The first record of chigutisaurid amphibian from the Late Triassic Tiki Formation and the probable Carnian pluvial episode in central India

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A new, partially preserved skull of chigutisaurid amphibian (temnospondyli) has been reported for the first time from the Late Triassic Tiki Formation of India. Chigutisaurids are now known to occur in Australia's Early and Late Triassic, the Late Triassic in India, Argentina, and Brazil, the Jurassic of South Africa and Australia, and the Cretaceous of Australia. In India, the first appearance of chigutisaurids marks the Carnian – middle Carnian / Norian Boundary. This work also attempts to correlate, again for the first time, the advent of chigutisaurids and the occurrence of Carnian Pluvial Episodes (CPE) in the Late Triassic Maleri and Tiki Formation of Central India. The new specimen belongs to the genus *Compsocerops* prevalent in the Late Triassic Maleri Formation occurring 700 km south. However, the chigutisaurid specimen recovered from the Tiki Formation is a new species when compared to that of the Maleri Formation. It has the presence of an inward curved process of the quadratojugal as opposed to the straight downward trending process of the quadratojugal, the presence of vomerine foramen, shorter and wider interpterygoid vacuities, wider subtemporal vacuities, the base of the interpterygoid vacuities at the same level with the base of the subtemporal vacuity, it proves that the Tiki Formation is coeval with the Lower Maleri Formation and a part of Upper Maleri.

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2 # Formation and the probable Carnian Pluvial Episode in Central India.

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11 **Abstract**

12 A new, partially preserved skull of chigutisaurid amphibian (temnospondyli) has been reported for

13 the first time from the Late Triassic Tiki Formation of India. Chigutisaurids are now known to

14 occur in Australia's Early and Late Triassic, the Late Triassic in India, Argentina, and Brazil, the

15 Jurassic of South Africa and Australia, and the Cretaceous of Australia. In India, the first

16 appearance of chigutisaurids marks the Carnian – middle Carnian / Norian Boundary. This work

17 also attempts to correlate, again for the first time, the advent of chigutisaurids and the occurrence

18 of Carnian Pluvial Episodes (CPE) in the Late Triassic Maleri and Tiki Formation of Central India.

19 The new specimen belongs to the genus *Compsocerops* prevalent in the Late Triassic Maleri

20 Formation occurring 700 km south. However, the chigutisaurid specimen recovered from the Tiki

21 Formation is a new species when compared to that of the Maleri Formation. It has the presence of

22 an inward curved process of the quadratojugal as opposed to the straight downward trending

23 process of the quadratojugal, the presence of vomerine foramen, shorter and wider interpterygoid

24 vacuities, wider subtemporal vacuities, the base of the interpterygoid vacuities at the same level

25   with the base of the subtemporal vacuity, it proves that the Tiki Formation is coeval with the Lower

26   Maleri Formation and a part of Upper Maleri.

Introduction

28   Temnospondyls are a very diverse and widespread group of extinct amphibians that thrived from

29   the Carboniferous to the Cretaceous reaching their peak in the Triassic (Konietzko-Meier et al. 2018;

30   Konietzko-Meier et al. 2019). Capable of flourishing in both land and water in a variety of ecological

31   niches, the fossils of these extinct amphibians are found in almost all places from Antarctica in the

32   South to Greenland in the North, India being no exception (Schoch et al. 2014). The temnospondyl

33   fossils in India are found in various Gondwana deposits throughout the country (Chakravorti &

34   Sengupta 2019; Chowdhury 1965; Sengupta 1995; Sengupta 2002; Tripathi 1969) . Chigutisaurids are by

35   far one of the most important temnospondyl amphibians having the longest temporal range

36   (Marsicano 1999) ranging from the Early Triassic to the Cretaceous (Dias-da-Silva et al. 2012).

37   However, the majority of them originated in the Upper Carnian to Lower Norian of the Late

38   Triassic Period. The family Chigutisauridae is much less diversified than the other temnospondyl

39   families. Falling within the superfamily Brachyopoidea which comprises parabolic, brevirostrine

40   skulled temnospondyls, Chigutisauridae forms a single monophyletic family in the phylogenetic

41   position (Warren & Marsicano 2000). The spatial and temporal distribution of the chigutisauridae is

42   schematically represented in Table -1 along with their general habitat (Bandyopadhyay & Ray 2020b;

43   Bonaparte 1975; Cabrera 1944; DIAS-da-SILVA et al. 2012; Pledge 2013; Rusconi 1949; Rusconi 1951;

44   Sengupta 1995; Warren 1981; Warren & Marsicano 2000). The earliest origin of the family

45   chigutisauridae is *Keratobrachyops australis* in the Early Triassic of Australia (Warren 1981) with

46   the latest being *Koolasuchus cleelandi* (Warren et al. 1997) in the Cretaceous of Australia as well.

47 So far, the origin and diversification of chigutisaurids remain restricted only to the Gondwana

48 countries.

49 The Gondwana successions of India are exposed in four discrete basins coinciding with some of

50 the major river valleys throughout the Indian subcontinent (Pascoe 1973; Robinson 1970; Veevers &

51 Tewari 1995). Of these, the Late Triassic Maleri and the Tiki Formations of the Pranhita-Godavari

52 Valley Basin and the Son Valley Basin respectively are long known to be coeval (Chatterjee 1974;

53 Chatterjee & Roy-Chowdhury 1974; Mukherjee & Ray 2014; Robinson 1970). Both Formations are

54 known for the metoposaurid *Panthasaurus maleriensis* (Arche & Lopez-Gomez 2014; Chakravorti &

55 Sengupta 2019; Sengupta 2002). In the Late Triassic Maleri Formation *P. maleriensis* is thought to

56 be restricted within the Carnian and the chigutisaurids appear in the mid-Carnian to early Norian

57 (Chakravorti & Sengupta 2019; Sengupta 1995). Though a considerable amount of work has been

58 done on the microvertebrates (Bhat 2017; Hussain 2018; Ray et al. 2016a), rhynchosaurs (Mukherjee &

59 Ray 2012; Mukherjee & Ray 2014) and phytosaurs (Datta et al. 2021a; Datta et al. 2019a; Datta et al.

60 2021b) of the Tiki Formation; no comprehensive work has been done in the last decade on its

61 temnospondyl faunal contents. Chakravorti & Sengupta (2019) in their taxonomic revision of the

62 Indian metoposaurids, included the metoposaurids of the Tiki Formation and grouped them into a

63 new genus *Panthasaurus maleriensis* based on morphometric and phylogenetic approaches.

64 However, the biostratigraphic implications of the Tiki Formation based on its temnospondyl

65 contents have not been attempted so far, though, the taphonomic aspects of metoposaurids from

66 the Tiki Formation have been discussed by Rakshit & Ray (2020). Also, to date, no chigutisaurid

67 remains were reported from the Late Triassic Tiki Formation though the same is widely prevalent

68 in the Late Triassic Maleri Formation (Sengupta 1995). Therefore, the finding of a chigutisaurid

69 amphibian from the Late Triassic Tiki Formation is very important in the context of correlating

70 the Late Triassic Maleri and Tiki Formation, India, and their position concerning global

71 biostratigraphic correlation. This paper will subsequently highlight a brief geological setting of the

72 Tiki Formation followed by the taxonomic status of chigutisaurids from the Tiki Formation and

73 subsequently its role in demarcating the Carnian Pluvial Episode in India.

74 *The Carnian Pluvial Episode – A Global Climatic Consequence*

75 The Carnian Pluvial Episode (CPE) can be defined as a geologically short-lived (234-232 Million

76 Years Ago) monsoonal period of extreme rainfall that brought about significant changes in several

77 depositional environments (Arche & Lopez-Gomez 2014; Dal Corso et al. 2015; Furin et al. 2006;

78 Schlager & Schöllnberger 1974; Simms & Ruffell 1990). The Carnian Pluvial Episode (CPE) was a

79 global phenomenon. Geochemical data suggest that global warming involved environmental and

80 biotic changes. Radioisotopic ages coupled with biostratigraphic correlation suggest a possible

81 link to the eruption of the Wrangellia Large Igneous Province (LIP) (Dal Corso et al. 2020). CPE

82 was a significant (but previously neglected) time of extinction linked to the Carnian explosive

83 diversification of many key modern groups of plants and animals (Dal Corso et al. 2020). The CPE

84 marks a distinct change in the hydrological cycle during which the climate shifted from arid to

85 humid conditions and back again to arid conditions (Bernardi et al. 2018). It is represented by

86 remarkable enhancement of the hydrological cycle demarcated by four episodes of increased

87 rainfall indicated by diverse sedimentary and paleontological data, repeated Carbon Cycle

88 perturbations, evidenced by sharp negative C-isotope excursions, coincided with global

89 environmental changes and climate warming all of which suggest a cause-and-effect relationship

90 (Dal Corso et al. 2015).

91   The Carnian is the earliest part of the Late Triassic and its base or lower boundary is dated at

92   approximately 237 million years based on U-Pb radiometric dating of a single crystal zircon from

93   a tuff layer within a section having strong biostratigraphic constraints (Dal Corso et al. 2015; Dal

94   Corso et al. 2012; Maron et al. 2019). The upper boundary of the Carnian is constrained at

95   approximately 227 million years based on magnetostratigraphic correlations between the marine

96   successions of Tethys and the astrochronological time scale of the continental Newark Basin (Kent

97   et al. 2017). The Carnian is subdivided into Julian (Early Carnian) and Tuvalian (Late Carnian)

98   substages. The Julian – Tuvalian boundary occurs at approximately 233 million years (Dal Corso et

99   al. 2015; Kent et al. 2017). The beginning of the onset of CPE is well defined from ammonoid,

100 conodont, and sporomorph biostratigraphic dating and is synchronous in several geological

101 settings. It coincides with the first appearance of the ammonoid genus *Austrotrachyceras* in the

102 Julian (Dal Corso et al. 2020; Dal Corso et al. 2012; Roghi et al. 2010; Simms & Ruffell 1990; Sun et al.

103 2016). However, the upper boundary or the end of CPE is poorly defined in most locations. It is

104 usually placed at the base or within the Tuvalian 2 based on sedimentological (e.g., end of

105 terrigenous sediment supply) and chemostratigraphic (last C-isotope excursion) evidence (Dal

106 Corso et al. 2020; Dal Corso et al. 2015; Dal Corso et al. 2018). The total duration of this pluvial episode

107 is variable. Cyclostratigraphy of marine successions of the South China Block and continental

108 successions of the Wessex Basin (United Kingdom) gives a duration of the CPE of approximately

109 1.2 ma but this is variable and longer than 1.6-1.7 million years as indicated by integrated

110 stratigraphy (biostratigraphy and magnetostratigraphy).

111 ***Temnospondyl amphibians in the Carnian Pluvial Episode***

112 The CPE facilitated the Dinosaur Diversification Event (DDE) (Bernardi et al. 2018). However, the

113 role of CPE on the temnospondyls has not much been discussed barring a few papers (Buffa et al.

114   2019; Fortuny et al. 2019; Gee & Jasinski 2021a; Lucas 2020a). The amphibious temnospondyls living

115   both on land and water were the most sensitive to the changes in climate. Two dominant groups

116   of temnospondyls, in this context, were the metoposaurids and the chigutisaurids. According to

117   Fortuny et al. (2019) the gigantism of the metoposaurids might have been linked to the Carnian

118   Pluvial Episode. Buffa et al. (2019) also stated that the diversification of the metoposaurids might

119   have been linked to the CPE and the post-CPE aridification led to the extinction of the

120   metoposaurids during the Rhaetian. Gee & Jasinski (2021a) have also commented on the fact that the

121   physiological variation of the metoposauridae and their palaeoclimatic range also corroborates a

122   palaeo-environmental barrier. Finally, Lucas (2020b) concluded that climate change that occurred

123   during CPE played an important part in the metoposaurid evolution. According to Lucas (2020b),

124   Metoposaurids appeared during the CPE, attained their highest diversity and cosmopolitan

125   distribution during this time and had reduced diversity and showed endemism in the post-CPE

126   climate.

127   Thus, the presence of *Compsocerops* in both Maleri and Tiki Formation enhances the scope to

128   discuss the palaeoenvironment of these two Late Triassic basins in India and to compare the

129   possible reason for faunal turnover from Carnian to Norian concerning the amphibious

130   temnospondyls (Sengupta 1995).

Geological setting of the Tiki Formation and its comparison to the Maleri Formation

133   The Tiki Formation named after the small village of Tiki in the district of Shahdol, Madhya

134   Pradesh has been an interest to scientists for decades. Reports on the geology and palaeontology

135   of the Tiki Formation date back to as early as 1877 when Hughes (1877) noticed reptilian fossils

136   near this village. Cotter (1917) noticed several other such fossils and finally Fox (1931) formally

137 designated the area as the "Tiki stage". Aiyengar (1937) first divided the "Tiki stage" into

138 lithostratigraphic units viz. the lower unit being fossiliferous and composed dominantly of red and

139 green mudstones, proportionately lesser number of sandstones and mud-galls while the upper unit

140 is composed of ferruginous sandstones and shales. Robinson (1970) in her memoir kept the Tiki

141 Formation to be coeval with the Late Triassic Maleri Formation. However, Dutta & Ghosh (1993)

142 did not recognize the separate entity of the Tiki Formation and placed Tiki rocks in the upper part

143 of the Pali Formation forming the "Pali-Tiki Formation". Roychowdhury et al. (1975) based on the

144 megaflora assemblage noted the age of the Nidpur beds is Anisian and separated the upper part of

145 the Tiki Formation to be Carnian – Rhaetian in age. Maheshwari et al. (1976) separated the Tiki

146 Formation to be a separate entity (including the Nidpur beds) and based on the mega flora and

147 faunal assemblages suggested the age of the Tiki (including Nidpur beds) Formation to be ranging

148 from Anisian to Norian with a possible extension to Rhaetian. Mukherjee et al. (2012) revised the

149 stratigraphy of the Rewa Basin and put the Tiki Formation with the coeval Carnian Lower Maleri

150 Formation. Ray et al. (2016b) in the study of vertebrate faunal assemblage of the Tiki formation also

151 suggested Tiki Formation be of Carnian in age but they narrowed the range to Otischalkian to early

152 Adamanian. The common conclusions of all this literature are that the Late Triassic Tiki Formation

153 is dominantly Carnian and its fauna can be correlated with the Lower Maleri fauna. So far, no

154 evidence of a Norian age was assigned to any part of the Tiki Formation. As stated earlier, based

155 on the faunal pieces of evidence and correlating it with the Late Triassic Maleri Formation of the

156 Pranhita – Godavari valley a Carnian age was assigned to the Tiki Formation (Dutta & Ghosh 1993;

157 Kutty et al. 1987; Sengupta 1992).   Henceforth, through the Decades, the Tiki formation was

158 considered to be coeval with the Carnian Maleri Formation (Mukhopadhyay et al. 2010; Sengupta

159 1992; Veevers & Tewari 1995). Only recently, Datta et al. (2021b) while describing a new phytosaur

160   from the Tiki Formation, commented that the age of the Tiki Formation may range from Carnian

161   to Early/Middle Norian.

162   To date, the faunal assemblage of the Tiki Formation includes fishes belonging to the family

163   Ceratodontidae, Hybodontidae and new undescribed forms of Xenacanthidae (Ray et al. 2016a),

164   temnospondyl amphibians belonging to Metoposauridae; reptilian belonging to families

165   Rhyncosauridae, Rauisuchidae, Acrodanta, basal Saurischia, Dromatheridae, and

166   Traversodontidae. Mammaliaformes are also reported from the Tiki Formation (Tables 2a and 2b)

167   (Bandyopadhyay & Ray 2020b; Ray et al. 2016a).

168   The appearance of chigutisaurids in India is noted with the demise of the metoposaurs,

169   rhynchosaurs, and primitive phytosaurs. Prosauropods, large in size also appeared during that time

170   (Novas et al. 2010). These faunal turnovers were thought to demarcate India's Carnian – Norian

171   boundary (Datta et al. 2021b). However, recent signatures (Dal Corso et al. 2015) of the pluvial event

172   and its role in extinction might shift this boundary to Carnian – mid-Carnian/Norian.

173   The Maleri Formation starts with a 250-meter-thick mudstone (Dasgupta et al. 2017; Kutty &

174   Sengupta 1989). At the top of the mudstone, a sandy zone initiates the sand–mud alternations of

175   Upper Maleri (Kutty & Sengupta 1989). This sandy zone contains a maximum number of

176   rhynchosaur fossils, abundant metoposaurids, and unionids. The chigutisaurids in Maleri appear

177   just above this sandy zone (Sengupta 1995) and no rhynchosaurs or metoposaurids are known from

178   that level (or above that). The occurrence of chigutisaurids in upper part of Tiki Formation is also

179   restricted within a sandy zone which do not contain metoposaurids or rhynchosaurs. Unionids are

180   also present there but in lesser abundance than Maleri. Phytosaur teeth are also present. This sandy

181   horizon noticed in Maleri and Tiki has been stratigraphically placed below the Carnian – mid-

182   Carnian/ Norian boundary and may indicate the Carnian Pluvial Episodes (CPE) in India.

Materials used with an overview of their preservation and methods

184   The new skull material along with the clavicle (ISI A 202) excavated by the authors and the

185   specimen RH01/Pal/CHQ/Tiki/15 previously described as metoposaurid (Kumar & Sharma 2019)

186   has been studied in detail and referred to in this paper. The map of the temnospondyl-bearing

187   localities of the Tiki Formation has been modified here with faunal boundaries (hypothetical faunal

188   boundary demarcated in a red dotted line, after Mukherjee & Ray (2012)) (Fig: 1). The temnospondyl

189   bearing (metoposaurid and chigutisaurid) localities of the Maleri Formation have also been

190   extensively mapped and modified (after Dasgupta et al. (2017); Kutty & Sengupta (1989)) (Fig: 2).

191   Some distinct sections have been logged in the Tiki Formation and has been compared with the

192   existing and modified logs of the Late Triassic Tiki and Maleri Formation.

193   **Preservation of specimen ISI A 202 -** The skull along with a fragmentary clavicle, ISI A 202, is

194   poorly preserved (Figs: 3,4,5,6). Only the left half of the skull is preserved and the specimen is

195   heavily eroded. Thus, the ornaments are not well observed in all the areas. The upper part of the

196   parietal and postfrontal have coarse ridges and grooves preserved in them. The skull, its fragments

197   and the clavicle, all have been excavated from the same point in the location and were present

198   together with the same individual as the skull.

199   **Preservation of specimen RH01/Pal/CHQ/Tiki/15-**

200   Only the picture of the palate published as *Metoposaurus* in the paper published by Kumar & Sharma

201   (2019)(Fig: 7) could be studied. As mentioned in the paper (Kumar & Sharma 2019) the material

202   could not be excavated from the field. The photograph of the said publication was reproduced with

203   permission of the journal editor and a higher resolution image was reproduced for better clarity

204 and study. The palate is dorsoventrally elongated and slightly sheared. The edges of the palate are

205 not well preserved.

206 The new specimens with ISI numbers, ISI A 202 and the published specimen of Kumar & Sharma

207 (2019) RH01/Pal/CHQ/Tiki/15 were recovered from mudrocks at a distance of about 100 meters

208 from each other from the village of Tenduadh in the Late Triassic Tiki Formation. Thus, ISI A 202

209 and RH01/Pal/CHQ/Tiki/15 (previously published by Kumar & Sharma (2019) as metoposaurid) are

210 now the two chigutisaurid individuals that are being reported for the first time from the Tiki

211 Formation.

212 The electronic version of this article in Portable Document Format (PDF) will represent a

213 published work according to the International Commission on Zoological Nomenclature (ICZN),

214 and hence the new names contained in the electronic version are effectively published under that

215 Code from the electronic edition alone. This published work and the nomenclatural acts it contains

216 have been registered in ZooBank, the online registration system for the ICZN. The ZooBank

217 LSIDs (Life Science Identifiers) can be resolved and the associated information viewed through

218 any standard web browser by appending the LSID to the prefix http://zoobank.org/. The LSID for

219 this publication is urn:lsid:zoobank.org:pub:1B45D1E1-9FFE-421D-8060-4174334A7EF4. The

220 online version of this work is archived and available from the following digital repositories: PeerJ,

221 PubMed Central SCIE, and CLOCKSS.

222 ## Chigutisauridae from the Tiki Formation
223 ### Systematic Palaeontology

224 Temnospondyli Zittel 1887

225 Stereospondyli Zittel 1888

226   Chigutisauridae [Rusconi 1951](#)

227   *Compsocerops* [Sengupta 1995](#)

228   *Compsocerops tikiensis* sp. *nov*. (ISI A 202/1, ISI A 202/2, ISI A 202/3, ISI A 202/4, and ISI A

229   202/5, RH01/Pal/CHQ/Tiki/15) (Fig: 3)

230   **Type material:** ISI A 202/1 which comprises the left half of a skull roof, ISI A 202/2 – a

231   nearly complete clavicle and ISI A 202/3, ISI A 202/4, and ISI A 202/5 – broken parts of the skull

232   are the holotype. The holotype materials are housed in Geological Studies Unit, Indian Statistical

233   Institute, Kolkata, India (Fig: 3).

234   **Paratypes:** ISI A 202/2, ISI A 202/3, ISI A 202/4 and ISI A 202/5, RH01/Pal/CHQ/Tiki/15.

235   **Referred material:**   A palate (RH01/Pal/CHQ/Tiki/15) previously assigned to a

236   metoposaurid by (Kumar & Sharma 2019) has been referred (Fig: 7). The parabolic skull outline,

237   vaulted pterygoid, shape and proportion of the interpterygoid vacuities, wide and folded palatine

238   ramus of the pterygoid, and comparatively narrow cultriform process of the parasphenoid in

239   RH01/Pal/CHQ/Tiki/15 indicate that it is not a metoposaurid. The cultriform process is wider than

240   *Compsocerops cosgriffi* but narrower than any of the metoposaurids. This palate is comparatively

241   well preserved and bears definite characteristics of a chigutisaur as it appears from the field

242   photograph (Fig: 7). Only the photograph of the palate is available for study.

243   **Locality:** Southwest of the Village of Tenduadh (23°59'41" N; 81°25'02" E), just next to

244   the Barakachh - Beohari Road in the district of Shahdol, Madhya Pradesh, Central India.

245   **Etymology:** The new species of chigutisaur is named after the Late Triassic Tiki Formation

246   from where the specimen has been excavated and studied.

247   **Diagnosis of genus:** A chigutisaur temnospondyl identified as *Compsocerops* by the

248   presence of the following combination of characters: skull outline parabolic in shape, orbits

249   anteriorly placed, raised rim of the naris, presence of a well preserved conspicuous quadratojugal

250   projection, presence of squamosal horn (which though broken and eroded is recognizable), and ill

251   preserved postparietal horn (though ill preserved the presence of horns can be clearly identified),

252   well preserved vaulted pterygoid, long and narrow cultriform process of the parasphenoid,

253   dentigerous area restricted to the anterior portion of the palate, short and restricted palatine

254   dentition not reaching to the middle of the choana, wide ramus of the pterygoid with a gentle fold,

255   walls like quadrate ramus of the pterygoid, presence of postpterygoid process, typical shape of the

256   ramus of the pterygoid and that of the subtemporal vacuities, long dorsal process of the clavicle

257   with a distinct groove and bean-shaped cross section.

258   **Diagnosis of species:** The new species of *Compsocerops* is identified by the presence of an

259   inward curved process of the quadratojugal as opposed to the straight downward trending process

260   of the quadratojugal in *Compsocerops cosgriffi*, presence of vomerine foramen, shorter and wider

261   interpterygoid vacuities, wider subtemporal vacuities, the base of the interpterygoid vacuities at

262   the same level with the base of the subtemporal vacuity as opposed to *Compsocerops cosgriffi*

263   (where the base of the interpterygoid vacuity is lower than the base of the subtemporal vacuity

264   making the interpterygoid vacuities longer and slenderer in *Compsocerops cosgriffi*) and wider

265   cultriform process of the parasphenoid.

266 Description and comparative anatomy

267   *The skull roof* (Fig: 3)

268   The dorsal part of the skull roof can only be studied in ISI A 202.

269   The skull roof is parabolic in shape with a broad and concave posterior part of the skull table. Even

270   though the anterior part of the skull roof is mostly broken, a major portion of the left orbit is

271   preserved. The orbit is subcircular in shape and bordered by the prefrontal, jugal, postfrontal and

272   postorbital. The orbit is located in the anterior half of the skull and is laterally placed. The posterior

273   and posterolateral part of the left external nares is also preserved. It can be understood from the

274   posterior outline of the external nares that they are oval. The external nares are located very close

275   to the anterior border of the skull roof. The posterior part of the external nares is thick and raised.

276   This character is noted in chigutisaurids and is found in *Pelorocephalus tenax* (Marsicano 1999)

277   and *Compsocerops cosgriffi* (Sengupta 1995). The supraorbital sensory canal in the region of the

278   naris is unusually deep around the posterolateral border of the naris which is responsible for the

279   thick and raised posterior part of the naris in the ISI A 202. This characteristic feature has also

280   been noted in *Compsocerops cosgriffi* (Sengupta 1995) where anteriorly the naris is flushed with

281   the skull roof. The entire disposition of the sensory sulci is not well preserved in the specimen.

282   Apart from the supraorbital sulcus, the presence of postorbital dermal sensory sulcus through the

283   postfrontal can be recognized by the deep continuous canal like structure in these two bones. The

284   infraorbital sulcus is visible in the maxilla but gradually becomes less prominent as it enters the

285   jugal to form the jugal lateral dermal sensory sulcus.   Just like other comparable chigutisaurids

286   like *Keratobrachyops australis* (Warren 1981), *Siderops kehli* (Warren & Hutchinson 1983),

287   *Pelorocephalus tenax* (Marsicano 1999; Rusconi 1949), *Compsocerops cosgriffi* (Sengupta 1995) the

288   lacrimal is absent in ISI A 202 and the maxilla enters the border of the external nares.   However,

289   the anterior part of the skull is fragmentary and heavily eroded. The better-preserved left side of

290   the dorsal part of the skull roof consists of partially preserved prefrontal, postfrontal, postorbital

291   and supratemporal. The squamosal is broken at the posterior part, and parietal, postparietal,

292 tabular, jugal and quadratojugals are also partially preserved. The surfaces of the bones are eroded

293 in most places and ornamentations are poorly preserved. The parietal is comparatively large,

294 rectangular and broken along the midline. Coarse ridges and grooves can be recognized from the

295 anterior part of the parietal. Just as in *Compsocerops* the postparietal of ISI A 202 (Fig: 3) is much

296 shorter in length than the parietal. The pineal foramen is not preserved in the parietal. The suture

297 of the postparietal with the tabular is obliterated. The postparietal is broken and eroded along the

298 midline and at its posterior part in the region of the postparietal horn. The postparietal horn is

299 broken in ISI A 202 (Fig: 3). However, there is clear evidence that the horns exist. Postparietal

300 horns are the most unambiguous synapomorphy of *Compsocerops*. It is preserved in *C. cosgriffi*

301 (Sengupta 1995), *C. sp.* (Dias-da-Silva et al. 2012) and *C. tikiensis* sp. nov. These horns are not

302 preserved in any other chigutisaur (the relevant area is not preserved in *Siderops* (Warren &

303 Hutchinson 1983) and *Koolasuchus* (Warren et al. 1997). The tabular is most likely to be in contact

304 with the parietal though that part is not very well preserved. The broad tabular–parietal contact is

305 considered to be a diagnostic character of *Compsocerops* (Sengupta 1995). The tabular horn is

306 broken. This post-quadratojugal process is robust and despite the very poor preservation of the

307 skull in general, the posterior quadratojugal process is well preserved. The shapes and sutural

308 patterns of the posterior left side of the skull are very similar to *Compsocerops cosgriffi*.

309 *The Palate* (Fig: 4)

310 Kumar and Sharma 2019, (Fig: 7) described the palate (RH01/Pal/CHQ/Tiki/15) as a metoposaurid

311 palate (Fig:7). However, no detailed osteological description or identifying characters were

312 described by the authors as to why the specimen was identified to be a metoposaurid. The authors

313 only described the palate to be the 'dorsal' part of a metoposaurid as it has conical teeth present

314 on the anterior part. However, this description is vague and of no taxonomical significance

315   whatsoever as all temnospondyls have conical teeth and both chigutisaurids and metoposaurids

316   have teeth and tusks in the anterior part of the skulls. Again, dentition restricted to the anterior

317   margin of the skull is a characteristic of all temnospondyls with parabolic skulls. Additionally,

318   Kumar & Sharma (2019) grouped the palate collected from the village of Tenduadh with the

319   specimens of metoposaurid clavicle collected from the village of Jora. This grouping is not viable

320   as the two villages are approximately 12 kilometres apart from each other and there is a probability

321   that these two villages might be parts of the Upper and Lower parts of the Tiki Formation and may

322   even be of different ages as discussed later. The specimen, as said in Kumar & Sharma (2019), was

323   too friable and could not be excavated by them. Thus, there is no option to study the specimen

324   first-hand. Henceforth, the image of Kumar & Sharma (2019), has been replicated into a high-

325   resolution photograph with the required permission from the editor of the Journal of the

326   Palaeontological Society of India to study the detail of the described specimen

327   (RH01/Pal/CHQ/Tiki/15) (Fig: 7).

328   The studied specimen is the palate of a temnospondyl and not the dorsal view of the skull as

329   erroneously stated by Kumar & Sharma (2019). The palate showed in the picture

330   (RH01/Pal/CHQ/Tiki/15) (Fig:7) has a distinct vaulted pterygoid, parabolic skull outline, and

331   comparatively   narrow   cultriform   process   than   metoposaurids.   The   specimen

332   (RH01/Pal/CHQ/Tiki/15), (Kumar & Sharma 2019) (Fig:7) has a parabolic skull, thickening of the

333   pterygoid, presence of vaulted pterygoid, presence of post-pterygoid process and concave vertical

334   wall of pterygoid that are characteristic of chigutisaurids as written repeatedly above. The

335   specimen is indeed friable with dense networks of fractures that obscured the clear identification

336   of the sutures. The specimen (RH01/Pal/CHQ/Tiki/15) is partly eroded along the lateral margins

337 as well as anteriorly and posteriorly. The right half of the palate is slightly compressed, deformed

338 and curved (Fig: 7).

339 The anterior portion of the palate is considerably broken both anteriorly and anterolaterally.

340 Though the sutures cannot be delineated, the presence of vomer is very apparent. The vomer is

341 broken anteriorly and the anterior palatal vacuity is not preserved (RH01/Pal/CHQ/Tiki/15) (Fig:

342 7). The posterior part of the preserved vomer includes the anterior tongue of the cultriform process

343 of the parasphenoid. The left half of a possible vomerine cavity is preserved. The vomerine cavity

344 is present only in Jurassic chigutisaur *Siderops kehli* (Warren & Hutchinson 1983) and it is absent in

345 *Compsocerops* (Sengupta 1995) or *Pelorocephalus* (Marsicano 1999). The left lateral margin of the

346 right choana is aligned to the left lateral margin of the right interpterygoid vacuity. The

347 ectopterygoids are exposed on the anterolateral margins of the interpterygoid vacuities and are

348 preserved on both sides. The ectopterygoid borders the anterior portion of the subtemporal vacuity

349 inwards. The subtemporal vacuity is wide and broad bordered by the ectopterygoid and the

350 parasphenoid on the inward margin and the quadratojugal, the alar process of the jugal on the

351 outward lateral margin. The dentigerous area is restricted to the anterior region of the palate. The

352 anterior and the anterolateral margins of the palate are broken, and all teeth are not preserved.

353 However, two broken ectopterygoid teeth can be seen preserved at the anterolateral corner of the

354 ectopterygoid in contact with the palatine in the left part of the palate. The palatine teeth row in

355 the left half of the skull is also preserved partially. Like other chigutisaurids, the dentigerous area

356 of the palate is remarkably short. The palatine row of teeth is not continuous up to the middle of

357 the choana. This character has been considered to be a synapomorphy of *Compsocerops cosgriffi*

358 (Sengupta 1995). Conical, inward curved four complete palatine teeth are preserved in the margin

359 of the left palatine bone of the palate. Since, the dentigerous area is restricted to the anterior part

360   of the skull the posterior part is longer in proportion and covered by large and wide subtemporal

361   vacuity (Fig: 4).

362   In (RH01/Pal/CHQ/Tiki/15) (Fig:7) (Kumar & Sharma 2019) both the interpterygoid vacuities are

363   well preserved. The interpterygoid vacuities are quadrangular in shape, shorter and wider

364   compared to *Compsocerops cosgriffi* (Sengupta 1995). The borders of the interpterygoid vacuities

365   are approximately parallel-sided. The interpterygoid vacuities are bordered dominantly by the

366   cultriform process along the inward margin as well as the vomer. Anteriorly, it is bordered by the

367   vomer and the palatine. The pterygoid forms the dominant margin of the interpterygoid vacuities

368   laterally with a small area being occupied by the ectopterygoid. Posteriorly, these are formed by

369   the parasphenoid. In ISI A 202/1, the interpterygoid vacuities are not completely preserved. In

370   both, the specimens ISI A 202 and (RH01/Pal/CHQ/Tiki/15) (Kumar & Sharma 2019), the

371   interpterygoid vacuities are shorter and broader than *Compsocerops cosgriffi* where the base levels

372   of the interpterygoid vacuities are lower than that of the subtemporal vacuities. The subtemporal

373   vacuity extends anteriorly to the level higher than the centre of the interpterygoid vacuities.

374   In (RH01/Pal/CHQ/Tiki/15) (Kumar & Sharma 2019) (Fig:7) both the pterygoids are preserved.

375   They are deep and vaulted. The vertical lateral wall of the pterygoid projects posteriorly possibly

376   up to the posterior level of the occipital condyles which are broken. The palatal ramus of the

377   pterygoid is visible on both sides in (RH01/Pal/CHQ/Tiki/15). The palatal ramus of the pterygoid

378   is longitudinally concave with a gentle fold which is again a character of some chigutisaurids

379   specially *Compsocerops*. The quadrate ramus of the pterygoid is better preserved on the right side

380   of the palate (RH01/Pal/CHQ/Tiki/15). The quadrate ramus of the pterygoid looks like a wall as

381   they are deeply vaulted. The ascending ramus of the pterygoid is not visible in

382   (RH01/Pal/CHQ/Tiki/15). A broken post pterygoid process that is a projection from the posterior

383   border of the pterygoid corpus is visible on the right side of the palate (RH01/Pal/CHQ/Tiki/15).

384   This area on the left side of the palate of (RH01/Pal/CHQ/Tiki/15) is broken. The postpterygoid

385   process is considered to be an apomorphic character for *Compsocerops cosgriffi* (Marsicano 1999).

386   The suture of the quadrate and pterygoid is present on the outer side of the downturned part of the

387   quadrate ramus of the pterygoid. In ISI A 202, (Fig: 4) only the right pterygoid is ill-preserved but

388   the bone surface is crushed. However, a distinct post pterygoid process characteristic of

389   *Compsocerops* is present. Though the bone is crushed and compressed, the vaulted nature of the

390   pterygoid can be made out because of the concavity of the vertical wall of the pterygoid. In both,

391   the specimens (RH01/Pal/CHQ/Tiki/15) (Kumar & Sharma 2019) and ISI A 202, the palatine ramus

392   of the pterygoid is much broader and wider than that in *Compsocerops cosgriffi.*

393   Just like other chigutisaurids, the base of the parasphenoid is almost hexagonal with a long

394   extension in the form of the cultriform process placed between two interpterygoid vacuities in

395   (RH01/Pal/CHQ/Tiki/15) (Kumar & Sharma 2019). The parasphenoid has a long suture with the

396   pterygoid laterally and the exoccipitals posteriorly. A distinct raised longitudinal keel is present

397   on the ventral surface of the cultriform process in this specimen. The presence of this keel in the

398   cultriform process has been noted by Marsicano (1999) as a distinguishing character present only in

399   *Pelorocephalus mendozensis.* However, first-hand studies reveal that this longitudinal keel of the

400   cultriform process is also present in *Compsocerops cosgriffi* from the Maleri Formation of Pranhita

401   - Godavari Valley Basin. The cultriform process of parasphenoid of this specimen is comparatively

402   narrower than all other specimens of *Compsocerops cosgriffi.* The cultriform process of the

403   *Compsocerops* species from Tiki is wider than *C. cosgriffi*, the cultriform process is also

404   comparatively broader than *Siderops kehli*, more comparable to the width of the cultriform process

405   in the specimen previously denoted as *Kuttycephalus triangularis* (Sengupta 1995). The cultriform

406   process preserved in (RH01/Pal/CHQ/Tiki/15) (Kumar & Sharma 2019) is thin and constricted in the

407   middle part of the interpterygoid vacuities and gets broader as it progresses to the anterior part of

408   the process. This type of cultriform process is unique among the chigutisaurids. In the specimen

409   photographed by Kumar & Sharma (2019), the anterior tongue of the cultriform process is in contact

410   with the vomer and lies posterior to the level of the anterior margin of the interpterygoid vacuities.

411   The cultriform process is not preserved in ISI A 202. The occipital condyles are broken as well. In

412   the earliest known chigutisaur *Keratobrachyops*, the cultriform process of the parasphenoid is also

413   narrower than ISI A 202.

414   *The Occiput* (Fig: 5)

415   The occiput is very ill preserved only in ISI A 202 (Fig: 5). The occiput could not be prepared due

416   to the extremely fragile nature of the skull. Removing the matrix load from the occiput would

417   result in the sagging of the entire specimen. However, from the little that could be studied, it can

418   be said that in occipital view, the quadrate ramus of the pterygoid is deeply downturned. The vagus

419   nerve foramen is preserved on the left exoccipital lateral to the broken occipital condyle. The

420   ascending process of the exoccipital is wide and inclined and meets the descending process of the

421   postparietal. A sub-circular, matrix filled, paraquadrate foramen is present in the quadratojugal.

422   The quadrate is partially preserved in the occipital view. It is bounded by the squamosal,

423   quadratojugal and the downturned pterygoid. The absence of occiput makes the comparison of ISI

424   A 202 difficult with the different species of *Pelorocephalus* as different species of the genus are

425   differentiated, to a great extent, by their occipital characters (Marsicano 1999).

426   *Clavicle* (Fig: 6)

427 An almost complete left clavicle (ISI A 202/2) (Fig: 6) was found associated with the skull (ISI A

428 202/1) during excavation. The clavicle has a flat eye-drop shaped blade and a long straight dorsal

429 process that ascends almost straight, nearly at ninety degrees with the plate. The cross-section of

430 the process at the dorsal end is bean shaped as a feeble furrow runs along the process. This is very

431 similar to the clavicle of *Compsocerops cosgriffi* (Sengupta 1995), *Siderops kehli* (Warren &

432 Hutchinson 1983) and *Koolasuchus cleelandi* (Warren et al. 1997).

433 Results

434 *Tiki Formation:*

435 To date, no temnospondyl fauna has been recorded from the upper part Tiki Formation. Excavation

436 taken up in 2018 by the authors revealed the first chigutisaurid from the Tiki Formation in the

437 Tenduadh locality (Fig: 8) in the upper part of the Tiki Formation. Several vertebrae and

438 postcranial bones of metoposaurid have been excavated from the Jora and Tiki Nala sections which

439 have been assigned to the lower Tiki Formation from our field studies. Based on the changes in

440 the faunal assemblage in the lower and the upper Tiki Formation (Tables 2a and 2b) and

441 considering the lithostratigraphy, a boundary between the basal and upper Tiki Formation has been

442 assigned and the zone demarcating the Carnian to Norian faunal turnover in the Tiki Formation

443 has been approximated and marked in red dotted line in the map (Fig: 1). The lithological logs

444 modified after Kumar & Sharma (2019) and Mukherjee & Ray (2012) reveal that just like the Maleri

445 Formation, the basal Tiki Formation is dominated by a large band of red mudrock intercalated with

446 peloidal calcirudite-calcarenite (Sarkar 1988) (Fig: 9). The Jora Nala section in the Carnian basal

447 Tiki has been logged in detail in this work (Fig:9a). This shows the dominance of greenish to

448   reddish siltstones and mudstones in the Jora Nala section with sparse deposition of trough cross-

449   bedded sandstones in between.

450   *Maleri Formation*

451   In the revised map of the Maleri Formation and (after Dasgupta et al. 2017; Kutty & Sengupta 1989)

452   a boundary between the Carnian basal Maleri and Middle Carnian / Norian Upper Maleri has been

453   established from both lithological and faunal contents (Fig: 2 – faunal boundary indicated by a

454   green broken line). From our field studies and maps it is evident that though sandstone - mudstone

455   alternation is present throughout the Maleri Formation, the Carnian basal Maleri is abundant in red

456   mudrocks and calcirudites (Fig: 2,10) and moving towards Upper Maleri there is a sudden increase

457   in the deposition on siliciclastic sediments leading to the more frequent occurrence of sandstone

458   bands alternating with red mudstone (Fig: 10).

459   # Discussion

460   The CPE had a significant impact on the terrestrial environment and ecosystem globally. The

461   evidence of CPE has never been worked upon or mentioned in India because of the lack of proper

462   age constraints present in the Late Triassic Maleri and Tiki Formations in India.

463   ***Tiki Formation***

464   No detailed sedimentological or geochemical studies have been carried out in the Late Triassic

465   Tiki Formation in India to analyse the associated changes from Carnian to Norian through the

466   humid phase of the Carnian Pluvial Episode. Though, Ahmed & Ray (2010) presented a geochemical

467   analysis of 42 nodular carbonates confirming their pedogenic origin, no details of the localities of

468   collection in terms of lower and upper Tiki have been provided.

469   The terrestrial influx of sediments is significantly low at the period denoted by the sparse

470   occurrence of sandstones in the basal Tiki Formation (Fig: 9). The presence of Unio beds in

471   between the basal thick layers of mud reflects a stagnant quiet and well-watered environment. This

472   basal mud encompasses areas like the Jora and Tiki River sections. Abundant postcranial

473   fragments of metoposaurids and rhynchosaurs have been collected from these sections. Moving

474   upwards in the direction of the dip of the beds, there is a sudden influx of siliciclastic sediments

475   marked by thick sandstone units with little intermittent mudstone. This could be a demarcation of

476   the rapid influx of siliciclastic sediments that took place during CPE in the Tiki Formation. Only

477   two dominant sand bodies are observed in Tiki before the recurrence of a thick horizon of mud

478   and subsequently sand-mud alternations indicating the onset of seasonality and aridity in the

479   Norian. The Norian of Tiki Formation is demarcated by red mudstones, whitish sandstones and

480   sparse calcirudites. The Norian Upper Tiki Formation is exposed in sections near Tenduadh as

481   shown in the map (Fig: 1) and an estimated approximate faunal boundary between the Carnian and

482   the Norian in the Tiki Formation is also furnished as in Fig: 1. Tiki has a long history of yielding

483   fossil vertebrates (Bandyopadhyay & Ray 2020b; Chatterjee & Roy-Chowdhury 1974) (Table 1). It has

484   a rich Late Triassic faunal association as shown in Table 2a and 2b (Bandyopadhyay & Ray 2020a;

485   Chatterjee & Majumdar 1987; Mukherjee & Ray 2014). The Tiki faunal assemblage was thought to be

486   coeval to the Lower Maleri faunal assemblage (Datta 2005; Kutty & Sengupta 1989). However, Datta

487   et al. (2019b) stated that the Tiki fauna ranges from Middle Carnian to Early Norian and is younger

488   than Lower Maleri Fauna. The mid Carnian / Norian Upper Maleri fauna has chigutisaurids. The

489   discovery of a chigutisaurid from the upper part of the Tiki Formation confirms the views of Datta

490   et al. (2019b) regarding the presence of Middle Carnian / Norian fauna in the Tiki Formation.

491

492 *Maleri Formation*

493 The abundance of red mudstone in the basal Maleri Formation (Fig: 11) with a sudden increase in

494 the frequency of sandstone bands in the upper part can be correlated with the advent of the Carnian

495 Pluvial Episode (CPE) in India. The overall palaeoenvironment and sedimentology of the Maleri

496 formation have been worked upon by earlier workers (Dasgupta & Ghosh 2018; Sarkar 1988). Most

497 of these studies were done on the Maleri Formation as a whole without distinguishing its basal and

498 upper parts. Also, no detailed analyses about the changes in sedimentology or geology or

499 geochemistry have been done to study the changes in the pattern of sedimentation from the Carnian

500 basal Maleri to the Norian Upper Maleri.

501 Evidence from detailed geological mapping, logs and associated faunal turnover in the Late

502 Triassic Maleri Formation all point toward the distinctive effect of CPE in India. The overall

503 thickness of the Maleri Formation is about 350-600m which is variable in different places. From

504 the map of the Maleri Formation and log of the same near Achlapur and Nalapur (Fig: 10), it is

505 evident that the basal part of the Maleri Formation has a large stretch or band of red mudrock-

506 dominated unit. This unit of red mudrock stretches from about 100m-200m in thickness in basal

507 Maleri and is the thickest band of red mudrock encountered in the entire Maleri Formation (Fig:

508 12). It encompasses villages namely Aigerrapalli (19°15'22.4" N; 79°27'23.4" E), Achlapur

509 (19°09'34" N; 79°31'51" E) and Nambala (19°13'47" N; 79°26'07" E), areas slightly north of

510 village Gampalpalli (19°10'11" N; 79°30'53" E) and is rich in vertebrate fossils, the most

511 significant among them being rhynchosaurs and metoposaurids. This significantly thick basal

512 Maleri mudstone has sporadic carbonate grainstones [*sensu* (Dunham 1962); calcarenites–

513 calcirudites of Sarkar (1988)] and the presence of palaeosols with no significant siliciclastic

514 deposition of sandstone present within this mud. The upper part of the Formation is approximately

515   200–350 m thick and has three to four multi-storeyed sheet sandstone bodies (each 10–35 m thick)

516   vertically separated by mudrock-dominated intervals (15–55 m thick). The mudrock intervals in

517   the upper part are lithologically similar to those occurring in the lower part of the Formation. The

518   mudrock units comprise both stratified and massive mudstones (Dasgupta et al. 2017) with sporadic

519   carbonate grainstones (calcirudite of Sarkar (1988)). Moving upwards from the thick stretch of

520   mudrock, the influx of siliciclastic sedimentation increases as evident from the increase in the

521   deposition of frequent sandstone units. The beginning of these sandstone units is marked by the

522   presence of metoposaurids and rhynchosaurs and unionid fossils in a sandy zone. In the upper part,

523   apart from the chigutisaurids, there are basal sauropods like *Jaklapallisaurus*, and

524   sauropodomorphs like *Nambalia*, probable Guaibasaurids-and-Herrerasaurus-like forms (Novas et

525   al. 2010). The authors in the same work, also mentioned that early theropods are known from the

526   Norian-Rhaetian time from North and South America, India, South Africa, and Europe and the

527   demise of members of Lower Maleri fauna like rhynchosaurs together with the global extinction

528   of *Chiniquodon* (cynodont) and Proterocampsidae (archosauriform) mark the Carnian − Norian

529   boundary and also the North Tethyan Pluvial Episode of end Carnian (CPE). Benton et al. (2018)

530   have argued that CPE triggered the diversification of early dinosaurs. It has been discussed earlier

531   those indications of CPE are present in Maleri and Tiki Formations of India. The sudden

532   appearance of several basal dinosaurs like *Jaklapallisaurus*, *Nambalia*, probable Guaibasauridae

533   and *Herrerasaurus* (Novas et al. 2010) in the Norian Upper Maleri fauna also corresponds to that.

534   Thus, the palaeoenvironment of the Maleri Formation shifted from a comparatively arid and dry

535   climate in the Julian at the basal substage of Carnian to a high competence fluvial-lacustrine

536   environment with the presence of small, ephemeral and vegetated swamps or ponds along the flow

537   path of the channels at the time of Carnian Pluvial Episode from the end of Julian to Tuvalian and

538   back again to fluvial deposition in the Norian (Dasgupta et al. 2017). The episodes of increased

539   rainfall during the Carnian Pluvial Episode demarcated by increased frequency of sandstone

540   deposition are intervened by seasonality as evident from the red mudrock alternations between

541   sandstones. Similar climatic shifts are seen from the coeval Santa Maria to Caturrita formations

542   of Brazil (Dal Corso et al. 2015). These shifts indicating a major variation of the hydrological regime

543   in terrestrial depositional settings suggest an enhancement of the hydrological cycle during the

544   CPE. Recently, Lucas (2010) stated that the demise of metoposaurids in most parts of the world

545   during the Carnian is related to the end of the enhanced hydrological cycle at the dying phase of

546   CPE. The disappearance of key herbivorous groups such as dicynodonts and rhynchosaurs of

547   Carnian and their places taken up by giant sauropodomorphs seems to be linked to CPE which is

548   not documented in India so far.

549   Also, the *Hyperodepadon* Assemblage Zone (HAZ) is characterized by the presence of

550   rhynchosaur *Hyperodepadon* and is present in the lower part of the Ischigualasto Formation of

551   Argentina, the Lossiemouth Sandstone Formation of Scotland, and the Lower Maleri Formation

552   of India (Langer et al. 2010). The HAZ is dated as late Carnian to early Norian, approx. 228–224

553   Ma by some authors (Benton et al. 2018; Brusatte et al. 2010; Ezcurra et al. 2017). Most metoposaurids

554   in the Gondwana deposits are considered to be Carnian in age (Chakravorti & Sengupta 2019; Gee &

555   Jasinski 2021b; Sengupta 2002). The demise of the metoposaurids *Panthasaurus maleriensis*

556   (Chakravorti & Sengupta 2019) in India along with the demise of *Hyperodepadon* (Chatterjee 1974;

557   Mukherjee et al. 2012) in both Late Triassic Maleri and Tiki Formation also points to the presence

558   and effect of CPE in India. The demise of the metoposaurids left a vacant niche to be occupied by

559   the chigutisaurids in the Norian suggesting short-lived aridity in post Carnian stage.

560 The Carnian of Argentina has its age radiometrically constrained between 231.4 ± 0.3 and 225.9

561 ± 0.9 Ma (Martínez et al. 2016) and similar reports are present from Santa Maria and Caturrita

562 Formations of Brazil (233.2 ± 0.7 and 225.4 ± 0.4 Ma) (Langer et al. 2018). The onset of CPE is

563 well constrained in stratigraphic sections like the Southern Alps of Italy, Northern Calcareous Alps

564 of Austria, Transdanubian Range of Hungary, and the Nanpanjiang Basin of the South China block

565 and is placed at the substages Julian 1 – Julian 2 boundary of the Carnian (Gallet et al. 1994). Due

566 to the lack of any radiometric dating, Late Triassic Maleri and Tiki Formations are poorly

567 constrained and pose difficulty in global correlation, their correlation is based only on available

568 fauna. The CPE has always been dated as mid-Carnian (Ruffell et al. 2016) but this is not a

569 unanimous viewpoint. The Italian Dolomites occur between the Aonoides/Austriacum interval

570 (about Julian) and the base of the Subbullatus Zone (Tuvalian), dated at 234–232 Ma (Dal Corso et

571 al. 2015; Roghi et al. 2010). Further constraint has been documented in borehole successions in the

572 southwest UK, which indicates a maximum duration of 1.09 MYA (Miller et al. 2017). The precise

573 radiometric dating to constrain the Maleri and Tiki Formations and to denote the beginning of CPE

574 in India will shed further light on the pattern of faunal diversification post CPE event in the

575 subcontinent and help in the global stratigraphic correlation. A continental carbon isotope record

576 in southwest England shows multiple carbon cycle perturbations during CPE (Miller et al. 2017).

577 The CPE is not only the time interval of increased humidity but also a major carbon perturbation.

578 Unfortunately, no carbon isotope data is noted from the Maleri and the Tiki Formations of India.

Conclusion

579

580 1. In the current work a new species of chigutisarid amphibian, *Compsocerops tikiensis* sp.

581   nov. from the Late Triassic Tiki Formation of the Rewa Gondwana Basin has been

582   described in detail. The presence of chigutisaurid *Compsocerops tikiensis* sp. nov. in the

583   Upper part of the Tiki Formation is the first evidence of the Norian chigutisaurid amphibian

584   from the said Formation and is important for correlation of the Late Triassic basins

585   worldwide.

586 2. The presence of *Compsocerops* (Sengupta 1995) in Tiki, for the first time, confirms the

587   presence of the Upper Maleri faunal element in Tiki. Lucas (2020b) thought that the demise

588   of metoposaurids in most parts of the world was at the end of Carnian and that tallies with

589   the last appearance datum of the metoposaurids of Maleri. The chigutisaurids, both in

590   Maleri and Tiki have their first appearance datum at the onset of the Middle Carnian or

591   Early Norian.

592 3. Along with the extinction of the rhyncosaurs and *Parasuchus* (primitive phytosaur)

593   (Chatterjee 1978), chiniquodontids (cynodonts), the Carnian – Norian Extinction Event

594   (CNEE) also caused the extinction of the metoposaurids in India. Chigutisaurids appeared

595   in Middle Carnian / Norian and India is the only place which accommodates definite

596   metoposaurids and chigutisaurids within the same formations (the Late Triassic Maleri and

597   Tiki Formations) the former being replaced by the latter. Incidentally, among the

598   phytosaurs, the *Parasuchus* of Lower Maleri fauna is replaced by the *Leptosuchus* like

599   forms of Upper Maleri and *Volcanosuchus statisticae* (Datta et al. 2021b) in the upper part

600   of the Tiki Formation.

601 4. The post-CNEE empty niche left by the metoposaurids in the Late Triassic Gondwana

602   deposits of India (controversially Brazil as well, (see Dias-da-Silva et al. 2011) was occupied

603   by the chigutisaurids in the Norian. The availability of phytosaur teeth along with *C.*

604   *tikiensis* sp. nov. only indicated their co-existence in the same aquatic niche but does not

605   necessarily point towards any prey-predatory relationship between the phytosaurids and

606 the chigutisaurids. However, detailed studies on histology and growth pattern of the

607 chigutisaurids might shed light on the gigantism of these amphibious animals in the post-

608 CNEE and recovery of the temnospondyls.

609 5. The presence of both metoposaurids and chigutisaurids and the faunal turnover from the

610 Carnian to the Norian along with the extinction of the rhynchosaurs (*Hyperodapedon*)

611 ([Mukherjee et al. 2012](#)) and *Parasuchus* ([Chatterjee 1978](#))in the Carnian of both the Late

612 Triassic Maleri and Tiki Formation and the presence of prosauropods in the Upper Maleri

613 Formation and undescribed dinosauriformes including theropod-like forms

614 ([Bandyopadhyay & Ray 2020b](#)) sheds light and documents for the first time the existence and

615 effect of the Carnian Pluvial Episode in India.

616 6. The finding of *Compsocerops tikiensis* sp. nov. from the Tiki Formation and assessing its

617 importance in global palaeoclimatic and palaeoclimatic correlation paves the way for future

618 scope of works in finding the effect of CPE in India and comparing its faunal diversification

619 at a global scale. Also, finding any new and better-preserved specimen of *Compsocerops*

620 *tikiensis* sp. nov. from the Tiki Formation would help to establish the phylogenetic

621 relationship of the other chigutisaurids around the world with that of the Indian

622 counterparts. As the specimens are deformed broken and have poor preservation potential,

623 phylogenetic analysis is beyond the scope of this paper as it will add more missing and

624 misinterpreted data.

Acknowledgements

625
626 The author SC would like to thank Ms. Aindrila Roy, Project Linked Person (PLP) at the

627 Geological Studies Unit, Indian Statistical Institute, Kolkata for her help in editing and

628 formatting the manuscript. The authors' SC and DPS would like to acknowledge Mr Lakshman

629   Mahankur for helping in the preparation of the poorly preserved material. We acknowledge the

630   editor (Surendra Kumar) of the Journal of Palaeontology of India for providing us with

631   permission to reproduce the published picture published on page 159, (Plate IV. number 1) of the

632   journal volume 64(2), December 31, 2019. We are also very grateful to Dr Claudia Marsicano,

633   Dr Valentin Buffa and the anonymous reviewer who through their insightful comment and

634   meticulous suggestions has enriched this work to a great extent.

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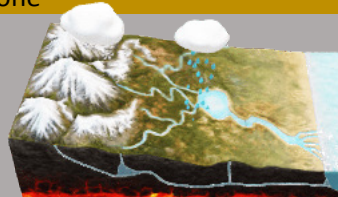
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853

Spatial and temporal range of the family Chigutisauridae along with their paleoecology and paleoenvironment.

Abbreviations Max ma = Maximum age million years ago, Min ma = Minimum age million years ago, Fm. = Geological Formations from which the specimen had been excavated. The table has been modified after data was acquired from the Paleobiology Database on 10th May 2022, using the family name "Chigutisauridae". Data for the table was modified after Bonaparte (1957); Marsicano (1999); Dias – da- Silva and Sengupta (2012); Warren (2006); Pledge (2013); Cabrera (1944); Rusconi (1949); Rusconi (1951); Sengupta (1995); Warren and Hutchinson (1983); Warren (1981); Warren and Marsicano (2000).

1 ## Table 1

Name	Early_interval	Late_interval	Max_ma	Min_ma	Country	Fm.	Lithology	Palaeoenvironm
Koolasuchus cleelandi	Late Aptian	_	122.46	112.03	Australia	Eumeralla Fm.	Sandstone	
Koolasuchus cleelandi	Late Aptian	_	122.46	112.03	Australia	Eumeralla Fm.	Sandstone	
Koolasuchus cleelandi	Late Aptian	_	122.46	112.03	Australia	Eumeralla Fm.	Sandstone	
Koolasuchus cleelandi	Late Aptian	_	122.46	112.03	Australia	Eumeralla Fm.	Sandstone	
Koolasuchus cleelandi	Aptian	_	125	113	Australia	Eumeralla Fm.	Sandstone	
Siderops kehli	Pliensbachian	Toarcian	190.8	174.1	Australia	Evergreen Fm.	Ironstone/Sandstone	
Chigutisauridae indet	Mid Carnian	_	228	_	Australia	Leigh Creek Fm.	Siltstone	
Compsocerops	Mid Carnian	Norian	228	208.5	Brazil	Santa Maria Fm.	Mudstone	
Compsocerops cosgriffi	Mid Carnian	Norian	228	208.5	India	Upper Maleri Fm.	Mudstone	
Kuttycephalus triangularis	Mid Carnian	Norian	228	208.5	India	Upper Maleri Fm.	Mudstone	
Compsocerops tikiensis	Mid Carnian	Norian	228	208.5	India	Upper Tiki Fm	Mudstone	
Pelorocephalus mendozensis	Carnian	Norian	237	208.5	Argentina	Cacheuta Fm.	"Siliciclastic"	The overall palaeoenvironm is fluviolacustri
Pelorocephalus tenax	Carnian	Norian	237	208.5	Argentina	Cacheuta Fm.	"Siliciclastic"	
Pelorocephalus cacheutensis	Carnian	Norian	237	208.5	Argentina	Cacheuta Fm.	"Siliciclastic"	
Pelorocephalus ischigualastensis	Carnian	Norian	237	208.5	Argentina	Ischigualasto Fm.	Siliciclastic	
Keratobrachyops australis	Induan	_	252.17	251.2	Australia	Arcadia Fm.	Mudstone	

2 Table -1: The table shows the spatial and temporal range of the family Chigutisauridae along with their paleoecology and paleoenvironment.

3 Abbreviations Max ma = Maximum age million years ago, Min ma = Minimum age million years ago, Fm. = Geological Formations from which the

4 specimen had been excavated. The table has been modified after data was acquired from the Paleobiology Database on 10th May 2022, using

5 the family name "Chigutisauridae". Data for the table was modified after Bonaparte 1957; Marsicano 1999; Dias – da- Silva and Sengupta 2012;

6 Warren 2006; Pledge 2013; Cabrera 1944; Rusconi 1949; Rusconi 1951; Sengupta 1995; Warren and Hutchinson 1983; Warren 1981; Warren and

7 Marsicano 2000)

Fossils excavated from the Late Triassic Tiki Formation (modified after Bandopadhyay and Ray 2020)

2a. Fish fossils excavated from the Late Triassic Tiki Formation (modified after Bandopadhyay and Ray 2020).

2b. Vertebrate fossil assemblage (tetrapod content) of the Late Triassic Tiki Formation of the Rewa Basin, India (modified after Bandopadhyay and Ray 2020).

1 ## Table 2a

Order/Family	Genus and Species	Order/Family	Genus and Species
Chondrichthyes		**Osteichthyes**	
Lonchididae	*Lonchidion estesi*	Ptychoceratodontidae	*Ceratodus sp.*
	Lonchiodon incumbens		*Ptychoceratodus oldhami*
	Pristrisodus tikiensis	Gnathorhizidae	*Gnathorhiza sp.*
Xenacanthidae	*Mooreodontus indicus*	Actinopterygii	Undescribed
	Mooreodontus jaini		
	Tikiodontus asymmetricus		

2 **Table- 2a:** Fish fossils excavated from the Late Triassic Tiki Formation (modified after Bandopadhyay and Ray 2020).

3 ## Table 2b

Order/Family	Genus and Species	Order/Family	Genus and Species
Amphibia		**Diapsida**	
Metoposauridae	*Panthasaurus maleriensis*	Archosauriformes	*Galtonia sp., Protecovasaurus sp.,* and other intermediate forms
Chigutisauridae	*Compsocerops tikiensis*	Dinosauriformes	Undescribed Theropod-like (?) forms
Diapsida		Aetosauria	Undescribed
Phytosauria	*Volcanosuchus statisticae(?) leptosuchomorph*	**Synapsida**	

Rhynchosauria	*Hyperodapedon tikiensis*	Cynodontia	*Ruberodon roychowdhurii*
Rauisuchidae	*Tikisuchus romeri*	Mammaliaformes	*Tikitherium copei*
Rhynchocephalia	*Undescribed*		*Gondwanadon tapani*

Table- 2b: Vertebrate fossil assemblage (tetrapod content) of the Late Triassic Tiki Formation of the Rewa Basin, India (modified after Bandopadhyay and Ray 2020).

Figure 1

Palatal surface of the skull photograph (RH01/Pal/CHQ/Tiki/15) (Kumar and Sharma 2019). Recreated with permission from the editor of the Palaeontological Society of India.

a. Shows the field photograph published in Kumar and Sharma (2019). b. Line drawing showing the disposition of the bones in the palatal surface of the skull published in Kumar and Sharma (2019). The abbreviation stated in the figure are as follows: cf = cultriform process, ect= ectopterygoid, itv = interpterygoid vacuity, pal= palatine, ps = parasphenoid, q = quadrate, stf = subtemporal foramen, v = vomer.

15 cm

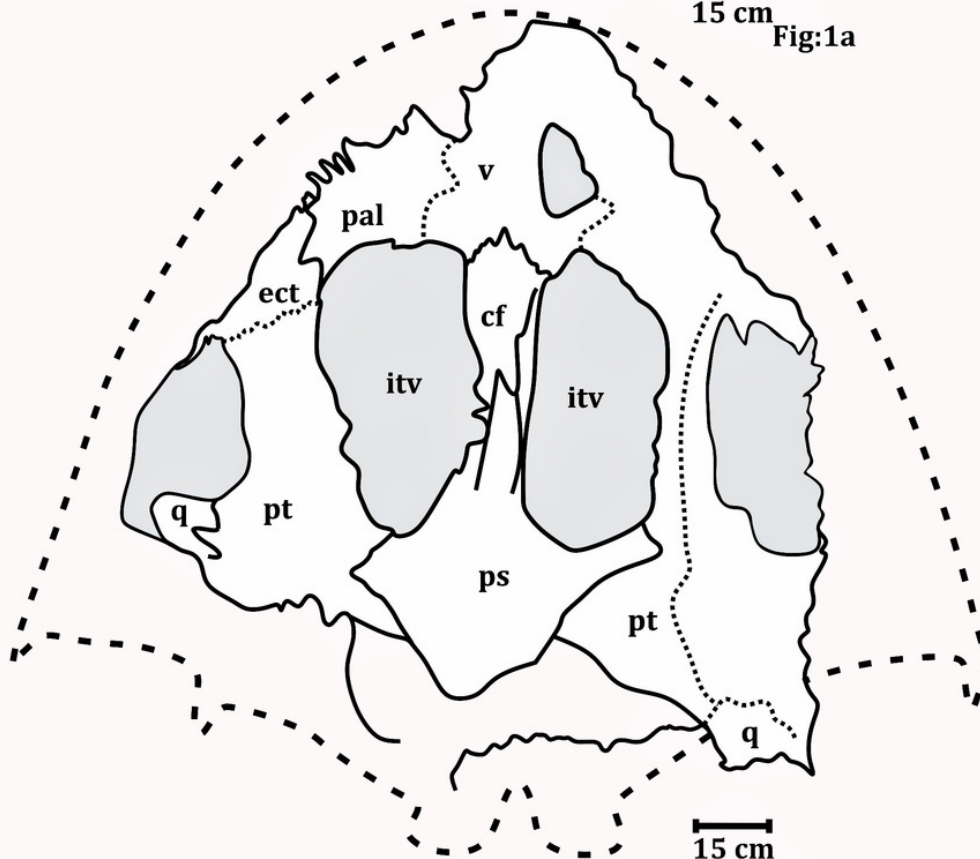
Fig:1a

15 cm

Fig:1b

Figure 2

Dorsal surface of the skull roof of ISI A 202 *Compsocerops tikiensis* sp. nov.

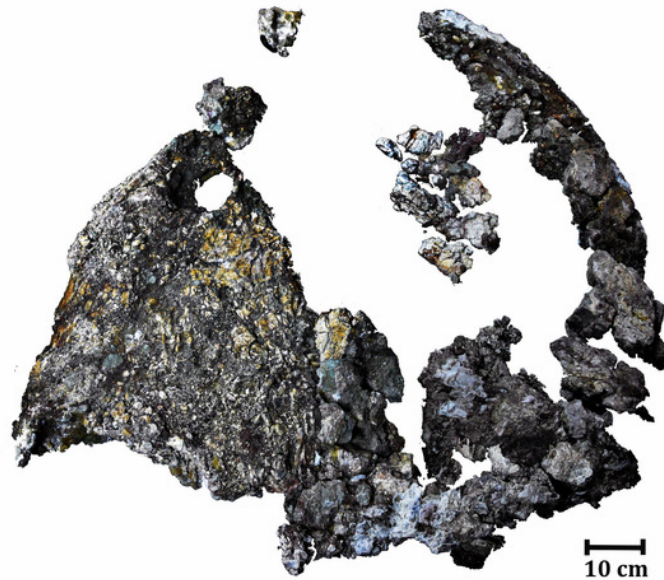
a. Reconstructed photograph of the dorsal surface of the skull roof of ISI A 202. Scale bar = 5 cm. b. Line drawing showing the disposition of the preserved bones in the dorsal part of the skull roof in ISI A 202. The abbreviation stated in the figure are as follows: j=jugal, mx=maxilla, n=nasal, p = parietal, po = postorbital, pof = postfrontal, pp = postparietal, prf = prefrontal, qj = quadratojugal, sq = squamosal, st = supratemporal, t = tabular. Scale bar = 5 cm.

10 cm

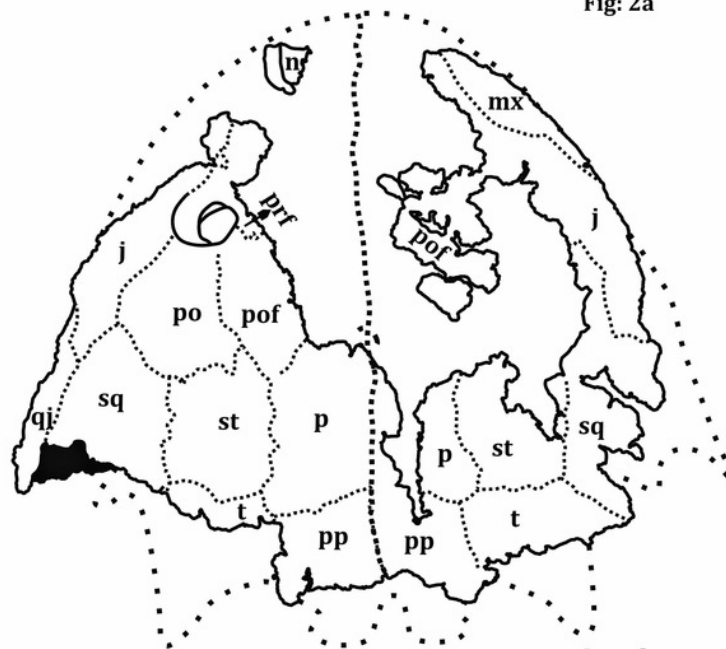
Fig: 2a

10 cm

Fig: 2b

Figure 3

Palatal surface of the skull of ISI A 202 *Compsocerops tikiensis* sp. nov.

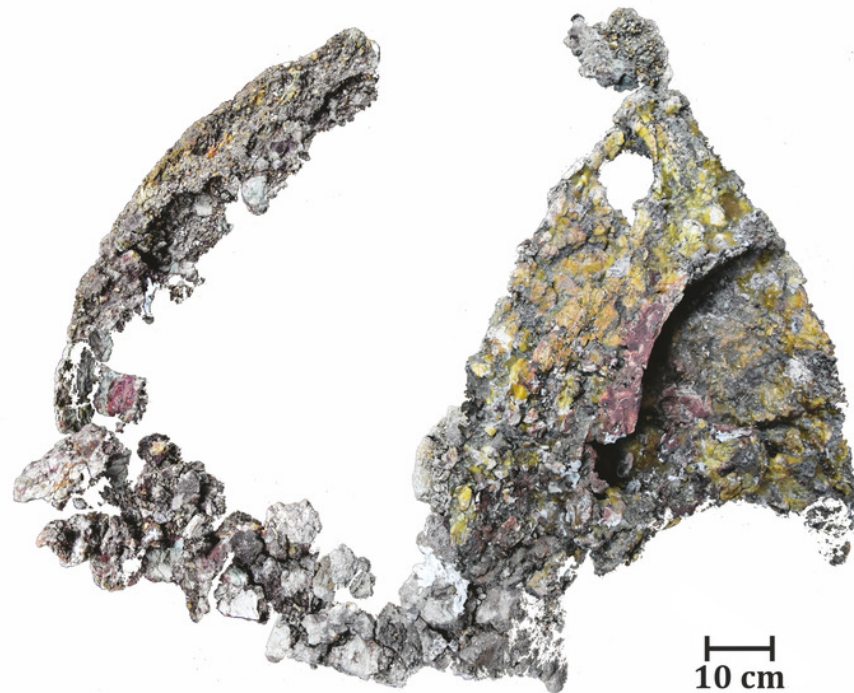
a. Reconstructed photograph of the palatal surface of the skull of ISI A 202. Scale bar = 10 cm. b. Line drawing showing the disposition of the preserved bones in the dorsal part of the skull roof in ISI A 202. The abbreviation stated in the figure are as follows: ect = ectopterygoid, eo = eoccipital, pal = palatine, ps= parasphenoid, pt= pterygoid, pv= palatine vacuity, q= quadrate, stf = subtemporal foramen.

10 cm

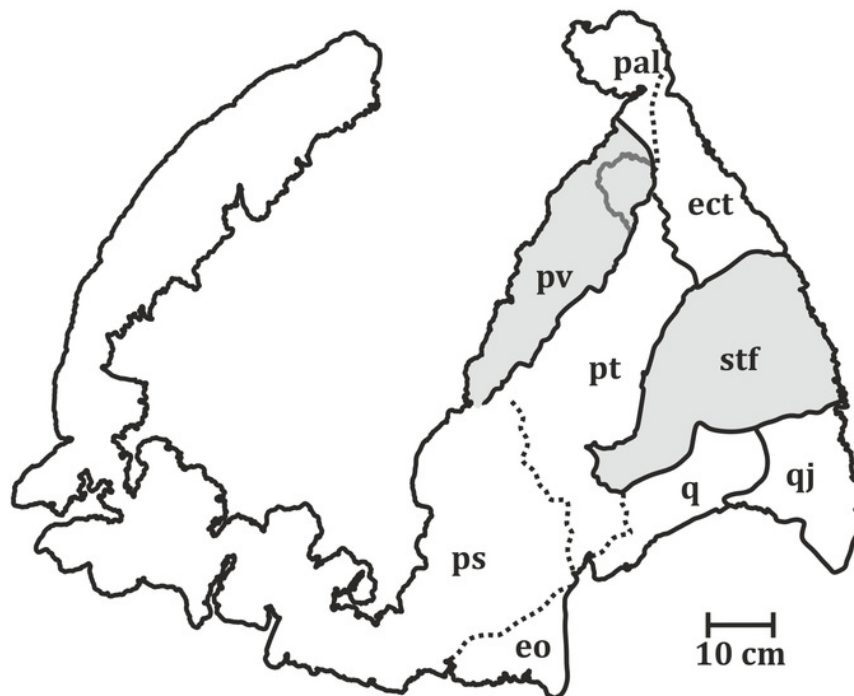
Fig: 3a

10 cm

Fig: 3b

Figure 4

The poorly preserved occiput of ISI A 202 *Compsocerops tikiensis* sp. nov.

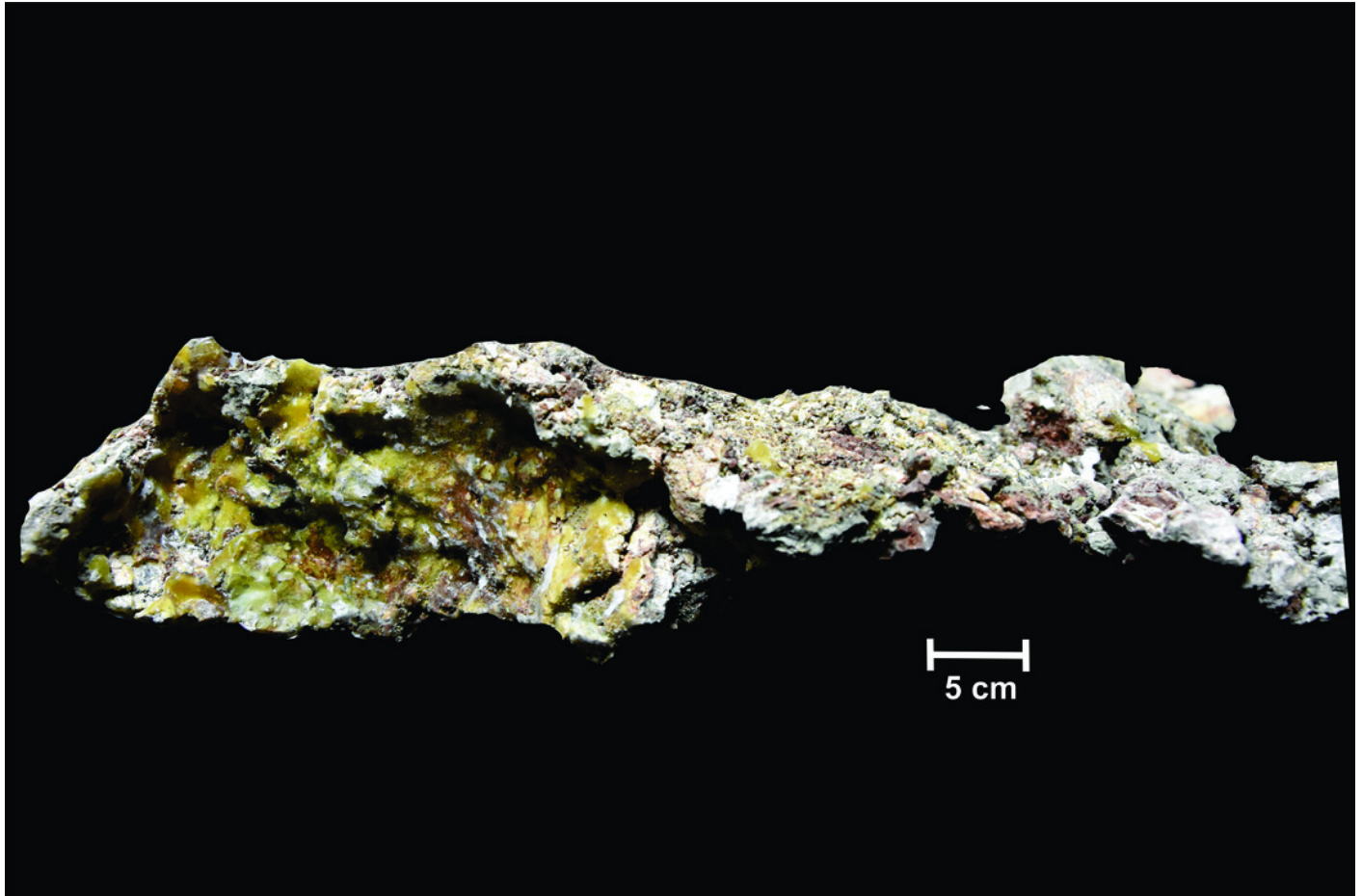



Figure 5

Dorsal view of poorly preserved left clavicle of ISI A 202 *Compsocerops tikiensis* sp. nov.

Medial edge
of right clavicle

Cleithral Process of the clavicle

10 cm

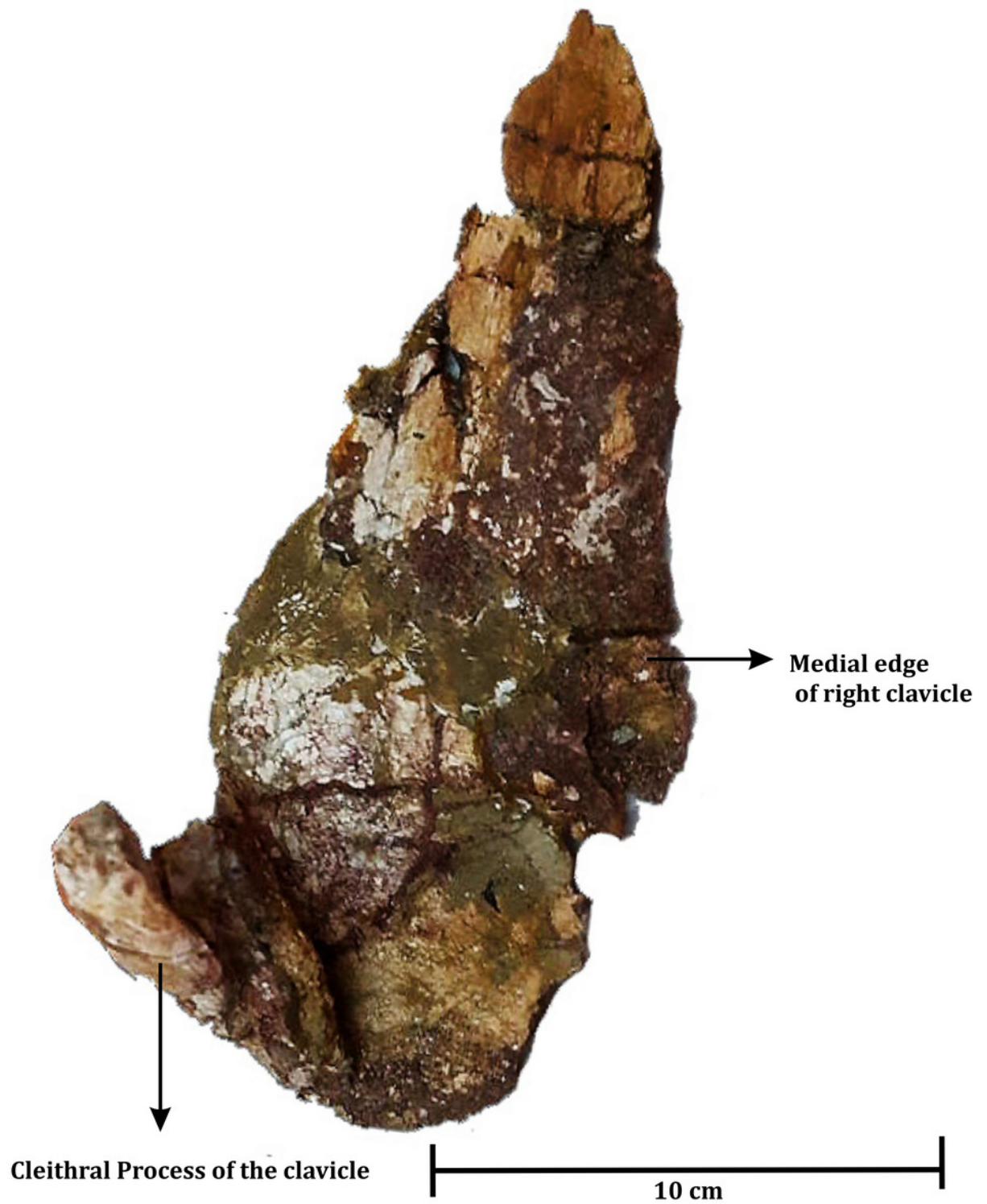



Figure 6

Geological Map showing the Tiki Formation, Rewa Basin, India.

Geological map of the Tiki Formation, Rewa Basin, India, modified after Mukherjee et al. (2012). The red dotted line shows the hypothetical faunal boundary.

N

81° 15'   81° 20'   81° 25'   81° 30'

24° 05'

F   F

F

Beohari

19°   4°

Tenduadh

10°

23° 55'   Tiki

7°   4°

Hirwah 9°

2°

Jora

5°

Hartala

10°

F

Balaundi

F

F

F

F

F

F

F

F

F

F

LEGEND

PRECAMBRIAN BASEMENT
PALI FORMATION
KARKI FORMATION
TIKI FORMATION
PARSORA FORMATION
DECCAN TRAP
.... FAUNAL BOUNDARY

F
    FAULT LINE
F

ATTITUDE OF BEDS

5 KM

23° 40'

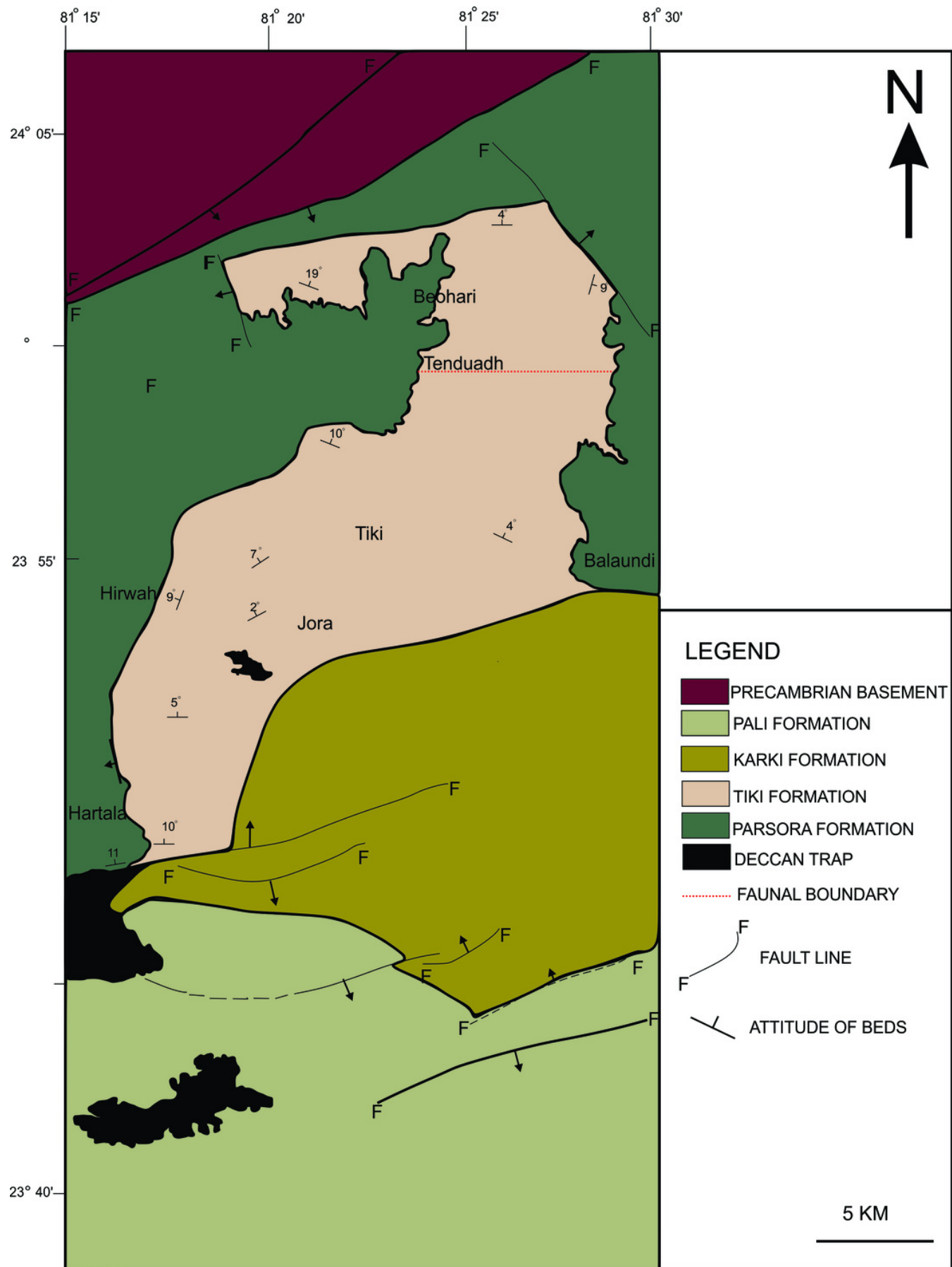



Figure 7

Field photograph showing the exposure of *Compsocerops tikiensis* sp. nov. embedded in mudstone in the Upper part of the Tiki Formation. Image taken by the authors during field season 2019.

Figure 8

Lithologs of the Tiki Formation.

a. Litholog in the Jora Nala Section in the Lower Tiki Formation. b. Litholog in the Lower part of Tiki Formation modified after Mukherjee et al. (2012). c. Litholog of the Tiki Formation modified after Kumar and Sharma (2019).

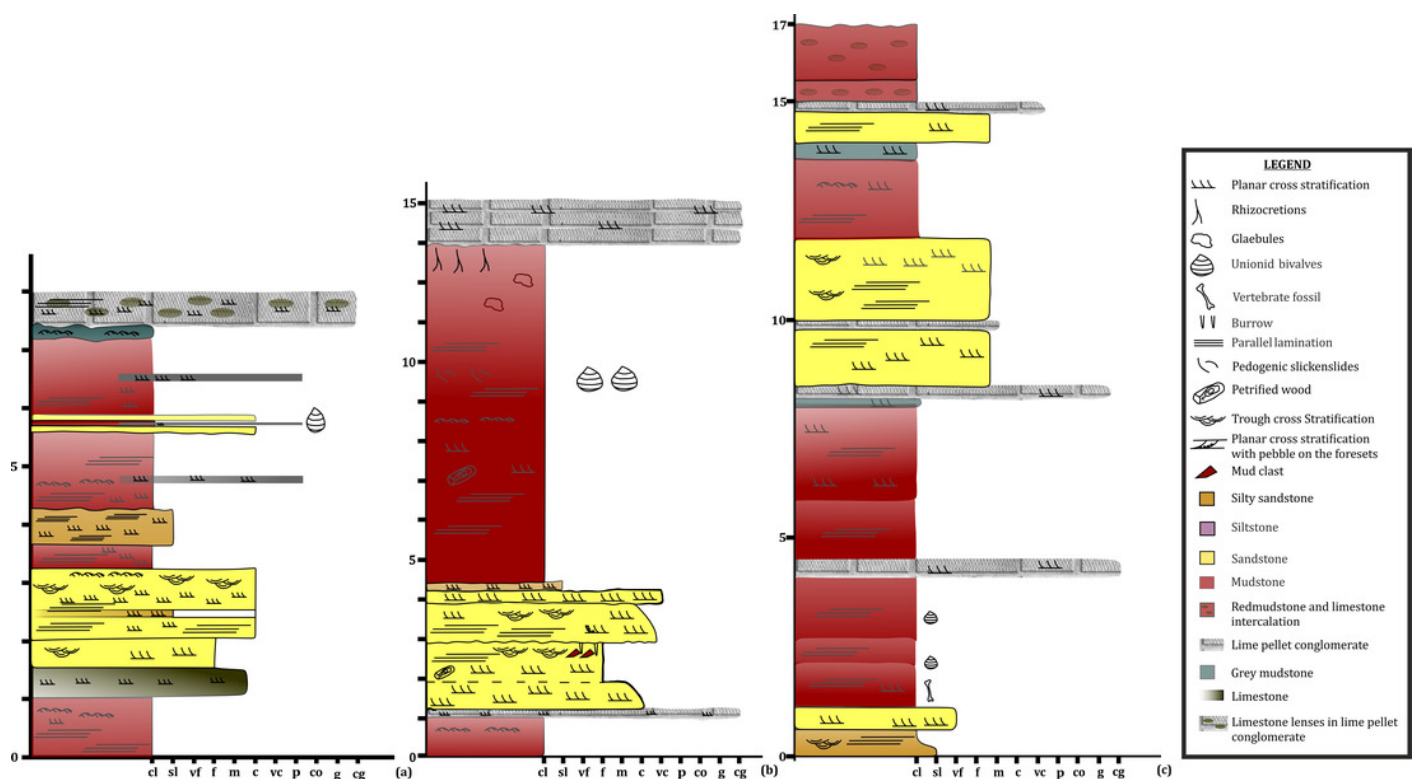



Figure 9

Field photograph of the sand-mud alternation in the Tiki Formation near Tenduadh. Photograph taken by the authors during field season 2019.

a. Trough cross- bedded sandstone in the Tiki Formation b. Extensive mudstone in the Tiki Formation.

Figure 10

Geological map of the Maleri Formation, Pranhita-Godavari Valley Basin, India

Geological map modified after Kutty and Sengupta (1989), Dasgupta et al. (2017) showing the sand- mud alternations in the Maleri Formation, Pranhita- Godavari Valley Basin, India. The green line represents the faunal boundary that occurred due to the faunal turnover from the Carnian Lower Maleri to the Norian Upper Maleri Formation.

Boundary between Upper and Lower
Dharmaram Fauna

Boundary between
Upper and Lower
Maleri Fauna

2m

Fault

Dip and Strike

Kota Fm.

Dharmaram Fm.
→Sandstone
→Mudstone
Maleri Fm.
→Sandstone
→Mudstone
Bhimaram Fm.

Yerrapalli Fm.

Kamthi Fm.

Poor/No Outcrop

Undifferentiated
Dharmaram Fm.
Calcirudite Bands

Carnian
Norian
Rhaetian
C. cosgriffi
P. maleriensis

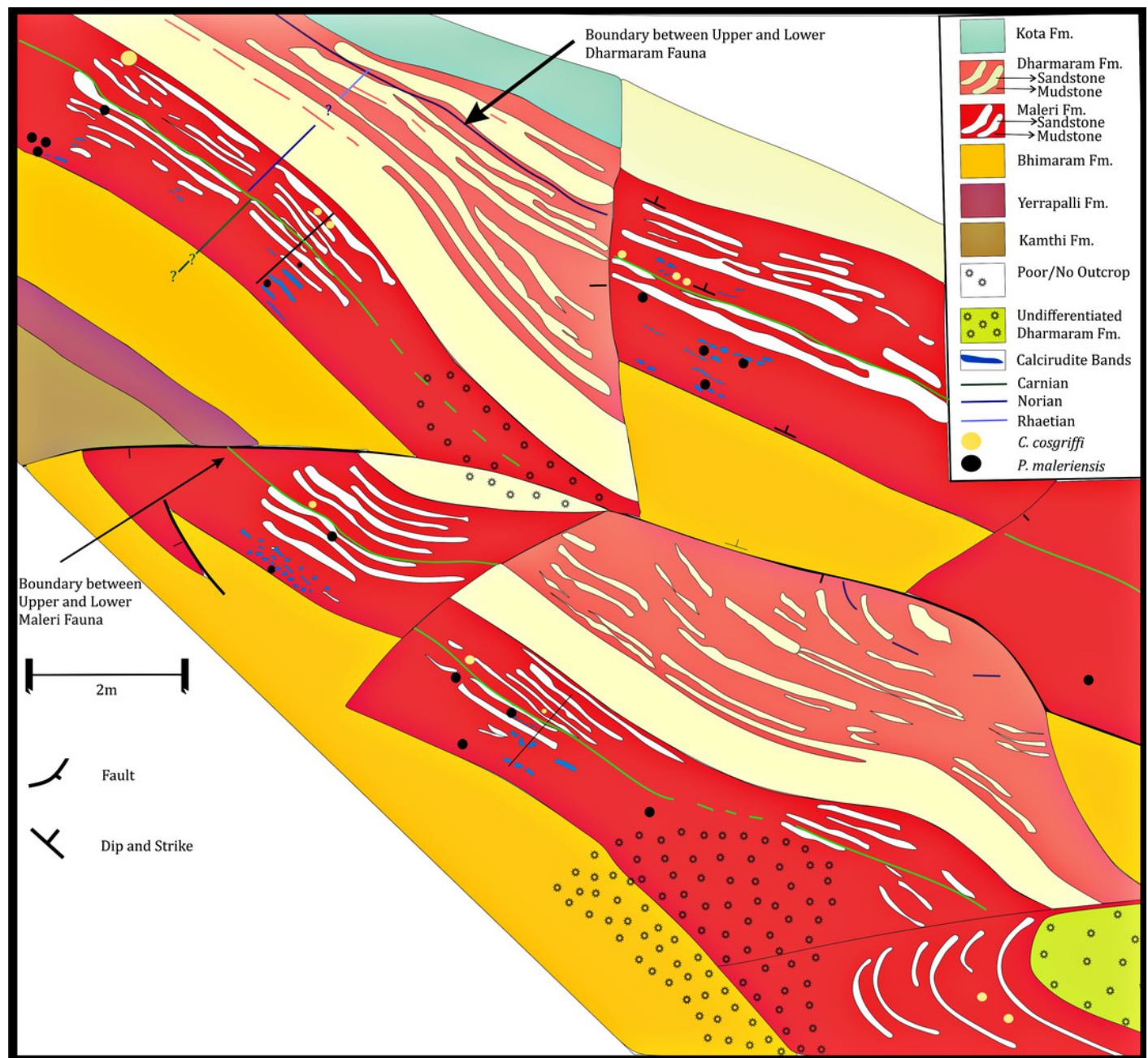



Figure 11

Litholog of the Maleri Formation modified after Kutty and Sengupta (1989).

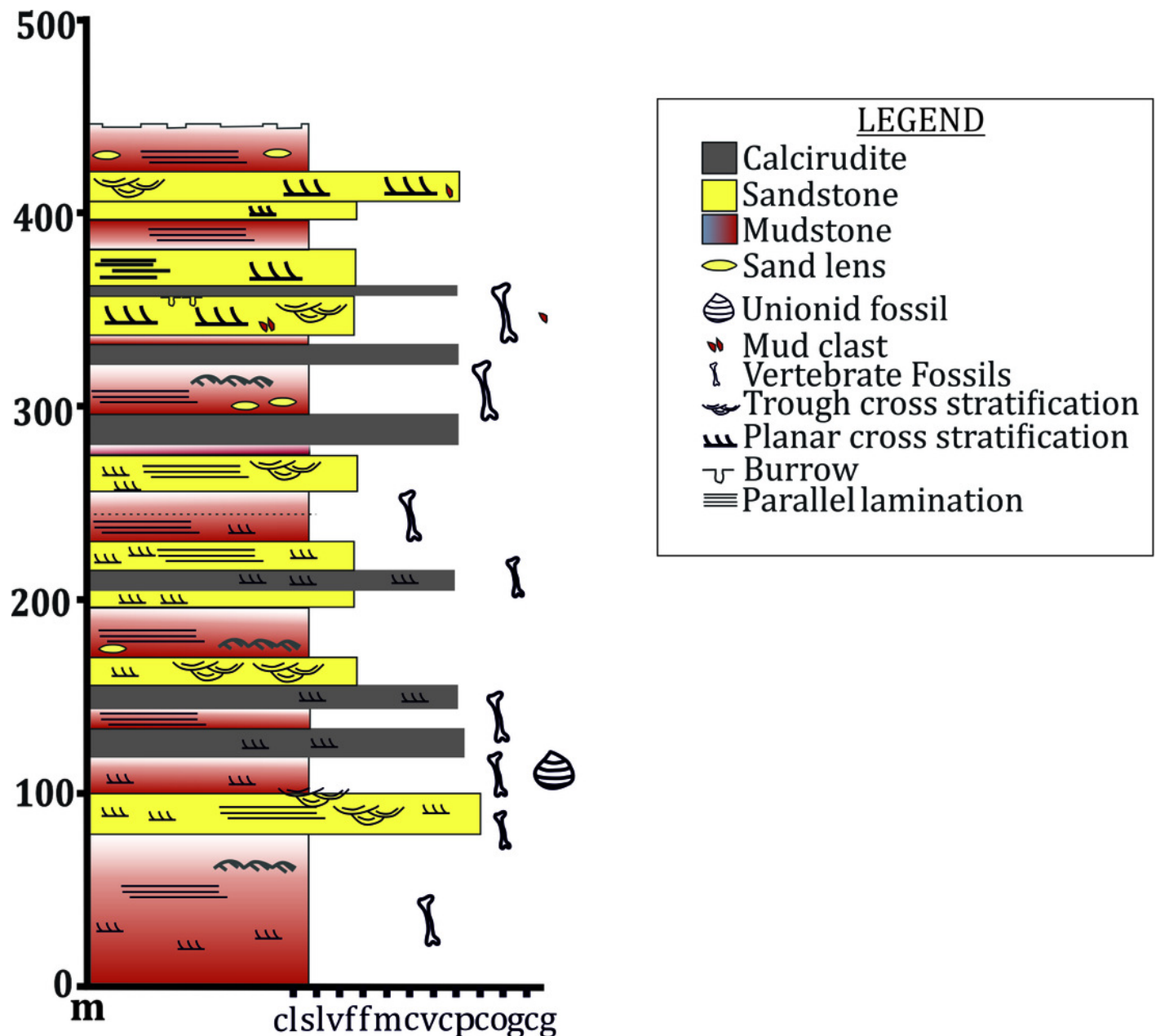



Figure 12

Field photograph showing the abundance of red mudstone in the basal part of the Maleri Formation. Image taken by the authors during field season 2015 at Pranhita- Godavari Valley.