

How to create the highest manganese ore grade in the world? A geodynamic story in the Atlas of Morocco.

Augustin Dekoninck, Jocelyn Barbarand, Gilles Ruffet, Yves Missenard, Nadine Mattielli, Rémi Leprêtre, Abdellah Mouttaqi, Omar Saddiqi, Michèle Verhaert, Johan Yans

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How to create the highest manganese ore grade in the world? A geodynamic story in the Atlas of Morocco

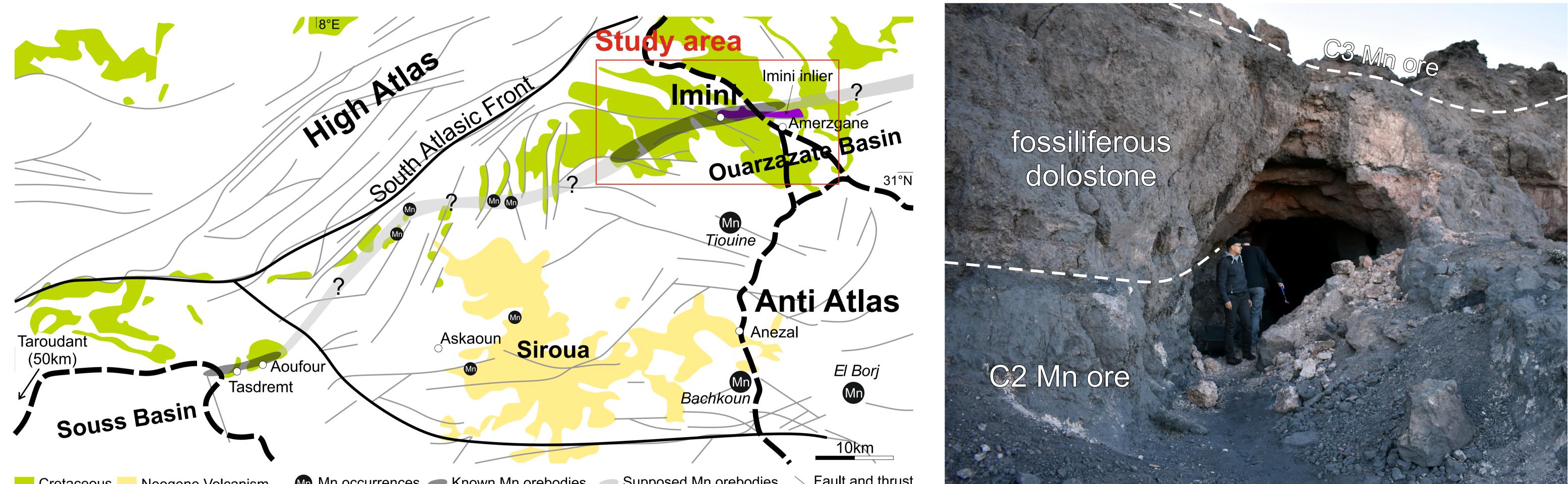
Augustin DEKONINCK^(1,2), Jocelyn BARBARAND⁽³⁾, Gilles RUFFET^(4,5), Yves MISSENARD⁽³⁾, Nadine MATTIELLI⁽¹⁾, Rémi LEPRETRE^(3,6), Abdellah MOUTTAQI⁽⁷⁾, Omar SADDIQI⁽⁸⁾, Michèle VERHAERT⁽²⁾, Johan YANS⁽²⁾

Introduction

The Imini mining district hosts the largest Mn resources of North Africa due to two laterally extensive ore bodies (~25-30 km) of nearly pure pyrolusite (MnO₂). A third medium-grade coronadite-rich (K,Ba,PbMn₈O₁₆) Mn ore occurs discontinuously over a wider area of ~100 km. The two ore types are hosted in a poorly deformed 10-15m-thick Cenomanian-Turonian dolostone unit located in the southern foreland of the High Atlas of Morocco. Until now, the source of the metals and the timing of ore deposition remains unclear for this unconventional karst-hosted deposit.

Objectives and methods

We examine the **Pb** isotope composition of the Mn ores and the most representative country rocks to track down potential sources of the metals. We also study the age of the K-bearing Mn oxides present in the Mn ore by ⁴°Ar/³°Ar. By combining these two methods we are able to produce a consistent model of the ore deposition.



Results

The new Pb isotopic ratios show that Triassic series (basalts and Triassic-Senonian gynsi Fe-rich sandstones) are likely the source of the metals. The 15.67 Cambrian basalt ⁴⁰Ar/³⁹Ar dating of these K-Mn oxides shows that the Mn-rich ore (leached) **D** 15.66 bodies formed during at least three periods: 15.65 late Cretaceous to late Paleocene (>58 Ma) 15.64 late Eocene (c. 36.3 Ma) 15.63 • early Burdigalian to early Serravalian (c. 19–20 Ma and c. 13 Ma) 15.62 These periods coincide with three known Atlas geodynamic CT dolostone 15.61 **deformation** events during late Cretaceous, late Eocene and the 15.60 🛛 18.20 18.40

Early(?)-Middle Miocene. ²⁰⁶Ph/²⁰⁴Ph



Fig. 1 Location map of the Imini Mn district and Mn occurrences in the Cenomanian-Turonian dolostone unit.

Fig. 2 Field photograph of the Lantenois mine showing the high-grade pyrolusite-rich ore (C2) and the medium-grade coronadite-rich Mn ore (C3)

Ordovician shale

of the Imini inlier

Triassic

basalts

(this study)

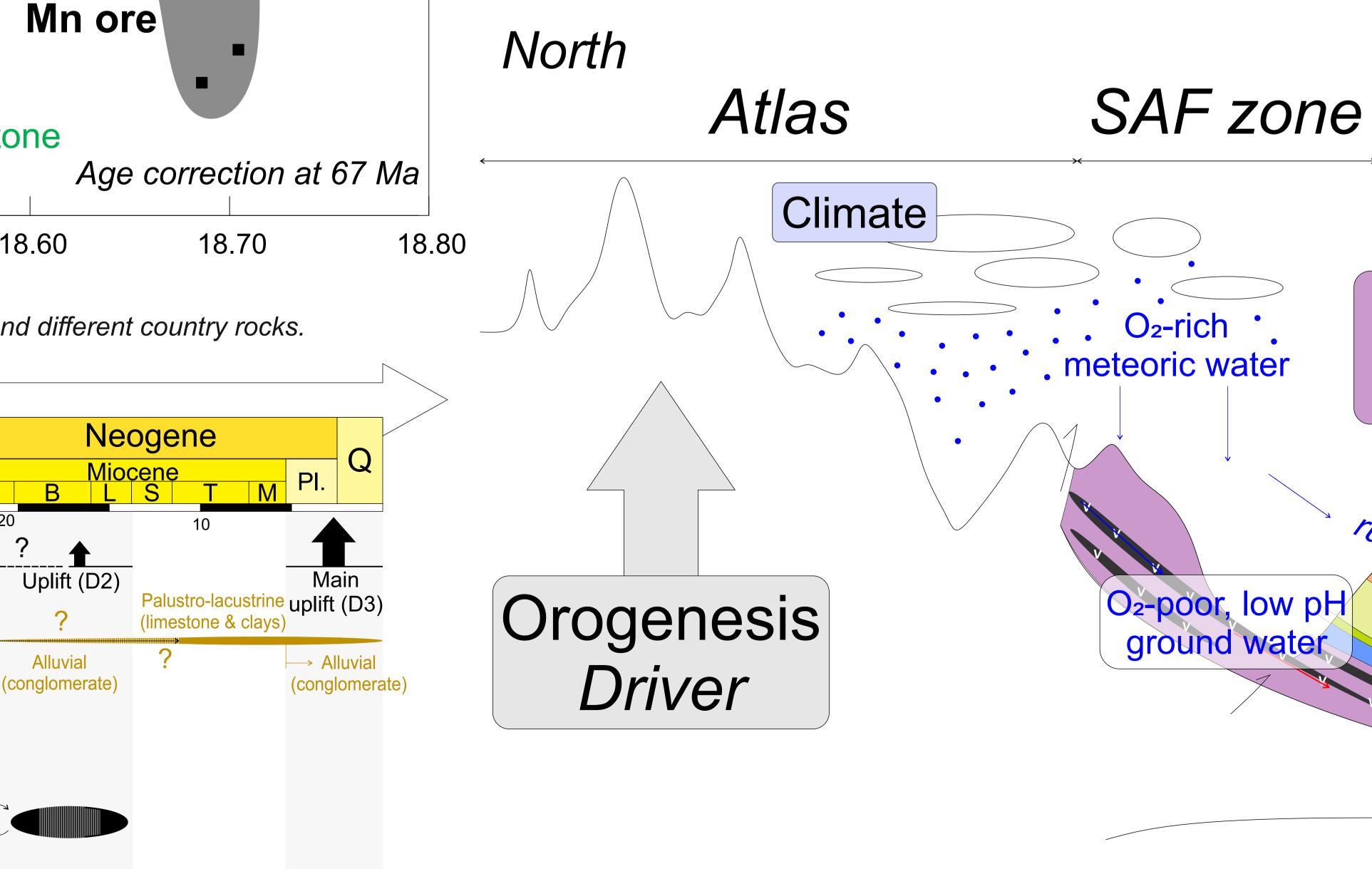
Fig. 3 Pb isotope composition of the Imini Mn oxide ores and different country rocks.

Upper Cretaceous			Paleogene						
TSenonianCSM			Paleocene D S T	Eocene Y L B P			Oligocene R C A		
90	80 Doming (D0)	70	60	50	40 up	lift (D1)	30		20 ? U
Exposure	< Exposure		?		K		Expo	sure	
Interti (evaporites and				Marine (carbonates and m	(200	Fluvial glomerate)			A (cong
Cavity-fillin	<u>ng</u>		→ Fracture-	-filling					
•	Main phase	Distur							
Primary ore Mainly coronadite group						Enrich Mainly p	ment ph <i>yrolusite</i>	ases	

Fig. 4 Chronology chart of Mn deposition based on ⁴⁰Ar/³⁹Ar dating of coronadite group minerals and other events of the area. See the best fit between uplift events and K-Mn oxide ages.

Key interpretations

- Atlas tectonics is the first-order control of the Mn mineralization.
- Periods with regionally high elevations modified the climate to wetter conditions that brought rather continuous supplies of meteoric water to feed temporary aquifers.
- Relief building created the required hydraulic head to sustain (1) fluid-rock interaction between O₂-poor acidic fluids and the Triassic series, (2) migration of the metal-rich fluid and (3) overpressure fluid in the Imini depositional site. • The disappearance of Triassic series in front of the Imini anticline forced these low-temperature (<100°C) fluids to mix with oxygenated ground and alkaline waters resident in the karst system and precipitate Mn oxides. • The N70°-oriented Atlasic tectonic structure controls the orientation of the
- Mn deposits.
- Post-Cretaceous uplifts generated additional supplies and/or in-situ remobilizations of the primary late Cretaceous medium-grade ore to form the high-grade pyrolusite-rich ore in Imini.



Foreland	South Anti Atlas
Triasic Source Structure Trap	, N70° orientation
Mn, Ba, Pb-rich hydrothermal fluid	<i>Karstified</i> <i>olostone</i>

Fig. 5 Formation model of the high-grade Imini Mn ore deposits due to multiple orogenic phases of the Atlas.