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Sedimentary processes in straits based on outcrop analogue and oceanographic data in the rift of Corinth (Greece)

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Tidal straits are narrow passages of water between two larger bodies, dominated and influenced by tidal amplification. The straits are a key area for the transfer of water heat, biota, or sediments. The study of straits' dynamics is based on models and oceanographic data, but the use of outcrop analogues is mandatory to remove the human timescale constrain.

The focus is made on the two straits that have existed in the Corinth Gulf and includes a comparison between the present-day Rion-Antirion strait (W) and the supposed outcrop analogue of the "Corinth Canal" (E). On the one hand, we investigate the Rion strait with an oceanographic survey: ADCP, MBES bathymetry, CTD, and Satellite SST data. This strait revealed a tidal strait influenced by an internal wave and bottom currents from the Gulf of Corinth. The observed bottom currents are fast (from 1 m/s up to 6 m/s) and are erosive in the strait central area. In terms of sediment deposition, no typical strait structures were observed, instead sediments were found veneered on the basin slopes.

On the other hand, thanks to the uplift, the Corinth Canal outcrops over 6 km long and 80 m high. This allows conducting a sedimentological survey combined with a 3D photogrammetric model to bridge the gap between the facies- and the basin-scale. We document the evidence of a tidal strait characterized by conglomeratic tidal dune-bedded structures. These dunes were highlighted both from the facies analysis and from the geometric structures at the canal scale. To form such geometries a tidal strait with a current of 1 m/s to 2 m/s velocity was estimated.

When comparing the two straits, despite their geographic similarities, their hydro-sedimentary model is different. If Corinth fits better with a "tidal strait" model, the Rion-Antirion strait model seems to be much more complex. Both tidal straits document specific oceanographic and sedimentological processes which highlight an internal tide, or a tidal amplification probably caused by the West and East opening of the Corinth gulf 300 ka ago.

Well logging signatures of the geothermal reservoir in Carboniferous carbonate of Hainaut and its cover based on Saint-Ghislain borehole data

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The Hainaut region in Belgium has several deep boreholes for which well logging data are still largely under-exploited. The analogue acquisition of these data and their paper format have greatly limited their quantitative analysis, favouring their qualitative use (Groessens et al., 1979; Delmer, 1988). However, the Mons area has a significant geothermal potential (Licour, 2012), thus the interest in these well logging data is obvious.

In this context, the present master thesis aims at making these data quantitatively usable and to develop a prospective study of the well log signatures of the geothermal reservoir in the Carboniferous limestones of Hainaut and its cover. Efforts were focused on the exploitation of the logs from the Saint-Ghislain borehole.

Firstly, this master thesis begins with a short presentation about the general context of geothermal energy in the region of Mons and the borehole of Saint-Ghislain. Thereafter, data are collected, digitised, and exported in the standard "LAS" format. This required the development of an original methodology for the valorisation of scanned log curves based on specific Python codes. This methodology, which can easily be adapted to other boreholes, has demonstrated the importance of considering the correction of offsets between successive well logs, their resampling on a regular depth meshing, and the correction of deformations linked to the original medium.

Then, this work is devoted to the prospective analysis of the well log signatures of the study area. Beforehand, the geological log was digitised and integrated into the subsequent processing. An additional correction of offsets between well logs and the geological log was also applied.

Finally, the Saint-Ghislain well log data were analysed from both a qualitative and quantitative point of view. The digitised data were subjected to a univariate statistical analysis, followed by a statistical analysis of trends in moving windows. Then, for each geological formation thrown by the borehole, discriminating and identifiable responses combining the

different well logs were highlighted based on a qualitative examination of the well log signatures. This examination was completed by a principal component analysis to synthesize the data by replacing six well log variables by two principal components. Finally, based on logging responses in documented parts, the K-means clustering algorithm was implemented to infer lithologies in the 560 m of non-cored intervals of the borehole.

At the end of this work, a series of results were obtained that clarify and question, with supporting data, previous assertions. Some lithostratigraphic attributions in non-cored intervals and the location of the karstified zones have been refined from former geological descriptions of Groessens et al. (1979). Furthermore, the total thickness of the massive anhydrites is now estimated at 294.6 m, halving some estimates made previously (e.g., De Putter et al., 1994).

Finally, an interesting perspective would be to apply the log curves valorisation methodology to well logs of other boreholes, such as those of Douvrain, Condée-sur-L'Escaut or Jeumont-Marpent. The production of a database gathering exploitable numerical data from well logs in the studied area would allow further univariate and multivariate statistical studies. This database could also be used to monitor future borehole and geothermal project with predictive logs and to highlight lateral variations encountered in the Dinantian reservoir in the Brabant Parautochton.

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Mapping and modelling riverine sand mining at the sub-continental scale: a case study for India

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Throughout the world, sand is mined from rivers. This is especially the case in the Global South where rapid urbanization leads to a huge demand for sand (Torres et al., 2017; Bendixen et al., 2019). Although riverine sand mining (RSM) can be an important source of income (e.g., Farahani & Bayazidi, 2018), it can also have many negative impacts, particularly on the environment (Koehnken et al., 2020). The volumes of extracted sand may far exceed the natural rate of replenishment of rivers and can result in local sand scarcity (Bendixen et al., 2019). To avoid this problem, efficient policies for sustainably RSM practices need to be put in place. However, important knowledge gaps currently exist hampering the development of such policies. For example, very few data exist on where and why RSM occurs on larger scales. This thesis aimed at helping address this research need by providing more insight into the spatial patterns of RSM at the subcontinental scale of India, a country where RSM occurs at a massive scale. The specific objectives were to: (1) develop a systematic mapping procedure to collect the first representative dataset on RSM at the scale of India; (2) use this dataset to identify potential controlling factors of RSM through statistical analysis; and (3) develop a statistical model to estimate the probability of RSM occurrences.

The systematic mapping procedure was developed by randomly selecting river reaches and scanning their entire length for visible signs of RSM, using high-resolution satellite images in Google Earth Pro. In total, 1504 RSM sites were mapped, along 420 reaches with an average length of 22 km in India. GIS and statistical analyses of this dataset allowed to identify possible driving factors of RSM. First, our analyses indicated that RSM is indeed mainly driven by urbanization. Conversely, the spatial patterns of RSM appear to be largely independent of patterns of river sediment transport and of the soil texture around the considered river reach. Yet, according to our analysis, RSM is more likely to occur where the access to the river reach is easy, which depends on the topography and the seasonality of rainfall patterns. Building on these results, we constructed a logistic regression model that estimates the likelihood that RSM occurs along a given reach based on four variables (percentage of build-up area in a buffer around the river reach, relative changes in population density over the past five years, the coefficient of variation of monthly rainfall and the slope steepness of the river reach). The model had an acceptable accuracy (AUC of ca. 0.70) and allowed to construct the first probability map of RSM occurrences in India.

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Evaluating contact hysteresis in porous rocks based on micro-CT imaging data: a study on pore-scale fluid displacements during imbibition in porous media

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Multiphase flow in porous rocks plays a key role in CO_2 sequestration, groundwater remediation and petroleum reservoir management. In the subsurface, drainage and imbibition typically take place at low capillary numbers, meaning capillary forces dominate the pore-scale behaviour. The fluid displacement is then strongly influenced by the wetting properties of the pore walls, which is typically characterized by defining an effective contact angle. Methods have been developed to measure contact angles inside of rock, using pore-scale images. The first approaches used micro-computed tomography (micro-CT) images of fluids in the pore space which had reached equilibrium (Andrew et al., 2014; AlRatrout et al., 2017). This led to contact angle distributions which were unexpectedly wide (Andrew et al., 2014; AlRatrout et al., 2017), making interpreting results and using them in pore-scale models challenging (Blunt et al., 2019). Recent work has shown that this problem can be addressed by locating the meniscus movements in time-resolved X-ray images and measuring contact angles locally at the time of movement (Mascini et al., 2020). This dynamic approach was used to characterise drainage, but it has remained unclear whether it could be used for imbibition, which consists of more complex displacement processes (Lenormand et al., 1983). Consequently, the aim of the work presented here is to gain insight into the process of imbibition by analysing contact angles and assessing the differences between imbibition and drainage via dynamic approaches.

In this work, imbibition is considered as a sequence of pore fillings of different types: piston-like displacements, snap-offs, and cooperative pore-filling events (Valvatne & Blunt, 2004). A contact angle analysis was performed on a time-resolved micro-CT dataset of imbibition in a glass bead pack (Schlüter et al., 2016). Contact angles were measured locally by measuring the geometric contact angles in and around pores at the time of filling. The effective contact angles linked to the curvatures of the menisci at the time of filling were also determined. The methodology was adapted from Mascini et al. (2020). To complement these measurements, thermodynamic contact angles (Blunt et al., 2019), as well as the conventional geometric contact angles measured on a fluid distribution at equilibrium (AlRatrout et al., 2017) were determined. A capillary pressure model was used in order to link the capillary pressures to the contact angle, the geometry of the pore space, and the distribution of the fluids at the time of displacement (Ruspini et al., 2017). These results were compared to measurements on drainage of the same sample (Mascini et al., 2020) to quantify hysteresis (i.e. the differences between imbibition and drainage seen in the same sample).

The results reveal that the local geometric contact angle distribution is narrower than that of the other types of contact angles. This suggests that the hinging of contact angles that occurs during imbibition results in narrower distributions of contact angles when they are measured locally at the moment of movement. Comparing imbibition to drainage on a pore-by-pore basis reveals an 8° contact angle hysteresis for this sample. Capillary pressure hysteresis is clearly evident. Contact angle hysteresis is estimated to account for approximately 30% of the capillary pressure hysteresis seen in this dataset.

In this thesis, the contact angles and capillary pressures during imbibition are compared to those during drainage. Dynamic methods are used which make interpreting the results and seeing the differences between these two fluid flow processes easier. Understanding how imbibition and drainage occur and being able to quantify hysteresis are important for modelling fluid flow in the subsurface which has implications for contaminant transport, subsurface energy storage, geological carbon dioxide sequestration, etc.

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Evolution of the Andaman Basin: geochronological constraints from its eastern (Myanmar) and western (Andaman Islands) margin

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The highly oblique convergence of the Indo-Australian and the Eurasian tectonic plates, along the Sunda Trench in Southeast Asia, initiated the formation of an active back-arc extensional basin in the Eocene: the Andaman Basin (Curray, 2005). The tectonic activity in the present-day basin is dominated by strike-slip motion and a spreading centre that has been active since the mid-Miocene (Morley & Searle, 2017). The Andaman Basin now links the Sagaing Fault, the West Andaman Fault, and the Sumatran Fault Systems, and separates the West Burma Block

from Sibumasu (Morley & Searle, 2017). These aforementioned continental blocks were accreted onto the east-facing Pacific margin of the Eurasian Plate during the closure of the Meso- and Paleo-Tehys Ocean Basins between Gondwana and Asia (Metcalfe, 2017).

The geological and tectonic history of the Andaman Basin is closely related to the history of Myanmar and Thailand at its northern and eastern margin, the Andaman-Nicobar Islands in the west and Sumatra in the south. Insights based on geochronological constraints from these regions can therefore aid in reconstructing the formation mechanisms and evolution of the Andaman Basin and its adjacent regions.

The Late Cretaceous Andaman Ophiolite crops out along the east coast of the Andaman Islands. This unit consists of mantle sequences, oceanic crust units, and diorite-plagiogranite veins (Bandopadhyay & Carter, 2017). Plagiogranite and gabbro-diorite samples were taken from outcrops in South and Middle Andaman.

In Myanmar, two principal magmatic belts extend southwards into the Andaman Sea: (1) the Mogok-Mandalay-Mergui (MMM) Belt; and (2) the Wuntho-Popa Arc (WPA). They are separated by the Sagaing Fault, which divides the Myanmar basement in two. Gardiner et al. (2015) proposed a model in which an Andean-type margin developed on western Sibumasu during the Cretaceous, due to subduction of the Neo-Tethys. While subduction-related I-type magmatism intruded western Myanmar (to form the WPA), S-type granites were emplaced in central and eastern Myanmar (MMM Belt). Granites and gneisses, outcropping along the Sagaing Fault, were sampled from the MMM Belt.

The LA-ICP-MS U-Pb dating technique was used on zircons (ZUPb) and apatites (AUPb) to gain information on the timing of their formation and crystallization. This was combined with the apatite fission track (AFT) thermochronology dating method, which gives an insight into the upper-crustal and near-surface evolution of the samples. Unfortunately, AUPb and AFT ages from the Andaman Islands were influenced by the low quality, quantity, and U-content of the apatites. Due to the high uncertainties on these specific ages, they have to be treated with caution.

Thermal history reconstructions could be made for the Andaman Basin, the Andaman Islands and Myanmar using the acquired ZUPb, AUPb, and AFT ages. ZUPb ages of 93.4 ± 0.3 Ma and 97.3 ± 0.3 Ma were obtained from the plagiogranite veins (Andaman Islands). Therefore, spreading of the Andaman Ophiolite probably occurred in the Late Cretaceous, when a subduction zone setting was established between the subducting Indo-Australian Plate and Sibumasu. According to Plunder et al. (2020), supra-subduction zone (SSZ) spreading of the mantle rocks and gabbroic crust already occurred around 106 Ma. The SSZ setting later evolved into a matured arc system, accompanied by the intrusion of plagiogranites. The data from this research thus suggests that the magmatic arc was active until at least ~93 Ma. The Andaman Islands afterwards collided with Sibumasu, when the magmatic arc was no longer active.

In Myanmar, the ZUPb and AUPb data from the granites and gneisses recorded phases of I-type Late Cretaceous and Eocene I-type magmatism, as well as latest Cretaceous S-type granite emplacement. This suggests the presence of an Andean-type subduction setting (subduction of the Indo-Australian plate underneath Sibumasu) in Myanmar during this period, as was proposed by Gardiner et al. (2015). The gneisses indicated that the compressional forces associated with this subduction setting resulted in several phases of metamorphism throughout the Late Cretaceous and Eocene–Oligocene.

At the end of the Eocene, the Andaman Basin started opening (Curray, 2005). The AFT ages from both the Andaman Islands and Myanmar suggest a phase of exhumation around the Oligocene–Miocene transition (~27–22 Ma for the Andaman Islands, ~27–19 Ma for Myanmar). This could be interpreted as the response of SE Asia, i.e. accommodating for transpression along the convergent margin by a series of strike-slip faults, to the collision between India and Eurasia.

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Mineralogical and geochemical study of sedimentation in Central Mexican crater lakes

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This study investigates the sedimentary sequences of Mexican crater lakes as climate-sensitive archives of past environments. Crater lakes are closed hydrological systems, highly sensitive to weathering and climate conditions (Newton et al., 2005). They contain proxies of the weathering of nearby rocks and soils that can provide information about changes in precipitation during the last thousands of years. Here we focus on the sedimentation record of two maar lakes situated in the State of Michoacán, in Central Mexico, as this region is highly sensitive to climate variability (Holmes et al., 2016).

At present the tropical climate of Mexico is dominated by the North American Monsoon (NAM), with a rainy season linked to the northward migration of the Intertropical Convergence Zone (ITCZ) (Caballero et al., 2016). The strength of the summer monsoon is affected by the El Niño-Southern Oscillation (ENSO). ENSO is a pseudo-periodic climate pattern involving variations in sea surface temperatures and winds over the eastern Tropical Pacific but with worldwide consequences

on multi-annual climate variability (Caballero et al., 2016). Some of these atmospheric phenomena are still poorly understood, but will be affected by climate change and have meteorological impacts on many locations around the globe, and are thus crucial to study.

The two maar lakes studied are Los Espinos and Tacámbaro, both located within the western Trans-Mexican Volcanic Belt, in the Michoacán-Guanajuato Quaternary Volcanic Field (Ortega-Guerrero et al., 2021). According to their key location, the mechanisms which control interannual variability in Mexican precipitation are complex but interesting to reconstruct. For this purpose, two short lacustrine sediment cores (LLEs19-2, 53 cm and LTa19-3, 94 cm) were retrieved in spring 2019 with a manual Uwitec© coring system. The sediments have been described by macroscopic and smear slide observation and analysed for physical (magnetic susceptibility, grain size distribution by laser diffraction, loss-on-ignition for water content and organic matter abundance), mineralogical (X-ray diffraction on bulk and clay fraction) and geochemical (X-Ray fluorescence, C/N for organic matter origin) parameters with variable resolution. Sedimentation rate and dating of the short core are currently being measured with ^{210}Pb and ^{137}Cs geochronometers.

Continuous SCOPIX X-ray imaging system and XRF Core Scanner performed at 2 mm resolution evidence a finely laminated sediment with a few coarser and darker layers. A robust PCA was applied to SCOPIX and XRF core scanner data to identify the different sedimentary components (detrital, volcanic, or biogenic) and to link the sedimentary grey-scale levels with specific geochemical elements (e.g., Ti) or element ratios. Mineralogical assemblages and geochemical composition of the sediments were used to reconstruct the type (physical or chemical) and intensity of the weathering processes, both controlled by precipitation abundance. By applying the age model of recent sediments, the XRF elemental data or elemental ratios will be compared with regional meteorological data to validate any geochemical proxy for rainfall intensity in complement to XRF-Ti signal that was already used in former paleo-ENSO studies (e.g., Newton et al., 2005; Ortega-Guerrero et al., 2021).

In Lake Los Espinos, geochemical proxies linked to the detrital elements indicate two periods with higher precipitation (between 10 and 15 cm and between 33 and 37 cm) interrupted by a drier period with higher productivity (between 16 and 30 cm). In Lake Tacámbaro sediments, geochemical proxies show rapid successions of higher and lower precipitation up to 59 cm. Tephras levels were supposed at 49–51 cm and 58 cm.

Any validation of the sedimentary proxies would request a calibration with instrumental data retrieved from local meteorological station. Proven weathering proxies could then be used to study past climate changes on longer cores, with the help of complementary proxies such as biological ones (i.e. diatoms). The approach is currently being further applied to several crater lake sequences within the framework of the FNRS-funded HolMeCl project.

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The nine young graduates who presented the results of their master thesis during the Master Day organized this year in Namur. They come from UGent, ULiège, KULeuven, and UMons.

The award winner of the Master Day receiving his diploma from the president of Geologica Belgica.