of diamond use synthetic rather than natural diamond

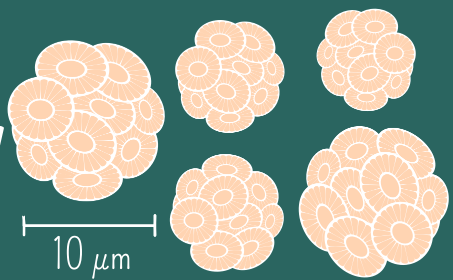
LIMESTONE
FORMATION

1. ACCUMULATION OF $CaCO_3$ FROM ALGAE, CORAL, SHELLS & FAECAL MATTER IN WARM SHALLOW SEAS
2. ACCUMULATION OF $CaCO_3$ IN DEEPER WATER (<4500m) FROM CALCIFYING PLANKTON
3. PRECIPITATION OF $CaCO_3$ IN SATURATED WATERS E.G. IN LAGOONS & HOT SPRINGS
4. EVAPORATION OF WATER LEAVES BEHIND $CaCO_3$ DEPOSITS



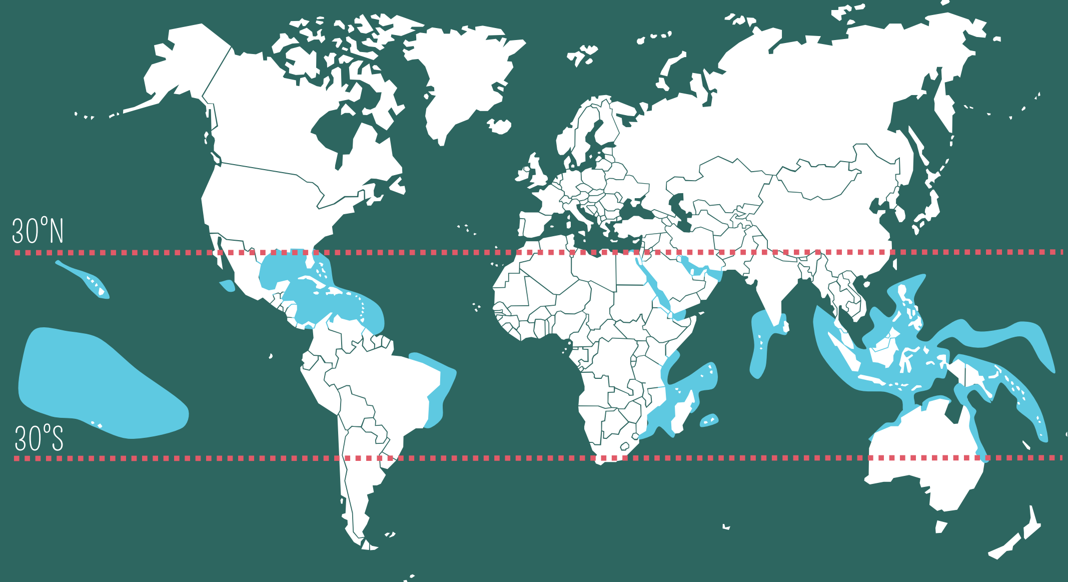
CHALK

- LIMESTONE FORMED PREDOMINANTLY FROM NANOPLANKTON CALLED COCCOLITHOPHORES



- CHALK DEPOSITED IN THE LATE CRETACEOUS PERIOD ~89-85 Ma FORMS THE FAMOUS WHITE CLIFFS OF DOVER & THE NEEDLES ON THE ISLE OF WIGHT
- THE UK CHALK ACTS AS AN AQUIFER - A PERMEABLE ROCK THAT HOLDS GROUND WATER

MODERN MARINE LIMESTONE FORMING ENVIRONMENTS

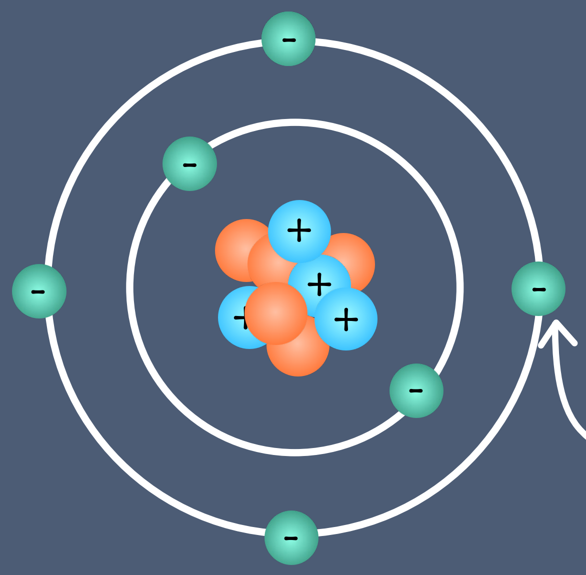


CARBON

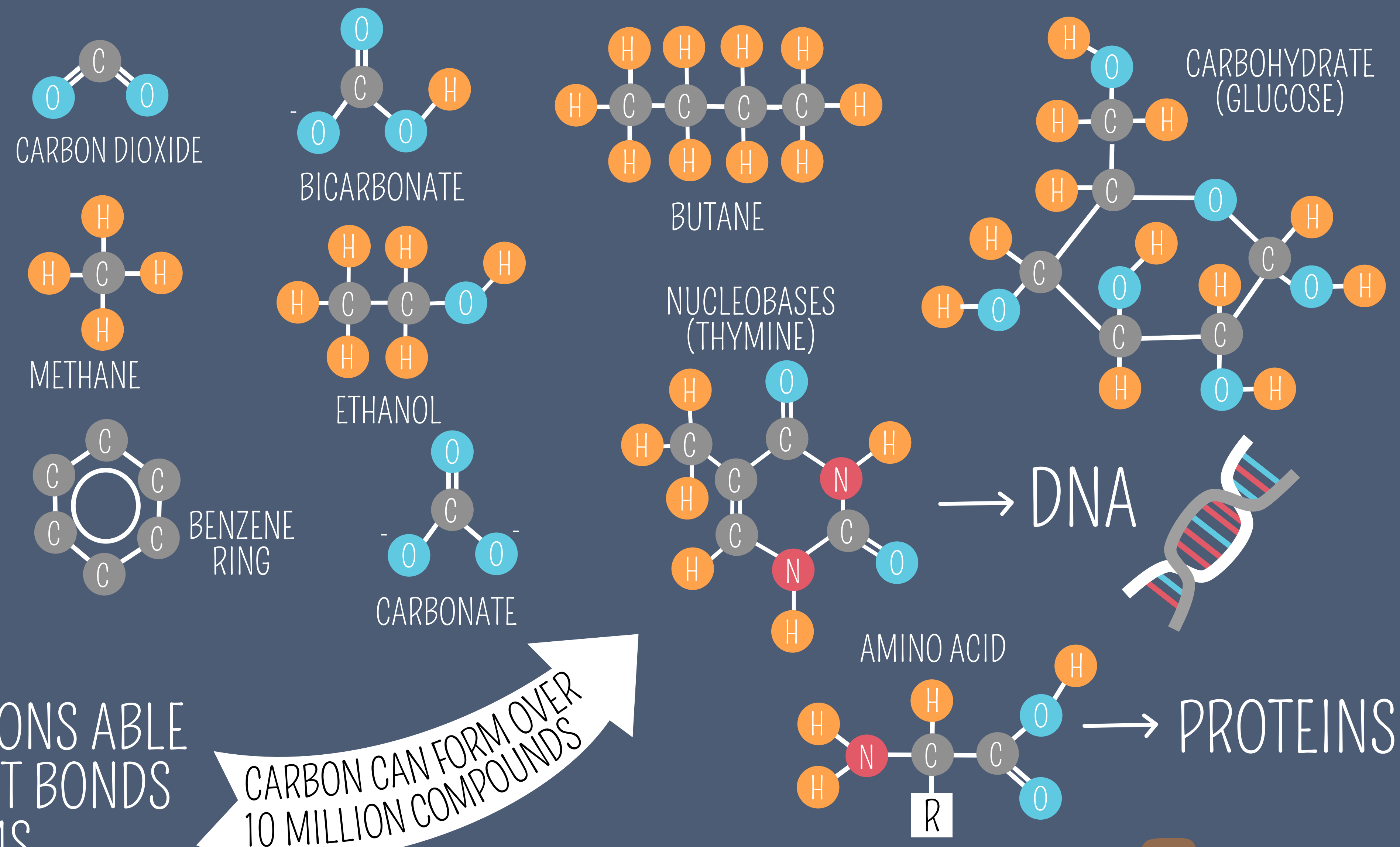
C_6

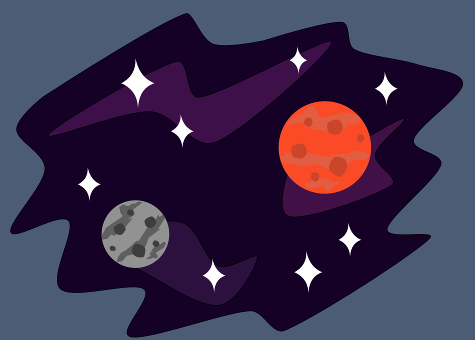
ATOMIC NUMBER 6

- 6 ELECTRONS
- 6 PROTONS
- 6 NEUTRONS



4 VALENCE ELECTRONS ABLE TO FORM COVALENT BONDS WITH OTHER ATOMS





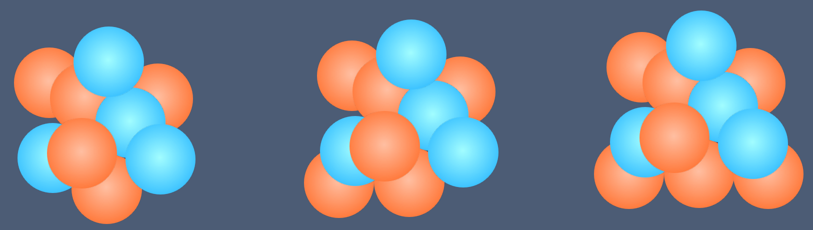
4th MOST ABUNDANT ELEMENT IN THE UNIVERSE

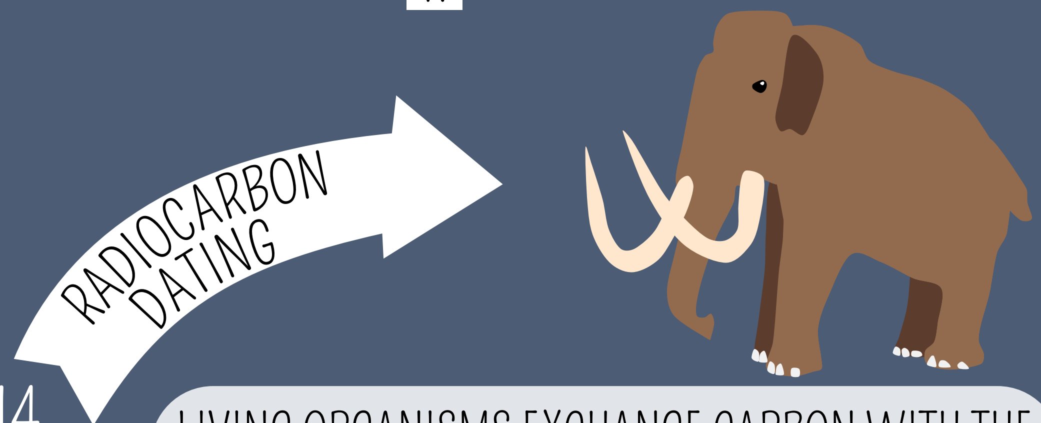
15th MOST ABUNDANT ELEMENT ON EARTH

NATURAL ALLOTROPES (PHYSICAL FORMS): GRAPHITE, DIAMOND & AMORPHOUS CARBON

ISOTOPES

C^{12}	C^{13}	C^{14}
98.9%	1.1%	TRACE
STABLE	STABLE	RADIOACTIVE HALF LIFE 5370 YEARS





LIVING ORGANISMS EXCHANGE CARBON WITH THE ATMOSPHERE/OCEAN AND INCORPORATE IT INTO THEIR TISSUES. DURING LIFE, ORGANISMS HAVE THE SAME PROPORTION OF C^{14} AS THE ATMOSPHERE (1 ppt). WHEN ORGANISMS DIE THEY NO LONGER EXCHANGE CARBON SO THE RADIOACTIVE C^{14} IN THEIR TISSUES STARTS TO DECAY. WITH TIME, THE RATIO OF C^{12}:C^{14} DECREASES AT A KNOWN RATE. THIS CAN BE USED TO DETERMINE HOW LONG AN ORGANISM HAS BEEN DEAD FOR, RELIABLY UP TO ~50,000 YEARS.