Sedimentary Ripple marks from pavements of forts in Jaipur, Rajasthan. India

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Abstract

Ripple marks and their patterns are strongly indicative of the depositional energy in fluvial, coastal and shallow-marine environments. Prolific occurrence of a variety of ripple trains in popular forts of Jaipur are observed during a tourist visit. These extensive ripples are described using few standard measures and methods through interpretation of their digital images. The objective is to elucidate the variety and extent of the observed samples and to bring forward their measurement and interpretation possibilities . The importance and convenience in detailed systematic study of sedimentary structures towards quantitative sedimentology is explained . These easily accessible and interpretable structures are significant in teaching and research of sedimentology and stratigraphy. The occurrence of such vast treasure of sedimentary record at very accessible and convenient locations is highlighted.

Introduction

Ripple marks are sedimentary structures produced by the interaction of waves or currents with the material on the sediment surface. They are formed in modern sedimentary environments by the small-scale processes that reshape the sediment into undulatory surface by systematic binning and motion of the loose particles. Found commonly in a great variety of scales and processes, ripple marks are seen from the active sedimentary systems to the most ancient rocks in Geology. Live and actively forming ripples can be seen in rivers, lakes, beaches, sea-floor, in wide variety of shapes, sizes, frequency and rate of formation. Ripple marks from tide and wave dominated coastlines are well reported from Archean to Recent.

Ripple marks are transient surface shapes formed by the solid material of sediment interacting through short-duration movements responding to the energy and motions of the fluid (water). The preservation of this dynamic surface in rock record – from the oldest to the youngest in earth history is a most validating evidence for the Law of 'Uniformitarianism'. The study of ripple marks, their process and interaction with the medium is a powerful and experimentally verifiable process-sedimentology approach.

Extensive and highly variable ripple marks are observed along the walk-ways and flooring slabs of two famous forts – Nahargarh and Jaigarh, in Jaipur. It is a museum of ancient ripple marks within a human edifice. The Geology of these forts, and the sedimentary successions are examined from literature to position these ripple marks in stratigraphy. Basic classification and few measurements are done on the digital image data of these ripples to report their variety and range. Importance and value of this extensive sample in teaching and research of Geology are pointed out to encourage more formal study and characterization of this magnificent sedimentary exhibition.

Objective & Scope

1. Report the occurrence of a wide variety of ripple marks in sedimentary rocks used for building walkways within the famous ports of Jaipur
2. Refer to the Geology of the area to identify the most likely source of the sediments
3. Demonstrate the variety of samples through a classification and comparison of these ripple marks using simple metrics and measurements.
4. Provide an overview of the studies on ripple marks, identify the gaps and show opportunity for studies in Sedimentology, Stratigraphy and Paleo-Environment analysis.

Observation and Record

Location – 1: Nahargarh fort – walk-way from the Jaipur Wax museum to Padao restaurant (Δ560m, 26°56'14.8"N 75°48'43.6"E).

Location – 2: Jaigarh fort – the walk-way to Jaivana Cannon (Δ596m, 26°58'28.80" N 75°50'22.36" E). {elevations are taken from http://www.mapcoordinates.net/en for the locations}

A large number of sandstone slabs with extensive ripple marks are seen in the entire length and width of walk-ways in these two locations. In extent, variety and clarity they are among the best collection of sedimentary ripple marks in one location.

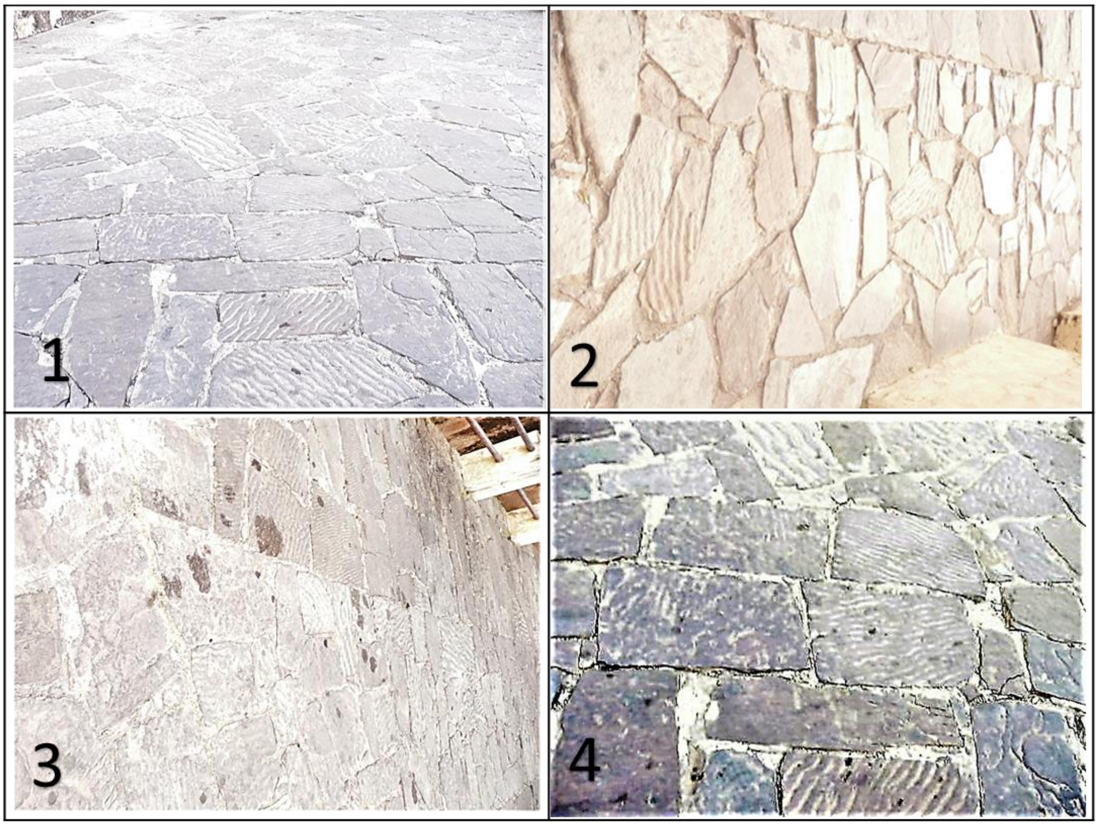

Figure 1 Ripple Ripples everywhere! View of the walk-ways in the Nahargarh and Jaigargh forts. Practically every slab is a unique ripple structure. These two locations have few hundreds of diverse and well preserved ripples among the walk-way slabs. It is possible that the ripple mark surface – a bedding plane favouring breaking into neat slabs led to such a large collection.

Photographs of some of these structures are taken with simple personal camera in near orthogonal angle under existing natural light. These are then classified according to the ripple pattern. One of the samples is processed for extraction of edges and manual mapping of the ripple parameters using the photograph scale (coin) as an example.

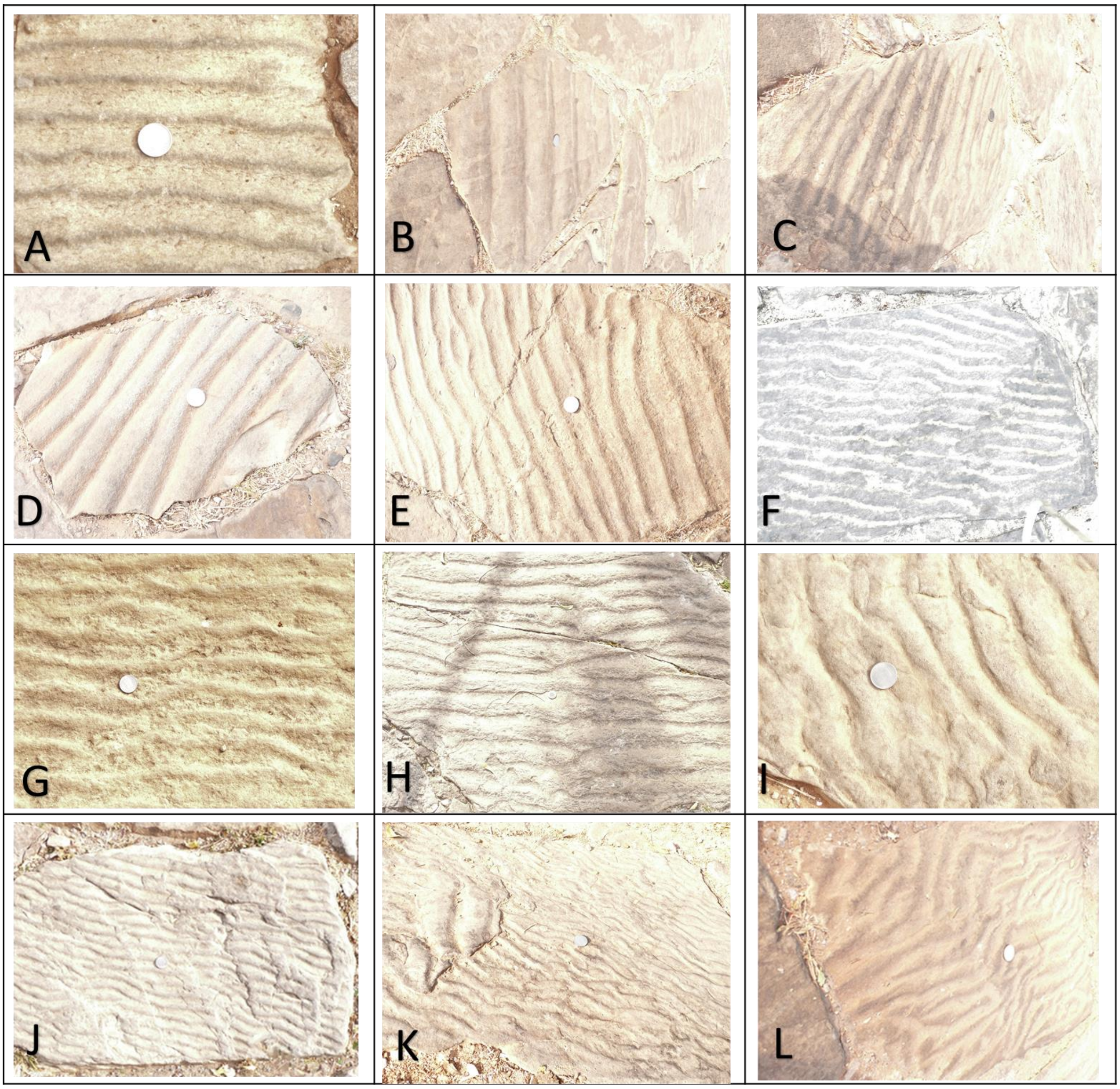

Figure 2 Representative ripple marks from the walk-ways of Jaipur forts. They are placed in order of increasing energy from - Small Straight current ripples(A-C), Sinuous (D, E, F), connected Linguoid (G, H) to wave ripples (I, J). The Superimposed ripples with out-of-phase crests are seen (K & L). Samples D and F are from Jaigarh fort, while the others are from Nahargarh fort.

Geology of Jaipur forts

Jaipur (26.9124° N, 75.7873° E) is described in a Geological map published by Geological Survey of India in 2002 (Jaipur Quadrangle, toposheet number 45N, Accession No GSM-45-N-03, 22-10-2008). The two forts of Jaipur are mapped as Pratapgargh Formation of Alwar group from Delhi Super Group (DSG). The DSG is Lower to Middle Proterozoic in age and consists of metasedimentary rocks. The Pratapgarh formation consisting of quartzite, quartz-mica schist, dolomite and amphibolite are well exposed in the forts NE part of Jaipur. The beds forming the Jaigarh fort (∆596m) and Nahargarh fort (∆ 560m) dip in different directions (30^o -50^o SE in Jaigarh and 30^o -35^o N in Nahargarh). The exposures of these native rocks can be seen along the fort sides and in excavations made within the fort walls.

The Geology of Rajasthan (Gupta, B.D. 1964, Geological Survey of India report, 2011) describes a variety of sedimentary successions in and around Jaipur displaying well-formed sedimentary structures and ripple marks. The formations within these 2 forts, are formed in a Proterozoic basin named as Alwar-Jaipur basin. The sedimentary sequences were deposited in fluvial and marginal marine environments. However, these rocks have been subjected to low-medium grade metamorphism. Gupta (1964) recognised the finely bedded quartzite with individual beds forming less than 10cm having current bedding and ripple marks.

DSG, Proterozoic Jodhpur Sandstone and younger Vindhya Super Group have multiple formations with well-developed ripple marks. Chauhan et.al (2004) have presented a similar record of 'prolific development of wave ripples and related structures' from Jodhpur sandstone. Gupta (1964) reported prolific development of cross-beds and ripple marks at all levels of Upper Vindhyan, Kaimur Sandstone (Chittorgarh fort, Rajasthan), Panna Shale, Indargarh Sandstone (L. Rewa Sandstone) and Jhiri Shale (U. Vindhyan). Multiple series of short transgressions and regressions are interpreted from these formations.

This paper reports extensive and easily accessible samples of well-preserved ripple marks from the forts of Jaipur.

Ripple Marks in Teaching and Research

Ripple marks are among the earliest Sedimentological structures described in scientific journals. The earliest scientific record are traced to Upper Ordovician (Richmond Group) large ripples of Ohio (Locke, 1838, p246). Their description, classification, interpretation and process-response models are studied by numerous workers. Earliest formal descriptions and process-sedimentological inferences from ripple marks are seen in the works of Bucher, W.H, 1916, 1917 and 1919. Over these 100+ years, the study and use of ripple marks holds active scientific interest with most recent work coming from Davis et.al (2017). The role of microbial mats and biofilms in sculpting the sub-ripple-scale sedimentary textures are now recognized.

The samples from Jaipur fort can be used effectively in teaching and research. Few clear avenues are presented.

1. Description and Classification
2. Metrics, Parameters and Modelling
3. Process Sedimentology: Forward and Inverse Models

1. Description

A ripple is conventionally described using various terms of vertical and lateral profile representing its size and shape. Ripples are further described depending upon the nature of the crest in to – i) Straight, ii) Undulatory, iii) Linguoid, iv) Cuspate, v) Lunate or iv) Rhomboid. Ripple trains (group of ripples as seen in the samples of this study) may form in-phase or out-of-phase undulations. Ripple marks occur in 4 orders of sizes from millimetre scale to 10s of meters. The samples reported from Jaipur fort are 2 orders of sizes and scales.

Most of the classification of ripple marks are based on their mode of origin. The shape, size and origin are often combined in classification schemes (Figure 3). A visual and descriptive match to the reference forms is attempted for each of the 12 selected ripples from Jaipur forts.

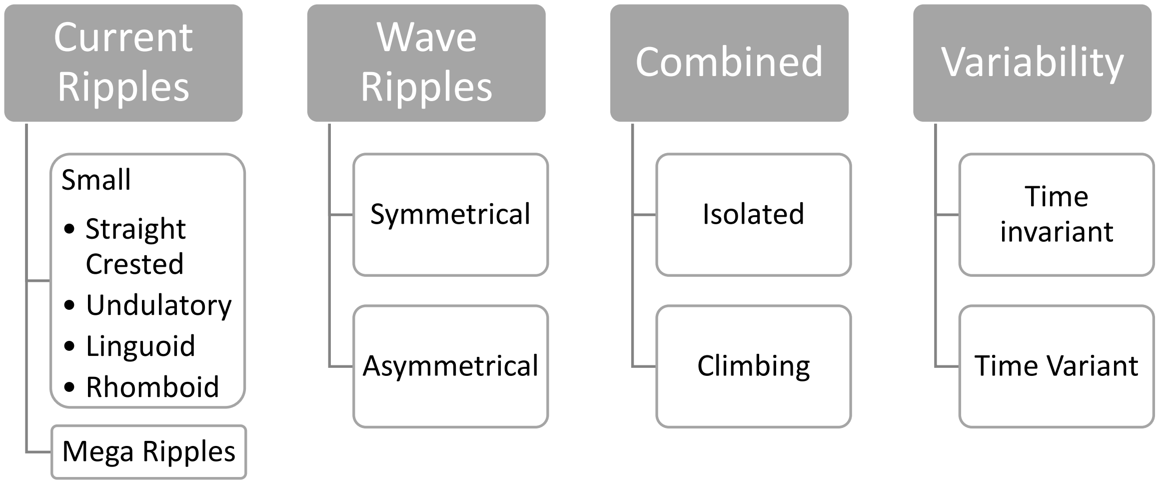

Figure 3 Classification of Ripples based on their mode of origin and temporal development

Classification of Observed Ripple patterns

The randomly picked samples of Ripple Structures show 4 main classes of ripples. Each of them have a refined diagnostic overprint of their depositional environment and represents distinctive energy and particle-size parameters of formation.

1. Unidirectional Current Ripples:

Straight and weakly sinuous. Symmetric Wave ripples with pointed crests and rounded troughs. Laminae are in one direction - Direction of wave propagation (orthogonal to ripples). Change in curvature on either side is very symmetrical and could be from weak transition between low-medium energy. Represents Low energy environment. Figure 2 A, B and C are representative of this group

2. Undulatory Small Ripples:

Sinuous Undulatory crests are clearly developed. The undulations are sometimes ‘in-phase’ and go ‘out-of-phase’ within the same ripple train. Crests are largely continuous. The lobes and saddles are not always in same line – and show a transition trend. Represents Medium energy environment. . Figure 2 D shows the transition from Unidirectional ripple to undulation by symmetrically developed curvature on either side. Figure 2 E and F are classic undulations in ripple train.

3. Wave Ripples:

Wave ripples are formed by the oscillatory motion of water under each passing wave. The ripples are sinuous crested. Symmetric and Asymmetric organization can be seen (Figure 2 G and prominently in 2 I). Linguoid ripples can be seen in parts of the Figure 2 H and 2 K. At places, discontinuous crests can be observed in Figure 2 H.

4. Sinuous Superimposed Ripples:

Figure 2 I is very similar to Sinuous ripple whose structure is formed by migrating, asymmetry-reversing bedforms with sinuosity migrating along crest. Figure 2 H is more symmetric wave ripple train in equilibrium form. Bifurcation, truncation and variable thickness of individual laminae can be seen in Figure 2 K and 2 L.

Faceted Classification and Pattern Recognition

Faceted Classification (Ranganathan, 1967; http://facetmap.com/) of ripple mark morphometry and origin is a significant gap area after nearly 200 years of study. The samples from Jaipur fort can be conveniently used in developing one or more schemes of classification. The use of computer based pattern recognition and classification of sedimentary ripple marks, is another potential high-impact inter-disciplinary research area.

2. Metrics and Parametric data

There is large variety and number of well-preserved ripple structures in these forts. Systematic measurements on these samples is identified as a useful teaching and research opportunity. An example measure is made using the digital photograph and presented (Figure 4). This sample has Ripple Distances between 3-6cm (~4cm average); Bifurcation Index value of 0.38; Parallelism Index of 0.44 and Uniformity of form Index value of ~0.5. Tanner (1967), Reineck and Singh (1980, p35) and Diem (1985) provide the descriptions to various measures and their use in quantitative interpretation.

More formal methods using Digital Signal Processing (DSP), Feature detection, Edge extraction and other Image processing methods can also be taught and practiced.

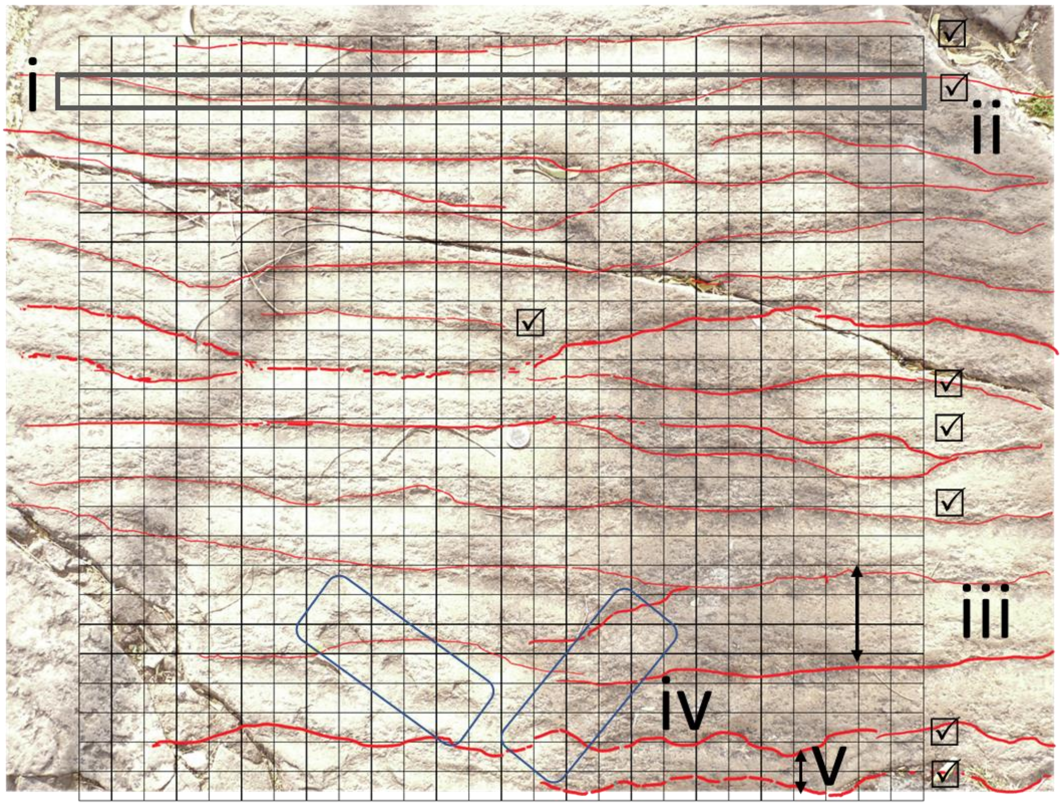

Figure 4 Template for measuring the different Ripple Parameters. (i) to (v) are pointers to the metrics taken from the image. The metrics are generated using an approximate 2x2cm grid and scaling it. Sample is ~60x52cm size. i: Parallelism index bar; ii. Parallel ripple marks ☑; iii. Maximum ripple distance; iv: Linguoid ripples among Asymmetric bifurcated wave ripples; and v: Minimum ripple distance

The scientific literature on Ripple marks and Sedimentary structures is devoid of any database of ripple parameters. Database is a formal technology for organizing and storing the data (measurements) such that their structure and semantics are captured for consistent analysis and interpretation. Databases have evolved as the foundation for the modern Data Intensive Scientific Methods. The large number of samples reported from Jaipur forts are good candidate to develop a database of ripple structures and measurements.

3. Process Sedimentology. Forward and Inverse models

A systematic measurement of the large number of ripple structures and a database opens avenues for studies, teaching and research on quantitative Process Sedimentology.

Kaneko and Honji (1979), Arnott and Southard (1990) have used sample measurements on ripples, numerical simulation and experimental sedimentology to infer Process Sedimentology. Diem (1985) developed analytical expressions for evaluating paleo-depth and paleo-wave conditions from wave ripple mark measurements. Using grain-size, ripple spacing and ripple shape data, the model is developed and tested. The results include: i) Wave ripple marks as predictive tool for epeirogenetic movements; ii) Local paleo-wave climate trends (marine to non-marine transitions); and iii) Regional paleo-wave trends – storm deposits and basin shape. The predictive power of these reconstructions in quantitative paleo-environmental interpretation are brought forward. Das (1988) generated 3 functions to describe – i) Growing, ii) Optimum and iii) Decaying ripples. A Ripple function 'Ψ_R' describes ripple geometries. This clearly demonstrate the approach to 'inverse model' from ripple geometry to optimum ripple process parameters.

Advent of modern Data Intensive Scientific Discovery methods (DISD) open a wide spectrum of new theoretical and process insights from large quantities of measured data in databases. Tony Hay (2009) provides examples of modern scientific advancements using DISD.

The role of life-forms in building, preserving and altering the ripple marks is discussed by Altermann (2002). Kulkarni and Borkar (1996) reported trace fossils and meandering trails along the epirelief of the upper surface in rippled Bhander Sandstone (VSG). and Davies et.al (2017) studied sub-ripple-scale sedimentary structures and identified the role of microbial mats and biofilms in sculpting and mediating the forms.

Samples from Jaipur forts, reported in this note can become valuable repository for these detailed studies.

Sequence Stratigraphy

Grabau (1917) discussing the presentation of Bucher (1916) on 'giant ripples' and their paleogeography asked clarification on the 'time lapse' for preserving the exposed ripples in sedimentary record. He ascertained, rippled beach sands always contain organic remains. Ripple structures which form on active modern systems become a rock record when the undulated surface is lithified and created as a hard surface and preserved, before subsequent sedimentation. The hiatus or non-deposition leading to a distinctive sedimentary surface – is in principle a high-order sequence stratigraphic boundary. It is a Sequence Boundary of some 10^{th} or higher order, indicating a relatively small time-interval of non-deposition involving a 'small duration' transgression-regression of a sub-basin or depositional sub-system scale.

Rapid transgressions and regressions are interpreted in many studies of ripple marks (Gupta, 1964). Short time (<20000 year) lithofacies evolution of the Meghna estuary (Meghna-Padma river system) points to the 24-48km drift and course change to the fluvial system (Roy et.al 2005). There is sufficient evidence of high frequency changes (intensity, direction and hiatus) during the formation and preservation of prolific ripple structures seen in numerous formations.

The time lapse and its impact on the paleogeographic interpretation is largely overlooked in interpreting and integrating the variable current trends observed from ripple marks and other sedimentary structures. Under good sampling and data conditions, high resolution paleo-ecological and depositional energy interpretations are conceivable. Basin reconstructions from such high-resolution models (their data and methodology) are valuable for assessment of climate-change impact in next 100 years (Schlager, 2000).

Discussion

A Geological Sample is commonly collected from the place of its formation (in-situ) giving location, datum and stratigraphic level. Transported samples, like the ones reported in this note, do not have any locational information. Meteorites are samples collected at arbitrary locations and studied scientifically. Such samples are capable of providing reliable and useful information in many areas of investigation. They are valuable in developing – i) metrics/ measurements, ii) morphometric classification; iii) methodology development; iv) parametric inter-relationships; and v) process – response modelling.

A systematic measurement of the large number of ripple structures in Jaipur fort has good potential to support Sedimentology – teaching, research and discovery.

Conclusions

This study is prompted by the observance of hundreds of rippled sandstone slabs in the walk-ways of Jaipur forts. The objective was twofold: i) To report this distinctive repertoire of ripple-marks and ii) demonstrate the ease (and value) of doing effective scientific work using them.

In demonstration of the variety and value, a basic classification of few samples and a measurement are shown. There are good variety of morphometric patterns among these samples. Quantitative sedimentology is possible from generating standard metrics and a quality database of parameters from these ripple structures.

The Geological community within easy access to Jaipur fort can convert these artefacts into a valuable scientific resource. Teaching, Student projects and Advanced research can be conceived around this unique and easily accessible sedimentary structure museum.

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List of Figures

Submission, Review history

Submitted to Journal of the Geological Society of India (JGSI) on May 17, 2017. Ref.: Ms. No. JGSI-D-17-00116R1. The paper was not accepted as 'These ripples have been already reported from this area. There is nothing new in this paper and there is no interpretation from the present investigation.'

1. *There is no report of swarm of ripples in the pavements of Jaipur fort.*
2. *As the sample locations are unknown, it is not possible to do any formal interpretation.*

Revision & Response to Review

20-04-2017

Updated manuscript submitted 17-05-2017.

"Reviewer #1: Author needs to present the research problem, gap areas in the subject and then provide detailed analysis of ripples. What is new in this paper? It is not clear from this manuscript. Authors should present what is the new methodology and new findings. It is more like a report at this stage"

Review Points and Changes (Summary):

1. More like a Report
    a. Spirit of this observation is correct.
    b. The submission is INITIATED to REPORT – the unique and prolific occurrence of Ripple marked sedimentary slabs.
    c. This is clearly pointed out in many parts of the submission:
        i. Title : Drafted more as a report than as any study → No change
        ii. Abstract: Points to 'Observation', 'Basic Description' to substantiate the observation and 'Importance' of the observation to further 'teaching and research' → No Change
        iii. Introduction—Objective & Scope : Originally the 4 points identified the limits fairly. It is now modified to make it more 'explicit' → Modified
2. Research Problem:
    a. The entire paper is presenting a 'Research Problem' / 'Research Opportunity' statement.
    b. This observation is noted and modifications are made in 4 sections of the writeup – Objectives & Scope, Introduction, Research and Teaching and Conclusions → Modified
    c. Figure captions are revised for Figure 1, 2 and 4.
3. Gap Areas
    a. Point is taken for → major revision
    b. Under the modified and reorganized section – "Ripple Marks in Teaching and Research", major gaps are clarified
4. Detailed Analysis
    a. NO detailed analysis of the samples is done or any such claims written.
        i. Objectives & Scope clarifies
        ii. In clear support of NO detailed analysis, Table-1 describing the measured parameters is removed.
        iii. Conclusions make this aspect clear.
    b. SCOPE and OPPORTUNITY for detailed analysis with a simple example is provided as a 'teaser'.
5. Newness in Paper

a. Reporting (possibly) – ‘World’s most prolific, rich and diverse collection of sedimentary ripple structures’ at one location.
b. Pointer to teaching and research opportunities from this ‘extensive’ sample.
c. The studies pointed in this note are in line with Future of Applied Sedimentology
d. Both the 1&2 points - are gaps or opportunities identified from accessed published information.