WATER QUALITY AND MINING
PART B: AN OVERVIEW OF ACID MINE DRAINAGE AND ITS CONSEQUENCES

The material presented here has been prepared by George Wilson in April 2021, with input from Dr. Laura Richards and Prof. David Polya of the Department of Earth & Environmental Sciences, The University of Manchester, and other sources as acknowledged. The associated video recordings have been made by George Wilson.

The Transformation by Innovation in Distance Education (TIDE) project is enhancing distance learning in Myanmar by building the capacity of Higher Education staff and students, enhancing programmes of study, and strengthening systems that support Higher Educational Institutions in Myanmar. TIDE is part of the UK-Aid-funded Strategic Partnerships for Higher Education Innovation and Reform (SPHEIR) programme (www.spheir.org.uk). SPHEIR is managed on behalf of FCDO by a consortium led by the British Council that includes PwC and Universities UK International. The TIDE project will close in May 2021.

Acid mine drainage

- Outline
  - Introduction
  - Objectives
  - Copper ore formation
  - AMD formation and characteristics
  - Environmental consequences of AMD
  - Learning exercise
  - References & Further Information
- Summary

Introduction

- Acid mine drainage a worldwide problem causing long-term impacts to waterways and biodiversity
- Example of point-source pollution* / geogenic pollutant with anthropogenic influence (Contamination of Water lecture)

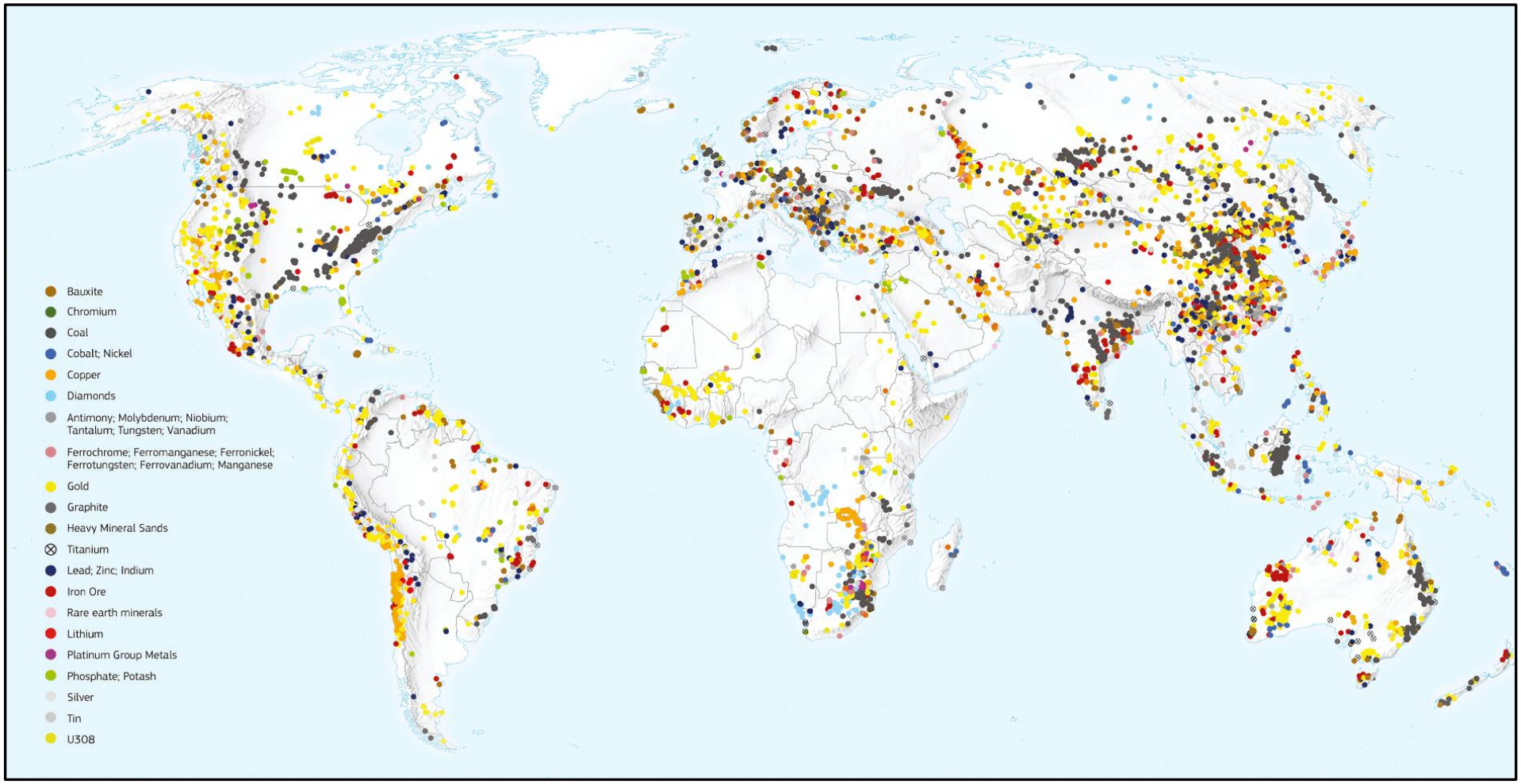
*Single identifiable source of pollution

Objectives

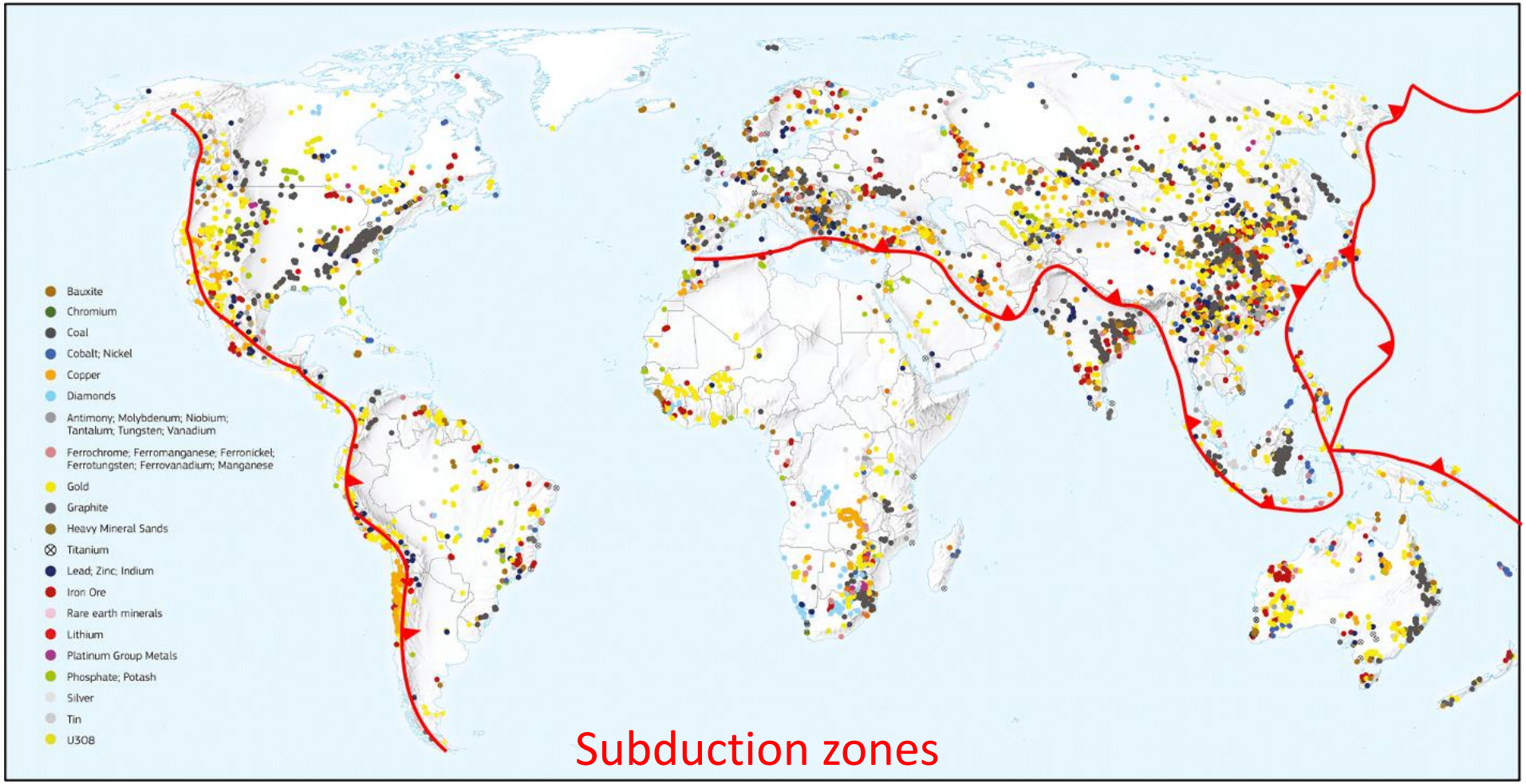
- Explain the geological processes which concentrate iron and copper in the Earth's crust
- Explain the fundamental processes which generate acid-mine drainage
- Explain the environmental consequences of acid-forming systems

COPPER ORE FORMATION

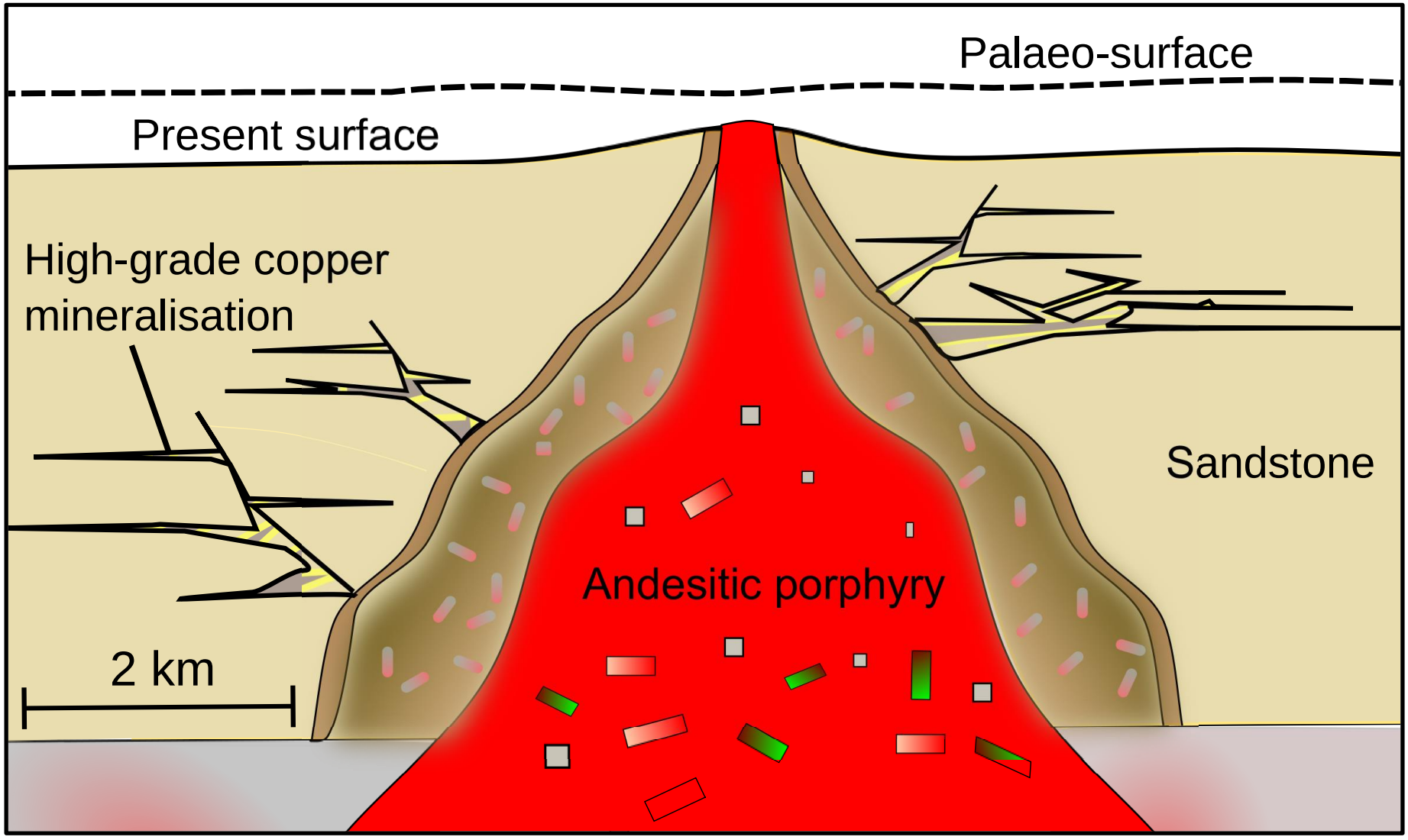
Active mining sites world map



Active mining sites world map



Kyisintaung copper mine



Produced by George Wilson from an adaptation of Mitchell *et al*. (2010) (OA)

ACID-MINE DRAINAGE FORMATION AND CHARACTERISTICS

AMD reactions

- Copper and iron minerals such as pyrite (FeS_2) or chalcopyrite ($CuFeS_2$) unstable on exposure to oxygen and water:

$$4FeS_2 + 14H_20 + 15O_2 \longrightarrow 4Fe(OH)_3 + 4SO_4^{2-} + 8H^+$$

pyrite or copper sulphide — Ferrous hydroxide — sulphuric acid

(Dold, 2014) (OA)

- Ferrous hydroxide and sulphuric acid are produced

AMD characteristics

- Drainage can occur from from open pits, adits or mine tailings
- AMD typically around pH 2-3, as low as -3.6! (pH = -log[H+]) (Nordstrom, 2000)
- Drainage typically orange/red from precipitation of ochre

Image from Wikipedia under a public domain license

Characteristics of abandoned mines in Tasmania

Parameter	Mean (TGS, 2005; OA)	WHO guideline values (WHO, 2017; OA)
pH	5.45	6.5-8.0
SO_4^{2-}	557 mg/L	250 mg/L
As	43.91 mg/L	0.01 mg/L
Cd	0.03 mg/L	0.003 mg/L
Cu	2.52 mg/L	2 mg/L
Pb	0.21 mg/L	0.01 mg/L
Zn	7.45 mg/L	3 mg/L

AMD characteristics

Image taken by George Wilson

Monywa Copper Project

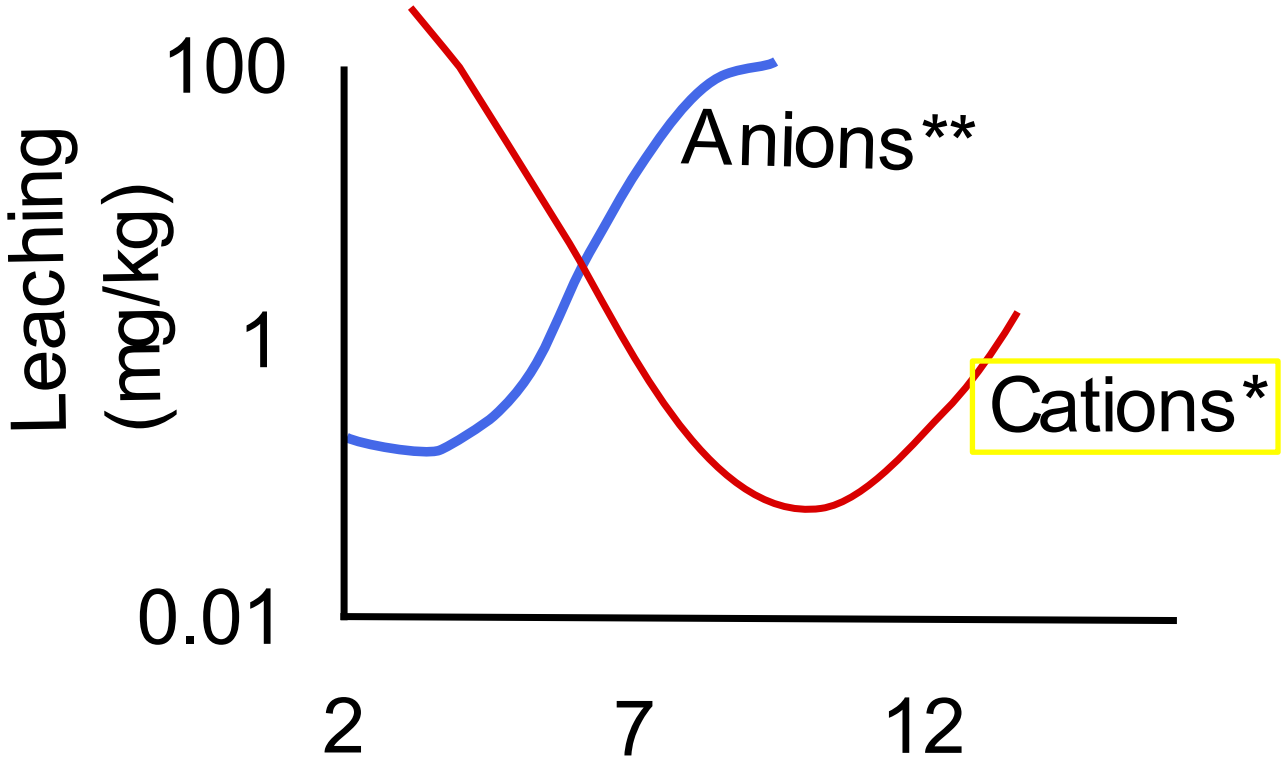
- Four sulfide-deposits (e.g. Kyisintaung) make up Monywa, Myanmar's largest mine
- Locals reportedly can no longer grow crops in areas in close vicinity to mining activities
- Artisanal mining exacerbates the problem here
- Mitigation of AMD does occur to some extent

(Smith, 2007) (OA)

ENVIRONMENTAL CONSEQUENCES OF AMD

Metal leaching and dependency on pH

- Many metals (e.g. cadmium, lead) will become mobilised or precipitated as a result of lower pH

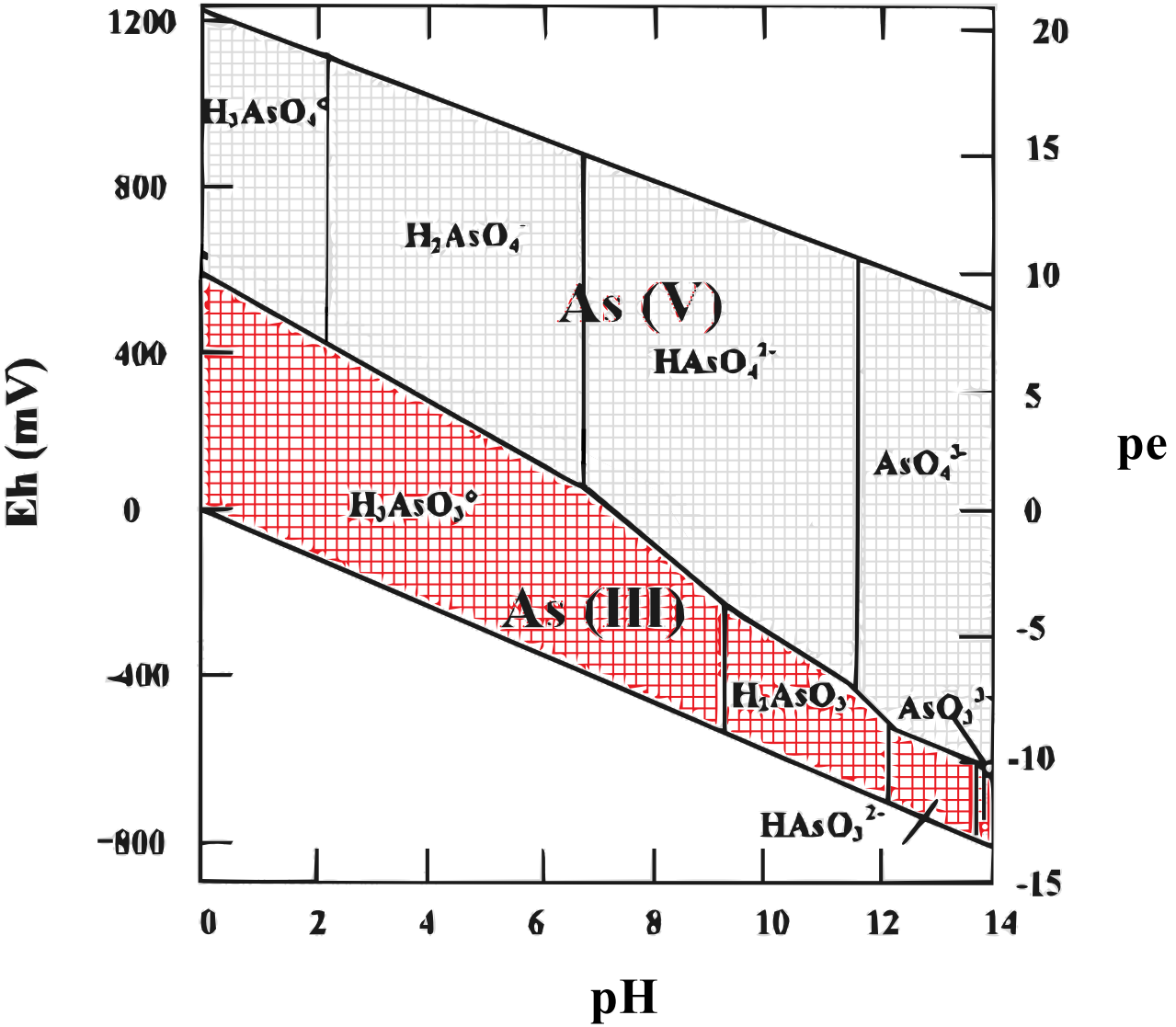


(*Ni, Cu, Zn, Cd, Pb, Al, Fe cations)

(**Mo, Cr(VI), As, Se, Sb, SO_4 anions)

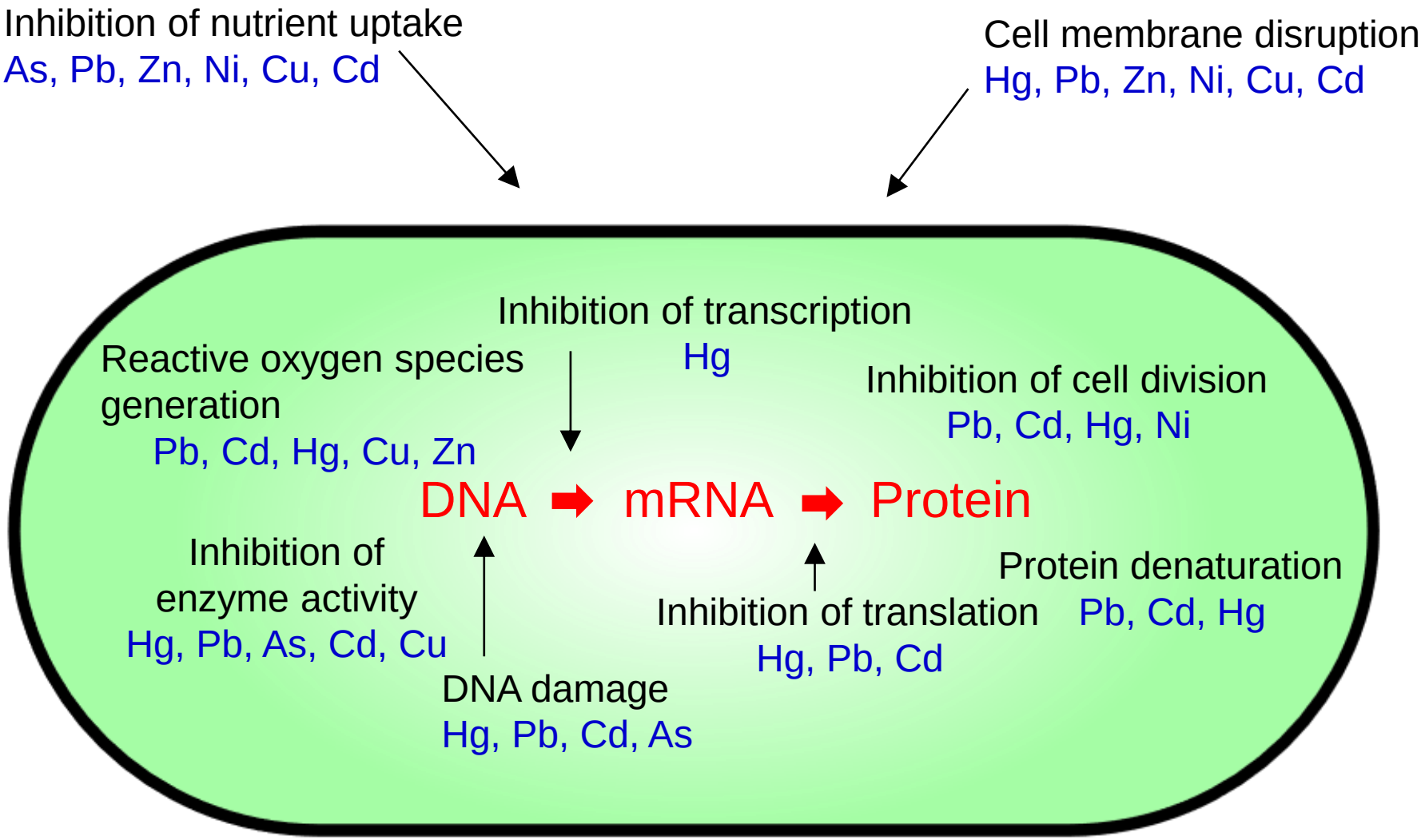
Produced by George Wilson from Król *et al.*, (2020) (OA)

Metal speciation



Produced by George Wilson

Heavy metal cellular toxicity



Produced by George Wilson from Bánfalvi (2011)

SUMMARY

Summary

- Acid mine drainage often a severe and complex problem in Myanmar and globally
- Low pH can increase metal mobility and speciation, which can have adverse effects
- Environmental and other impacts of acid mining drainage should be thoroughly considered, evaluated and mitigated where necessary

LEARNING EXERCISE

Learning exercise

1.Calculate H+ concentration from these documented mine pHs:

Parys Mountain, UK: 2.7

Richmond Mine, California: -3.6

$$pH = -\log[H+]$$

2.Discuss how acid mine drainage can degrade the environment. How may this affect the social and economic issues?

3a. What examples can you find (using Google Scholar or similar) of acid mine drainage occurring in Southeast Asia?

3b. Are there other examples of acid mine drainage in Myanmar that you are familiar with? If so, what impacts does this have? Are there controls in place to mitigate the impacts?

REFERENCES & FURTHER RESOURCES

References

Bánfalvi, G., 2011. *Cellular effects of heavy metals* (pp. 3-28). New York: Springer.

Dold, B., 2014. Evolution of acid mine drainage formation in sulphidic mine tailings. *Minerals*, *4*(3), pp.621-641. https://doi.org/10.3390/min4030621 (OA)

Król, A., Mizerna, K. and Bożym, M., 2020. An assessment of pH-dependent release and mobility of heavy metals from metallurgical slag. *Journal of hazardous materials*, *384*, p.121502. https://doi.org/10.1016/j.jhazmat.2019.121502 (OA)

Mitchell, A.H., Myint, W., Lynn, K., Htay, M.T., Oo, M. and Zaw, T., 2011. Geology of the high sulfidation copper deposits, Monywa Mine, Myanmar. *Resource Geology*, *61*(1), pp.1-29. https://doi.org/10.1111/j.1751-3928.2010.00145.x (OA)

Nordstrom, D.K., 2000. Advances in the hydrogeochemistry and microbiology of acid mine waters. *International Geology Review*, *42*(6), pp.499-515.

Smith, M., 2007. Environmental governance of mining in Burma. *Myanmar: The state, community and the environment*, p.48. Available at: http://press-files.anu.edu.au/downloads/press/p33841/pdf/ch1016.pdf [Accessed 05/05/21] (OA)

Tasmanian Geological Survey, 2005. *Report 1: Acid drainage from abandoned mines in Tasmania.* [Online] Available at: http://www.mrt.tas.gov.au/__data/assets/pdf_file/0006/242493/UR2001_05_REPORT.pdf [Accessed 10/04/21]. (OA)

WHO, 2017. Guidelines for drinking-water quality: fourth edition incorporating the first addendum. *World Health Organisation.* Geneva. Available at: https://www.who.int/publications-detail-redirect/9789241549950 [Accessed 11/04/21]. (OA)

Further Resources

Formation of porphyry deposits

https://www.britannica.com/science/mineral-deposit/Hydrothermal-solution#ref624262 [Accessed 04/04/21]. (OA)

Acid mine drainage overview

https://www.usgs.gov/mission-areas/water-resources/science/mine-drainage?qt-science_center_objects=0#qt-science_center_objects [Accessed 05/04/21]. (OA)

Acidophilic bacterial communities

Baker, B.J. and Banfield, J.F., 2003. Microbial communities in acid mine drainage. *FEMS microbiology ecology*, *44*(2), pp.139-152. https://doi.org/10.1016/S0168-6496(03)00028-X [Accessed 05/04/21]. (OA)

Disclaimer & Conditions of Use

The mention of specific companies or of certain manufacturers' products does not imply that they are endorsed or recommended by the authors in preference to others of a similar nature that are not mentioned. All reasonable precautions have been taken by the authors to verify the information contained in this work, however, the material is being distributed without warranty of any kind, either express or implied. The responsibility for the interpretation and use of the material lies with the reader. In no event shall the authors be liable for damages arising from the use of the material in this work. The views expressed by the authors do not necessarily represent the views, decisions or the stated policies of any organization or individual referred to in this work.

This work with the exception of material from other sources as indicated , copyrighted material of which is reproduced here as fair dealing for the purposes of research or private study, or criticism or review, as permitted under the UK Copyright, Designs and Patents Act (1998), is provided under the terms of the CC-BY-NC-ND Licence as detailed at: https://creativecommons.org/licenses/by-nc-nd/4.0/legalcode and which, in particular, subject to the terms and conditions of this Public License, grants a worldwide, royalty-free, non-sublicensable, non-exclusive, irrevocable license to exercise the Licensed Rights in the Licensed Material to:

(i) reproduce and Share the Licensed Material, in whole or in part, for **NonCommercial purposes only**; and

(ii) produce and reproduce, but not Share, Adapted Material for **NonCommercial purposes only**

If You Share the Licensed Material, You must: (A) retain the following if it is supplied by the Licensor with the Licensed Material: (i) identification of the creator(s) of the Licensed Material and any others designated to receive attribution, in any reasonable manner requested by the Licensor (including by pseudonym if designated); (ii) a copyright notice; (III) a notice that refers to this Public License; (iv) a notice that refers to the disclaimer of warranties; (v) a URI or hyperlink to the Licensed Material to the extent reasonably practicable; (B) indicate if You modified the Licensed Material and retain an indication of any previous modifications; and (C) indicate the Licensed Material is licensed under this Public License, and include the text of, or the URI or hyperlink to, this Public License.

For the avoidance of doubt, permission is not granted under this Public License to Share Adapted Material.

Enquiries concerning reproduction outside the terms stated here should be sent to the author at the contact details provided on the title page.