CHAPTER - 4
Animal Sediment Relationship

1. ZONE WISE DISTRIBUTION/ HABITAT/ MICROHABITAT PREFERENCE

    1.1. *Uca lactea annulipes*

    1.2. *Macrophthalmus depressus*

    1.3. *Macrophthalmus dilatatus*

    1.4. *Dotilla crepsyrodactyla*

    1.5. *Scylla serrata*

    1.6. *Cardisoma carnifex*

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    1.9. *Mudskipper sp.*

    1.10. *Amphipod/Isopod*

    1.11. Megacephala insect larva

    1.12. *Assiminea sp.*

    1.13. Spider sp.

    1.14. Birds

Benthos are amongst the sensitive forms in estuarine system which is influenced by water as well as changing sediment characteristics and chemistry. Being associated directly with sediments, benthic animals shows a great affinity towards sediment/substrate preference and further more behave depending on the microhabitat availability. Thus a sediment relationship can be established relating the environmental/habitat factors with benthic animal. Downstream site Kamboi showed a vast intertidal area and gradient of zones which provided suitable habitat/microhabitat and niche for benthic forms. Their displays in response to different factors can be reflected by various behavioural patterns like selection of habitat/microhabitat, zonal preference, burrow type and pattern, subsurface burrow architecture, feeding and foraging, burrowing/feeding pellets.

Kamboi (downstream of the Mahi estuary) thus, was the ideal site to study animal sediment relationship due to its diversity and approachable habitat. Furthermore, brachyuran crabs were the dominant benthic species which showed highest interpretable displays in terms of their burrowing pattern and other displays and thus was the foremost reason for their predominant study. Even it was not possible to study all species for their sediment relationship.

1. ZONE WISE DISTRIBUTION/ HABITAT/ MICROHABITAT PREFERENCE

As discussed above most of the benthic species showed affinity towards specific substratum and likewise their distribution restricted to specific zone.

Zone 2 was predominantly covered by coastal grass and silty in composition. The area was only preferred by *Uca lactea annulipes*. Moreover, few arthropods like ants, beetles also inhabited the area as the area remained dry most of the time. Table 4.1 shows the sediment composition of each zone with respective dwellers of that particular zone. Zone 3 with more silt and clay was the best preferred zone in terms of density of crabs. Even, zone 4 showed two distinct microhabitats; a gentle beach slope and a runnel system with pools and patches of hard substratum (Plate 3c). The occasionally exposed hard substrata towards lower intertidal area showed massive deposit and perforation harbouring high density of fauna. On examination (removing superficial sediment) it was seen that the inner portion was harder (Plate 3e) not allowing animal perforation and had a well defined soup ground at the base (Plate 3d). In case of *mudskipper sp.* they mostly preferred a more watery condition within the zone and hence forth use to create depression in surrounding of their burrow to facilitate water logging. Moreover, the shallow water pools were occupied by mudskipper young ones and at some instances nemertine worm. A higher affinity to watery (loose) substratum was seen by polychete, *Neries sp.* which also inhibited sandy substratum at zone 5 in higher density, though the encounter rate of their juvenile form was more frequent. In many cases, in the exposed ends a fine layering of sediment was seen indicative of regular tidal deposition (Plate 3 a & b).

D.clepsydrodactyla mostly preferred a gentle slope within Zone 4 mosaic with fine sandy plaster mixed with silt (Plate 9b). In Zone 5, the hydrodynamics and the bed structures formed various types of rippels ranging from large to very small ones which provided a distinct microhabitat to animals (Plate 4). The same species distinctly used two different microhabitats and made a niche selection. Towards the initial flat fine sand flat of zone 5, the species use to have a normal burrow in high density avoiding the pools and the runnel system. While, moving towards ripples down the same zone, the species used to occupy ripples in two fashions depending on the type of ripples. In case of loose (partially formed) ripples with very shallow water, the species use to share a microhabitat i.e. crest of ripple and use to form burrow in group (Plate 9 g & f) while in same of well formed ripples with compact sediments, the species solitarily used ripple crest (Plate 9h).

1.1. *Uca lactea annulipes* (Plate 5 & 6)

Habitat/microhabitat preference: *Uca lactea annulipes* was one of the dominant crab species and preferred muddy substratum which allow easy and deep burrowing. The species occupied zone 2 and 3, though the density of species was lower at zone due. The zones do not showed a varied type of habitat categories. Interestingly, the species showed large patches of exclusive males and/or females during some instances.

Burrowing pattern: *Uca lactea* was one of the prominent burrower found at Kamboi mudflat. The burrow openings were almost circular with average diameter of 9.65 mm ±1.94 mm (Min. 5 mm to Max. 17 mm). The species showed no external sculpture in terms of dome or a chimney over the burrow opening. The expelled burrowing sediments were usually dumped on one side which later on formed a small bulge. The burrowing pellets were usually oblong in case of females and large balls in case of males with well developed chela (Plate 5 c-e). The net wet weight of burrowing pellets ranged from 5.42g to 27.75g with an average of 15.66±7.87g.

Burrow morphometry: The species usually prepared two types of burrows viz. 'S' and 'J' shaped (Plate 1b). The burrows were simple, with single entrance and unbranched with distinct features like burrow opening, burrow neck, main shaft and different chambers (Plate 1a). The burrows were generally angular, making a ground angle yet not too much prominently distinct (Plate 1c).

The species was distributed in two distinct zones (Zone 2 and 3). Though the overall structure of the burrow remained same in both the zones, a remarkable difference in burrow morphometry was noted between two zones. Different morphometric evaluations were taken of casted burrow for both the zones (Table 4.2 and 4.4). A significant difference in depth and total length of burrow was seen between two zones wherein depth of burrow in zone 2 was more than double compared to Zone 3 (Plate 2, Fig. 4.1). Other morphometric dimensions do not showed prominent difference between two zones.

The burrow casted showed peculiar resting chambers (Plate 2) in the main shaft of burrow. Resting chambers are the bulged spaces in the crab burrow which is used for resting, breeding and hibernating during high tide events. The diameter of resting chambers was relatively higher (4-8mm) as compared to the diameter of main shaft of the burrow. A Pearson correlation was applied between different morphometric parameters at both the zones. Significant correlation was seen between the total length/depth of the burrow and number of resting chambers suggesting increase in number of resting chambers with increase in depth/total length of the burrow which was very well evident in Zone-2 (Table 4.3). In case of Zone-3 a positive correlation was observed between total length and number of bending points (NBP) (Table 4.5). Other parameters showed no significant interpretable correlation in both the zones. Burrow diameter (BD), Number of resting chambers (NRC), measn shaft diameter (MSD) etc. were slightly more in Zone -2 as compared to Zone 3 (Fig.4.2 & 4.4). Though no significant trend was seen in ground angle/degree (GD) in both the zones (Fig.4.4)

Behaviour: As a peculiar character of fiddler crab, *U. lactea* showed a waving display using larger chela (Plate 5b). As part of burrowing display, the crabs usually digged their burrow using their chela followed by preparation of sediment balls/pellets which were thrown out in nearby vicinity of the burrow. In case of male crab with larger chela, the pellets/mud balls were comparatively larger and were carried between the larger chela and the walking legs and were expelled near the burrow (Plate 5c-e). The males showed a prominent courtship display wherein the male waves the larger chela against female and slowly drives her to the burrow for successful mating (Plate 6h). Moreover, male crab displayed a territorial behaviour, doesn't allowing other male to enter its premises around burrow (Plate 6g).

1.2. *Macrophthalmus depressus:* (Plate 7)

Habitat/microhabitat preference: *M. depressus* preferred Zone 3 and 4 having notable amount of silt and clay (Plate 7 a & b). The species showed a dominant density in the area. The species formed a scarlet like pattern with their expelled pellets on the zone which evident their substratum preference.

Burrowing pattern: Externally, burrow opening of *M. depressus* showed pretty good similarity with that of *U. lactea* and were often confusing. The main difference between burrow openings was the burrow diameter where diameter of *U. lactea* was slightly larger compared to *M. depressus*. Moreover, the surrounding sculptures may provide the distinguishing features between the species. Average burrow diameter of the species was noted to be 9.65 ± 1.94 (Min. 5mm – Max. 11mm). The burrow opening was usually surrounded by expelled/burrowing pellets and feeding pellets (Plate 7c). The wet weight of burrowing pellets ranged from 0.69 g to 17.82 g with a mean of 5.45 g per burrow.

Burrow morphometry: *M.depressus* formed a simple and unbranched burrow with a single burrow entrance. The burrow architecture was similar to that was like *Uca lactea* and mostly 'J' shaped.

Behaviour: *M.depressus* was the dominant species at downstream mudflat. After a specific interval of low tide, the species actively starts burrowing. The second phase follows is a feeding phase, wherein the species starts actively feeing on the adjacent area surrounding the burrow (Plate 7 e & f). The species scraps the sediment on the mudflat and rolls them down from the ventral abdominal side in form of small balls/pellets. Mean wet weight of the feeding pellet per crab is 0.76 ± 0.40g. Moreover, the weight of feeding pellets ranged from 1.46 g to 0.1g in different age groups of the crab species. With progress in behaviour study, it was noted that the species foraged an upto an average the distance 6.01± 2.54 cm with maximum distance of 13cm and minimum distance of 2 cm in the vicinity of the burrow. The species, at certain occurrence showed a typical waving of both the chela at a time, though the aim of the display was not too clear.

Further, the species was one of the most sensitive species which swiftly entered the nearest burrow even at very slight disturbance/movement at few meters. After entering the burrow, the species passed some time in the burrow allowing the predatory risk to pass on. On feeling safe, the species slightly takes part of its body out from the burrow with raised eyestalk to check the surrounding safety. After safely emerging from the burrow, the animal initially feeds in close vicinity to the burrow and later on feeling the atmosphere safe starts exploring the territory freely. Finally, as the high tide arrival time comes closer, activity of the species gradually decreases; the animal closes its burrow entrance by plugging it from inside and remains inside the burrow.

1.3. *Macrophthalmus dilatatus* (Plate 8)

Habitat/microhabitat preference: The crab species was seen mostly distributed to the lower intertidal area which were dominated by fine sandy bed (> 63% fine sand), different type of ripples. Very specifically within the zone, the species preferred to inhibit area with sandy ripples as a microhabitat (Plate 8 a & c).

Burrowing pattern: The crab showed a typical burrowing pattern within the sandy ripples. The crab specially burrows on at the base of the ripple crest (Plate 8 a, b). Further, the burrow entrance was small and horizontally oblong (dorsoventrally depressed). The entrance and the surrounding area were not sculptured with any chimney or dome. Moreover, no burrowing traces in form or excavated sediment or sediment pellets are visible near the entrance of the burrow. Unlike *D.crepsydrodactyla,* the burrows are mostly scattered and away from each other.

Burrow morphometry: The burrows were mostly inclined or horizontal from the base of the ripple crest. The burrows were usually shallow and unbranched with single entrance. To know whether there was any inclination of burrow entrance towards in specific direction, direction evaluation was done using compass. From the available data it was seen that major portion (30 %) of the burrow openings faced North-west (NW) direction (Fig.4.5).

Behaviour: The crabs were sensitive and mostly seen foraging on the lower intertidal sandy plain. The species was reported feeding scraping the fine sandy substrate specially in watery areas (Plate 8e). Moreover, unlike *M. depressus*, the species was seen foraging upto long distances from the burrow. Also the species was seen to be fond of water and seen many times foraging/feeding in the shallow water doges between the ripples (Plate 8e). The long eyestalks of the species were typically kept upright for the vigilance whenever the crab remained underwater in the shallow water pools (< 2 inch depth) (Plate 8e,g).

On disturbing, the animal swiftly moved to the nearest burrow. In case of inaccessibility of the any close hide, the species either manoeuvre (shuffled) the sediments and partially burrows the body within the sediments (Plate 8f). Passing some time as it is, the animal checks the surrounding safety by just raising the eyestalks from the sediments. In case of more severity, the species simply remains as it is retracting its legs so as to camouflage with the habitat. In such cases, when the available habitat was with ripples, the animal will take a close hide in the trough (depression) of the ripple.

1.4. *Dotilla crepsyrodactyla:* (Plate 9-11)

Habitat/Microhabitat preference: *D.crepsyrodactyla* was one of the dominant crab on the lower intertidal mudflats of Kamboi. Even in terms of density the species showed its higher abundance. The species was distributed mostly from Zone 4 and 5 preferring fine sandy substratum (Zone 5) extensively compared to that mixed with silt and clay in Zone 4. In addition to that, the species showed a very keen preference at microhabitat level. Overall within the two zones, the crab was seen utilizing 3 distinct microhabitats;

i. Slope of Zone 4 with smooth carpet of fine sand.

The species in this area formed showed a good distribution, though in some cases it was patchy. The burrows were surrounded by scarlet pattern of expelled burrowing and feeding pellets. (Plate 9b)

ii. Flat lower intertidal plains of fine sand in Zone 5

This was the richest area in terms of density of crabs. Within it, some of the area was showed very high and dense population. (Plate 9c)

iii. Lower intertidal area with ripples.

The lower extension of the Zone 5 showed an area with ripples. Various type of ripples were seen forming variety of patterns which evident the hydrodynamics and churning of the tidal water. Many of the ripples showed permanent water logs in the trough (depression formed in inter-ripple space) area. Thus the species preferred crest of the ripple for burrowing (Plate 9f,g &h).

Burrowing pattern: The species formed small burrows in all the above mentioned zones with a mean burrow diameter of 5.1± 2.08mm with a range of 0.4 mm to 9mm respectively. Two type of burrows entrances were seen depending on where the burrow was made. In case of burrows made in many patches of zone 4, no sculpture was seen on or near the burrow entrance. Instead, the burrow entrance was surrounded by a design formed by feeding pellets.

In second case, the same species used to build a chimney over the burrow opening (Plate 9d). This type of sculpture was seen mostly in Zone 5. The chimneys were made up of small mudballs excavated from the burrow. The species arranged excavated/burrowing pellets on the edge of the burrow entrance subsequently by carrying them between their legs. The pellets were piled up on each other to giving a structure of chimney. Mean diameter of the chimney was 9.3± 2.31mm while the average height of the chimney was 16.2 ± 4.6mm. There was a close correlation observed between crab burrow diameter and height of the chimney (Fig.4.6) with a trend line of both running parallel to each other. The size of the pellets used to make a chimney ranged from 0.5 to 1mm (Plate 9e).

Burrow morphometry: Burrows of these species were usually simple, unbranched and with single opening. As the burrow openings were too small, it was not able to take a resin cast for detailed subsurface morphometry of the burrow. The burrows were straight and shallow ranging only to few inches. Especially in case of burrows formed on the crest of the ripple or in burrow congregation, the burrows were very shallow providing just a hide to the crab.

Behaviour: *D.crepsyrodactyla* was interesting species specially for their behaviour and displayed some of the fine behavioural displays. Some time after the tide retreats, the species starts building burrow (Plate 11). After completion of burrowing, the species starts chimney formation in case of Zone 5 while the species in Zone 4 which do not show chimney formation, starts actively feeding on the nearby areas surrounding the burrow(Plate 10i). The species after successful completion of burrow, starts actively feeding in nearby areas and was even noted foraging to long distances (Plate 10 j, k).

The species with the help of specified chelipeds scraps the surrounding area of burrow forming different pattern and scratch marks evidencing the feeding area explored (10 i & m). In order to calculate the magnitude of bioturbation the species does, the feeding area exploration was calculated in terms of total area explored and perimeter of total area explored. Moreover, the maximum distance travelled for feeding was 9.74 ± 3.97 cm. The average area explored by the crab in Zone 4 was 79.33 ± 53.8 sq.cm. Though not too much specific, 25% correlation was obtained between burrow diameters and burrow area suggesting larger the burrow diameter, more the feeding area covered in many cases (Fig. 4.7).

The crabs were not too much sensitive and in many cases remained in groups and moved to short distance in groups whenever disturbed during foraging away from the burrow. In case of close burrow opening, the crab entered the burrow on disturbance while feeding. Very interestingly, before 1 or half hour of the high tide arrival time activity of the species gradually ceases, the animal closes its burrow entrance and remains inside the burrow. In case of burrows without chimney, it simply moves some sediment mass against burrow from inner side while in case of chimney, the animal plugs the entrance of chimney using a sediment pellet/ball (Plate 10n). Important events like close clustering of burrows, utilization of ripple crest, mass plugging of burrow entrance etc can be presented by Plate 12.

1.5. *Scylla serrata* (Plate 13 a-d)

Habitat/microhabitat preference: The species is commonly known as mud-crab. Yet mostly the species was noticed in the crevices/Burrows of partially hardened substratum. Lower reaches of zone 4 and occasionally exposed part of zone 5 with partially hardened sediment was mostly preferred by the crab (Plate 13 a & b). Less frequently, the species was seen in the burrows at zone 3 and 4 having some soup ground.

Burrowing pattern and Burrow morphometry: Less is known about the burrowing pattern and subsurface of the species. The species showed a horizontal burrow in partially hardened sediment more or less parallel to the intertidal bed. The burrow entrance was usually dorsoventrally depressed and slightly oblong. The burrow were generally long and branched with inner/terminal end enough moist and watery. The species mostly rested at the terminal end deep inside the burrow. (Plate 13 b-d)

Behaviour: As the sighting of the species was not so frequent, very less is known about the behaviour of the species. Moreover, the species spend much of its time in the burrow which made its observation difficult. The species was much sensitive and not a swift runner.

1.6. *Cardisoma carnifex* (Plate 14)

Habitat/microhabitat preference: *Cardisoma carnifex*, commonly known to be a land adapted crab and is reported in either mangroves or terrestrial habitats in many of the studies. In Mahi estuary, specially Kamboi, the species showed its presence mostly towards the upper intertidal reaches in Zone 3 and initial part of Zone 4. The animal preferred substratum dominant in silt and clay for making a keenly architected burrow. Moreover, looking to the most of the burrows, the species mostly used slightly loose/watery ground for making a burrow (Plate 14a).

Burrowing pattern: Burrow of these species was typical and of its kind which marked their presence in the habitat. Burrow entrance/opening was circular with some portion formed with slope which was used as a passage for animal to move in and out (Plate 14 c & d). Further, the animal use to dump the burrow handsome amount of excavation nearby the passage (Plate 14b). The route mostly preserved the traces of animal walking through it.

Burrow morphometry: Among the 5 different burrowing species found in the area, *C. carnifex* had a typical and interesting burrow. The burrow entrance was nearly 1-1.5 inch in diameter. The burrows were complex, branched and with single entrance and horizontally spread instead of vertical in depth (burrow depth ~ 0.5-1ft from the surface). The total length of the burrow of *C. carnifex* was highest as compared to the burrow of other species found in the area. The highest recorded size of the total length of the burrow was 7.6 ft (225cm). Instead of completely cylindrical, burrow was slightly compressed making the shape oblong and comprised of many small branches with dead ends (Plate 15a). The lining of the burrow was moist with a thin coat of clayey soup whenever traced or digged (Plate 14f).

Behaviour: The crab showed well adaptiveness to terrestrial habitat which was even reflected from its bodily adaptations. The crab showed prominent terrestrial adapted features specially well developed walking legs and tough carapace. Also, prominent and bulky cheliped of the crab proved its capacity of excavating a long and branched burrow. The species was rarely seen actively feeding or foraging, instead it used to dwell the interiors of the burrow.

1.7. *Matuta lunaris* (Plate 13 e-g)

Habitat/microhabitat preference: The species preferred Zone 5 and its extensions and was very much confined to fine sandy substratum. *M. lunaris* does not make burrow of any kind which was even visible looking to its appendages.

Behaviour: *M. lunaris* is a predatory species predating on other species seen in its habitat. *M.dilatatus* was the only species abundantly sharing the habitat and was a good prey of *M. Lunaris* (Palte 13 f). The species when alarmed shuffles the sandy substratum and partially buries itself (Plate 13g). Additionally the carapace colour and pattern camouflages the find sandy substrata. The crab slowly approaches near the prey species and buries itself partially or stands still retracting its appendages. As the prey reaches in attacking range of the species, it gets hold of the species /prey using its powerful and armed chela.

Comparison of burrow diameter of five different crab species which were seen burrowing is shown in Fig. 4.8. *Cardisoma carniex* showed the highest burrow diameter with an average of 41mm followed by *M. dilatatus, U. lactea, M. depressus* and *D. crapsydrodactyla* respectively. The subsurface burrow structure of different crab species in which the resin casting was possible is shown in Plate 15 represented with their diagrammatic clone.

1.8. Important bioturbatory species

Bioturbation is a process of upwelling of the aquatic sediments aided by the benthic animals. It is one of the vital processes taking place at any aquatic/marine ecosystem. During the present study, the bioturbatory potential of few of the macorfaunal species was studied to understand their contribution to the prevailing habitat/environment. Burrowing was the most common and cost efficient activity reported by many of the crab species which was followed by feeding. Following species were reported in order or their bioturbatory potential on the Mahi estuarine floor;

i. *D. crepsydrodactyla*

ii. *Uca lactea*

iii. *Macrophthalmus depressus*

iv. *Cardisoma carnifex*

v. *Mudskipper sp.*

vi. Amphipod/Isopod

vii. Insect larva

viii. Spider

The burrow excavation done by different species was the main assessment tool to calculate their bioturbatory potential. Three brachyuran species mainly taken in account were *Uca lactea, M.depressus* and *D. crepsydrodactyla*. Bioturbation done by single species annually and by community per sq.m was calculated derived from their density (Table 4.6). Individually, *Uca lactea* was showed highest turnover with a rate of 11.43kg/crab/year followed by *D. crepsydrodactyla* 7.2kg and *M.depressus* 3.9kg per year (Fig. 4.9). A different picture emerged on calculating the data with their population (density) as bioturbation per square meter by members of same species. As a whole, *D. crespydrodactyla* contributed with highest level of bioturbation of 1526 kg/sq.m/year followed by *M.depressus* (329kg) and *U. lactea* (327 kg) (Fig. 4.10).

Additionally an impressive figure of surface processing was seen by *Dotilla crepsydrodactyla* through feeding area exploration. A single species explored an average of 124 sq.cm of area during a single tide giving 248sq.cm per two low tides a day, yielding 90520sq.cm i.e. **0.9 sq.km annually**.

1.9. *Mudskipper sp.* **(Plate 16)**

Habitat/microhabitat preference: The species as the name justifies preferred mudflats and were seen scattered in two distinct zones viz. Zone 3 and 4. Further the species is mostly prefers watery and loose muddy substratum. Very frequently the species was seen preferring muddy substrata with water pools and water logging.

Burrowing pattern and Burrow morphometry: Characteristically, the species build a typical burrow with no sculpture on the edges. Yet in few cases, the signs of the burrow excavations were seen on the edges. As discussed above, the soft muddy substratum was mostly preferred for burrowing and the burrows confined mostly towards low tide marks. In freshly formed burrows the burrow entrance was not very circular instead the entrance was slightly deflected making an oval shape of the entrance. Though, in cases of young one, the burrow was slightly smaller and circular entrance. The burrow entrance diameter ranged from 0.5 to 2 inches in case of larger animal. Burrows were simple or branched, complex and were filled with water (Plate 16c_). In many cases, the animal was seen making burrow with multiple entrance in close proximity (Plate 16 b). As most of the burrows were filled with water, it was not able to go for resin casting or wax casting and have a detailed burrow cast. But the detailed tracing of the burrow gave an insight to the subsurface morphometry revealing a complex and horizontal spread of the burrow. The foraging trail marks of the species in the close proximity of the burrow evidence the presence of animal in the burrow (Plate 16 f, Plate 17 d-e). By making the adjacent area of the burrow slightly depressed, the animal finely modifies and creates a microhabitat allowing water storage for longer duration (Plate 18).

Behaviour: Not much is known about the behavioural aspects of the species as it was not much possible to closely monitor the species. The animal is usually very shy and takes its place in burrow mostly as and when disturbed or on movement at few meters. Soon after the tide recedes, the animal is actively seen walking and hopping on the swampy mudflats (Plate 16a). After feeding, the animal forms the burrow by excavating the big pellets in the buccal cavity and dumping near the burrow entrance (Plate 18c). The young ones were also seen freely swimming in small water pools or water runnels

(Plate 16e). These foraging of young ones create a typical design in the small tidal pools as well as superficial structures (Plate 17 a-c). Very typically, the mudskipper was seen making a slight depression around the burrow or on the edge side which facilitates the logging of receding water and facilitate a moist habitat for longer time (Plate 18a). During the course of the study, it was observed that density of mudskippers on the southern bank (Kamboi) of Mahi estuary was less as compared to that on the northern bank (Badalpur and Khambhat).

1.10. *Amphipod/Isopod (Spheroma sp.)* **(Plate 19 & 20)**

Habitat/ microhabitat preference: Both the amphipod and isopod species obtained shared a common microhabitat. The species were confined to terminal portion of Zone 4. Instead of sandy or muddy substrata, the species preferred inhabited hard substratum (partially hardened sediment). (Plate 19 a &b)

Burrowing pattern and burrow morphometry: Both the species shared a common habitat. The substrata were highly perforated by the small burrows and channels. These burrows were used by the *Spheroma sp.*(Isopod) and amphipod sp. The burrows were highly complex and interconnected having a average diameter of 4.13± 0.64 mm. The isopod sp. were very rarely seen in the tidal pools or mudflat. Both the species were found actively burrowing in the sediment block avoiding the hard and calcrete within the block (Plate 20 a-b). A very fine plastered inner view of the burrow can be seen in Plate 20f. A very negligible difference in burrow diameter was noticed on close examination of the burrow which suggests probability of common burrow preference. CT scan of the sediment block densely occupied by both the species revealed interesting facts about various burrow diameters, density at various places in the sediment block and the 3D view of the inner architecture of the complex burrow within the sediment. Moreover an inner 3D view was available showing the condition of sediment block from inner side (Plate 26-31).

1.11. Megacephala insect larva: (Plate 21a-c)

These were predominantly seen from zone 2 to zone 4. The larva formed a superficial burrows which was in the form of very fine sediment pellets pilled over the burrow (Plate 21 a-c). In fewer cases the foraging by more developed form was seen in form of superficial pathway (Plate 21c).

1.12. *Assiminea sp.* (Plate 21 d-f)

The species were seen more after the tide recedes and showed its distribution in Zone 3 and 4. The species in many cases were seen burrowing in the water logged mudflat by whirling action (Plate 21d). At few instances the species was seen occupying its place in hard substrata perforations and expelling the excreta in form of fine structure (Plate 21f).

1.13. Spider sp. (Plate 22)

The species was seen sharing the intertidal area with the other benthic forms. More interestingly, it was seen that the particular species used to form burrow similar to crab by excavating mudballs. The species confined its range in Zone 3 and preferred building burrow in settled mud. Further, the species served as one of the predator on the intertidal mudflat predating actively on crabs. During initial study period the species burrows were mistaken with that of the *M. depressus*.

1.14. Birds (Plate 23 - 25)

Though this particular group remained slightly off track to the present investigation, they served as one of the important factor in the estuarine foodchain. The waders were one of the top most predators on the estuarine mudflat. Furthermore, many of the terrestrial species occupied the Mahi estuarine system and the adjacent ravines wherein few of them directly depended on the estuarine resources. Further, the small uplands and channel bars in the estuary were utilized as a resting ground by certain species. During the study tenure, presence of crab plover (*Dromas ardeola*) was notable in the area.

Table 4.1: Zone wise sediment composition with respective occupancy of benthic macrofaunal species.

Zones	Sediment composition	Obtained Benthic Faunal species
Zone - 2	Sand -68% Silt+clay 32%	*Uca lactea, ant spp.,*
Zone - 3	Sand-33.5% Silt+clay-65.5%	*Uca lacteal, Macrophthalmus depressus, Cardisoma carnifex, Uca dussumerie, Mudskipper sp., Nereis sp., Assiminea sp., Megacephala larva.*
Zone - 4	Sand - 37% Silt+clay 63%	*Macrophthalmus depressus, Cardisoma carnifex, Dotilla clepsydrodactyla, Scylla serrata, Mudskipper sp., Neries sp., Assiminea sp., Barnacle sp.*
Zone - 5	Sand - 63% Silt+clay 37 %	*Dotilla clepsydrodactyla, Matuta lunaris, Macrophthalmus dilatatus, Assiminea sp., Spheroma sp., Amphipoda sp., Neries sp., Sipuncula sp., Donax incarnates, Nemertine sp., barnacle sp., Metapograpsus messor.*

Table 4.2: Burrow morphometry from Zone 2.

Cast No.	Burrow Diameter (mm)	Total length (cm)	Depth (cm)	Ground angle (β)	Mean shaft diam. (mm)	No. of bending points	No. of resting chamber	Diam. of resting chamber (mm)
1	10	41	39.5	130	9.75	3	2	14.5
2	10	49	46	90	12.11	2	2	20.5
3	10	38.5	33	75	13.77	1	1	22
4	11	40	32	70	13.11	1	3	16.6
5	8	40.5	34	60	11.55	1	3	16.3
6	10	24	23	115	9.85	3	2	14
7	10	25	21	95	12.66	2	2	18.5
8	9	57	47	80	13.3	1	3	20.6
9	9	15	12.5	70	11	1	0	-
10	10	20	19	95	11.6	0	1	15
11	11	61	53	105	13.5	1	4	19.5
12	7	14.5	13	125	9	1	0	-
13	12	15	13.5	95	14	1	1	20
14	9	17	15	90	14.4	0	0	0
15	9	22	19	90	12.37	2	1	24
16	9	15.5	14.5	95	16.6	0	2	21.5
17	9	13	12	85	11.6	1	0	-
18	-	16	14	75	20	1	2	24.5

Table 4.3: Showing Pearson correlation between different morphometric parameters of *Uca lactea* burrows at Zone 2.

	BD	TL	D	GA	MSD	NBP	NRC	DRC
BD	-	0.25	0.26	0.01	0.32	0.15	0.35	0.15
TL	-	-	0.99	-0.06	-0.09	0.24	0.77	0.15
D	-	-	-	0.02	-0.13	0.29	0.75	0.13
GA	-	-	-	-	-0.42	0.42	-0.09	-0.2
MSD	-	-	-	-	-	-0.45	0.2	0.3
NBP	-	-	-	-	-	-	0.19	0.15
NRC	-	-	-	-	-	-	-	0.34
DRC	-	-	-	-	-	-	-	-

Table 4.4: Burrow morphometry from Zone 3. (Z0NE – 3)

Cast No.	Burrow Diameter (mm)	Total length (cm)	Depth (cm)	Ground angle (β)	Mean shaft diam. (mm)	No. of bending points	No. of resting chamber	Diam. of resting chamber (mm)
1	10	19	15	90°	14.6	2	2	18
2	10	20	16	65°	11.6	1	0	-
3	11	23.5	18.5	60°	13.0	2	1	18
4	9	10.5	10	90°	6.2	0	0	-
5	7	9	8.5	95°	9	1	1	10
6	11	14	13	110°	12.4	1	1	14
7	9	22	18	90°	12.6	2	2	16
8	12	19	16	85°	12.6	2	2	19
9	11	20	14.5	80°	12.3	2	2	14
10	11	26	22	115°	12.8	3	2	17.5
11	9	5	4	100°	8	0	0	-
12	10	8	6.5	85°	9.75	1	0	-
13	12	19	15.5	70°	11	2	1	16
14	9	13	10.5	95°	12.8	0	1	15
15	11	17.5	15	85°	12.8	2	1	16
16	12	22	19	105°	13.8	1	1	19
17	9	6	5	90°	10.7	0	1	14
18	15	8	6.5	100°	17	0	1	19
19	12	16	14	95°	11.8	2	1	16
20	10	18	-	85°	10	unknown	1	12

Table 4.5: Showing Pearson correlation between different morphometric parameters of *Uca lactea* burrows at Zone 3.

	BD	TL	D	GA	MSD	NBP	NRC	DRC
BD	-	0.25	0.25	0.03	0.67	0.21	0.2	0.69
TL	-	-	0.98	-0.22	0.41	0.81	0.57	0.42
D	-	-	-	-0.12	0.4	0.8	0.55	0.46
GA	-	-	-	-	0.09	-0.16	0.17	0.01
MSD	-	-	-	-	-	0.3	0.56	0.8
NBP	-	-	-	-	-	-	0.65	0.22
NRC	-	-	-	-	-	-	-	0.28
DRC	-	-	-	-	-	-	-	-

Table 4.6: Showing bioturbatory output of different crab species represented as in individual as well as per sq.m density.

Species	Average crab density/sq.m	Bioturbation /crab/year (kg)	Bioturbataion/sq.m/ year (kg)
Uca lactea annulipes	28.66	11.43	327.58
Macrophthalmus depressus	83	3.97	329.51
Scopimera sp.	210	7.2	1526.7

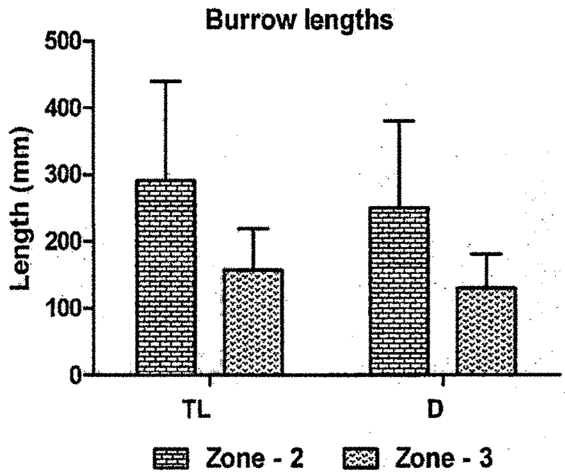

Fig. 4.1: Comparison of total length and depth of the burrows in Zone 2 & 3.

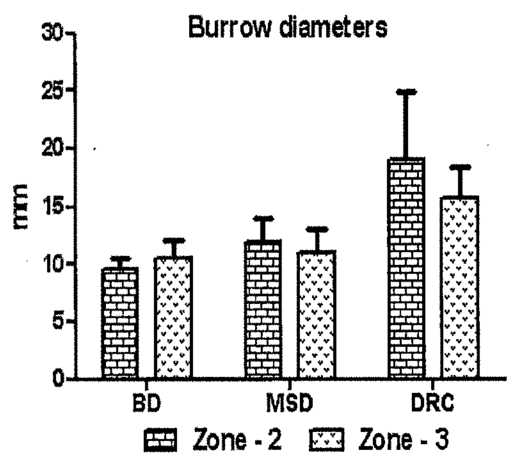

Fig.4.2: Comparison of BD, MSD and DRC.

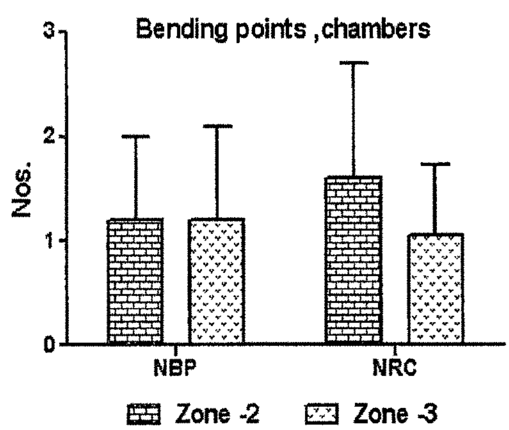

Fig. 4.3: Comparison of NBP and NRC.

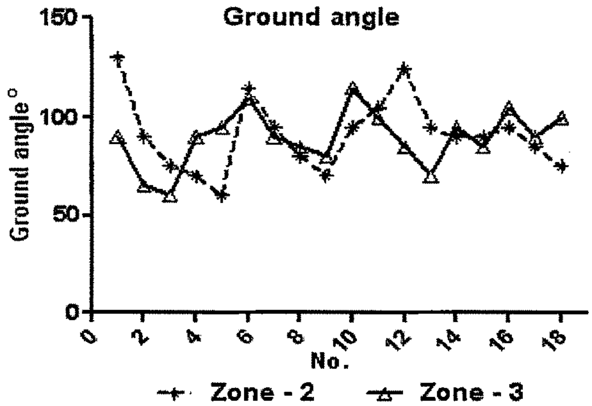

Fig.4.4: Comparison of burrow ground angle between two zones.

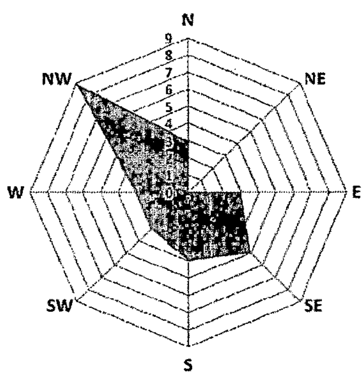

Fig. 4.5: Burrow orientation of M. dilatatus.

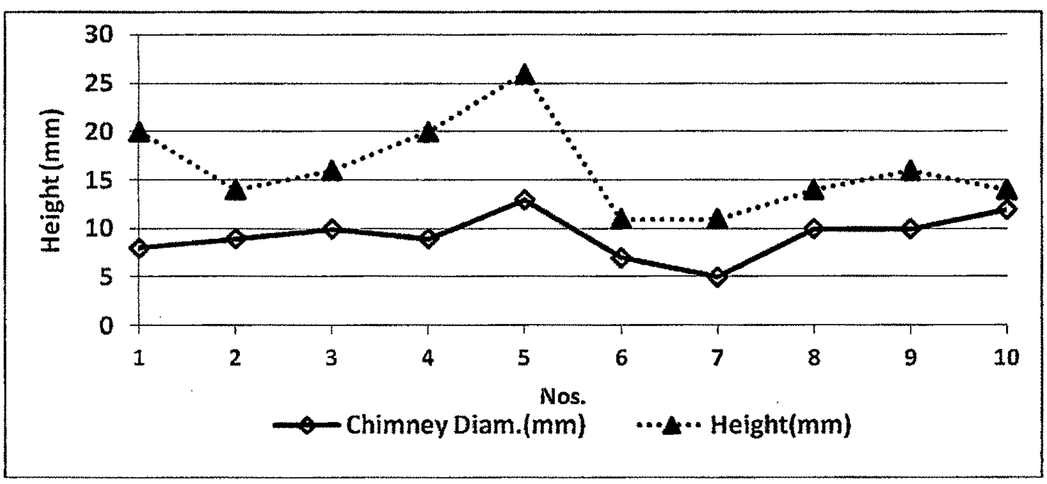

Fig. 4.6: Correlation between crab burrow diameter and chimney height.

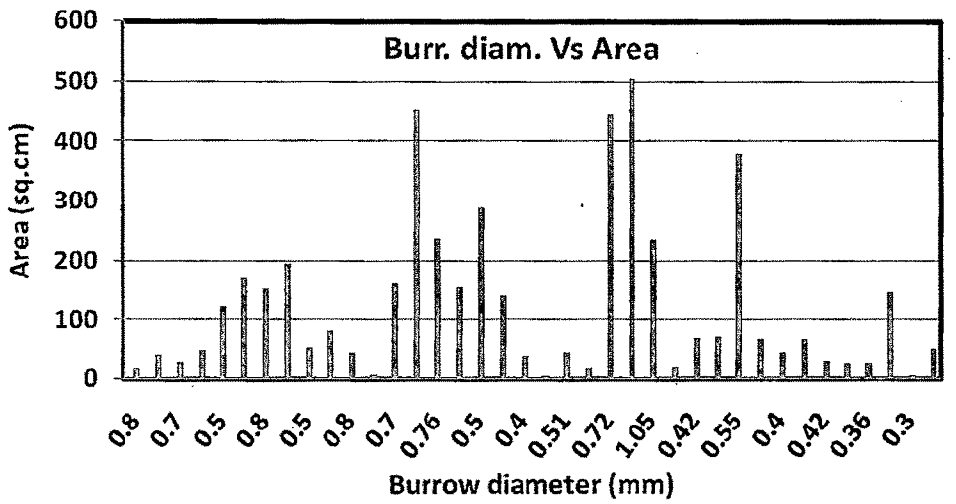

Fig. 4.7: Correlation between burrow diameter and feeding area explored.

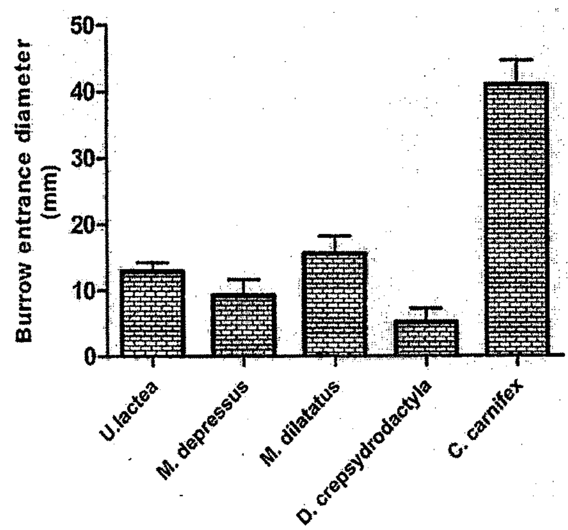

Fig. 4.8: Burrow diameter of different crab species.

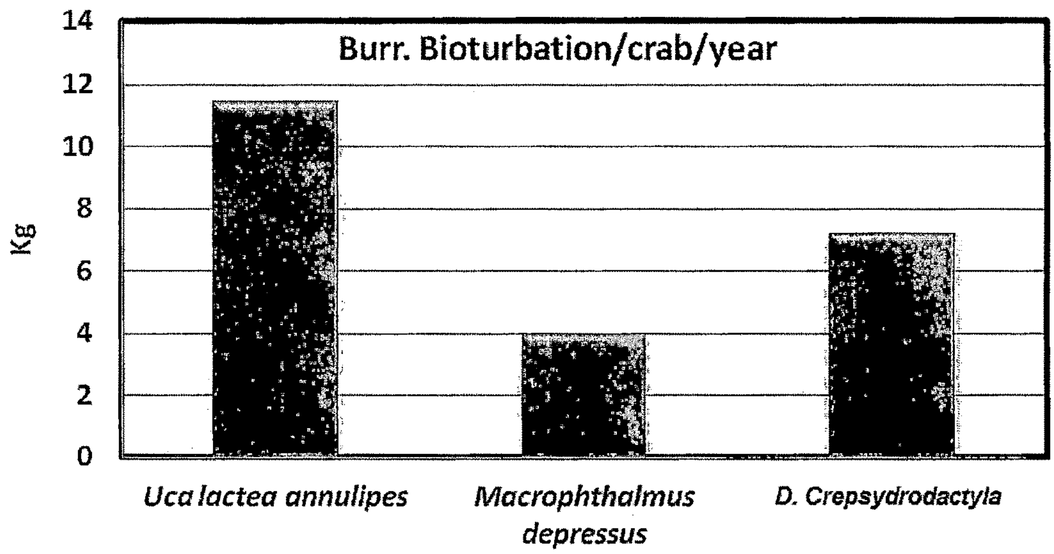

Fig. 4.9: Comparison of annual output of an individual

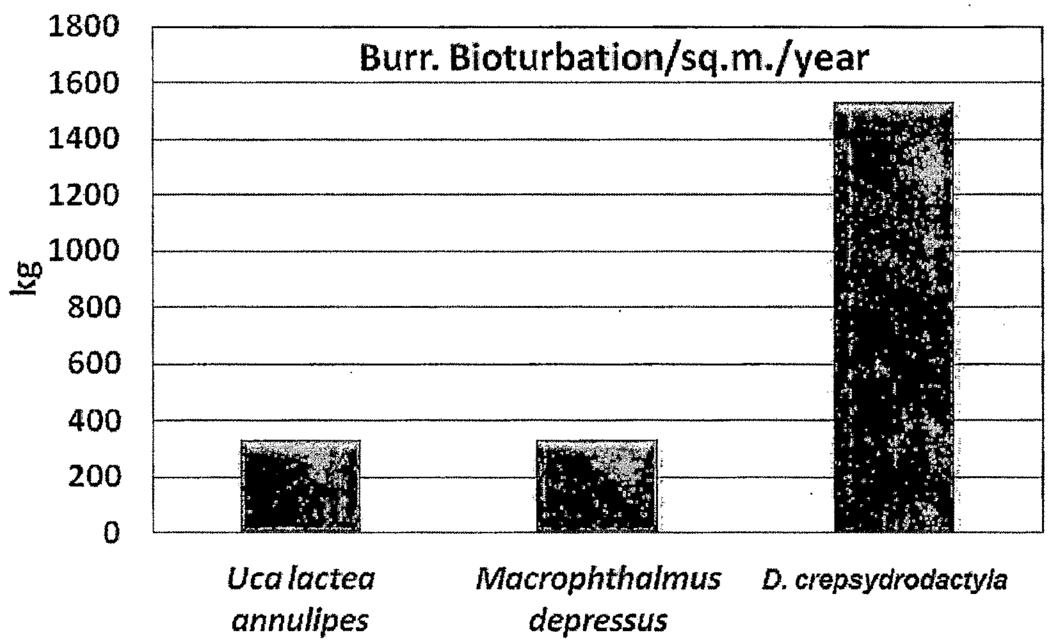

Fig. 4.10: Annual output of different crab species per sq.m.

Plate 1

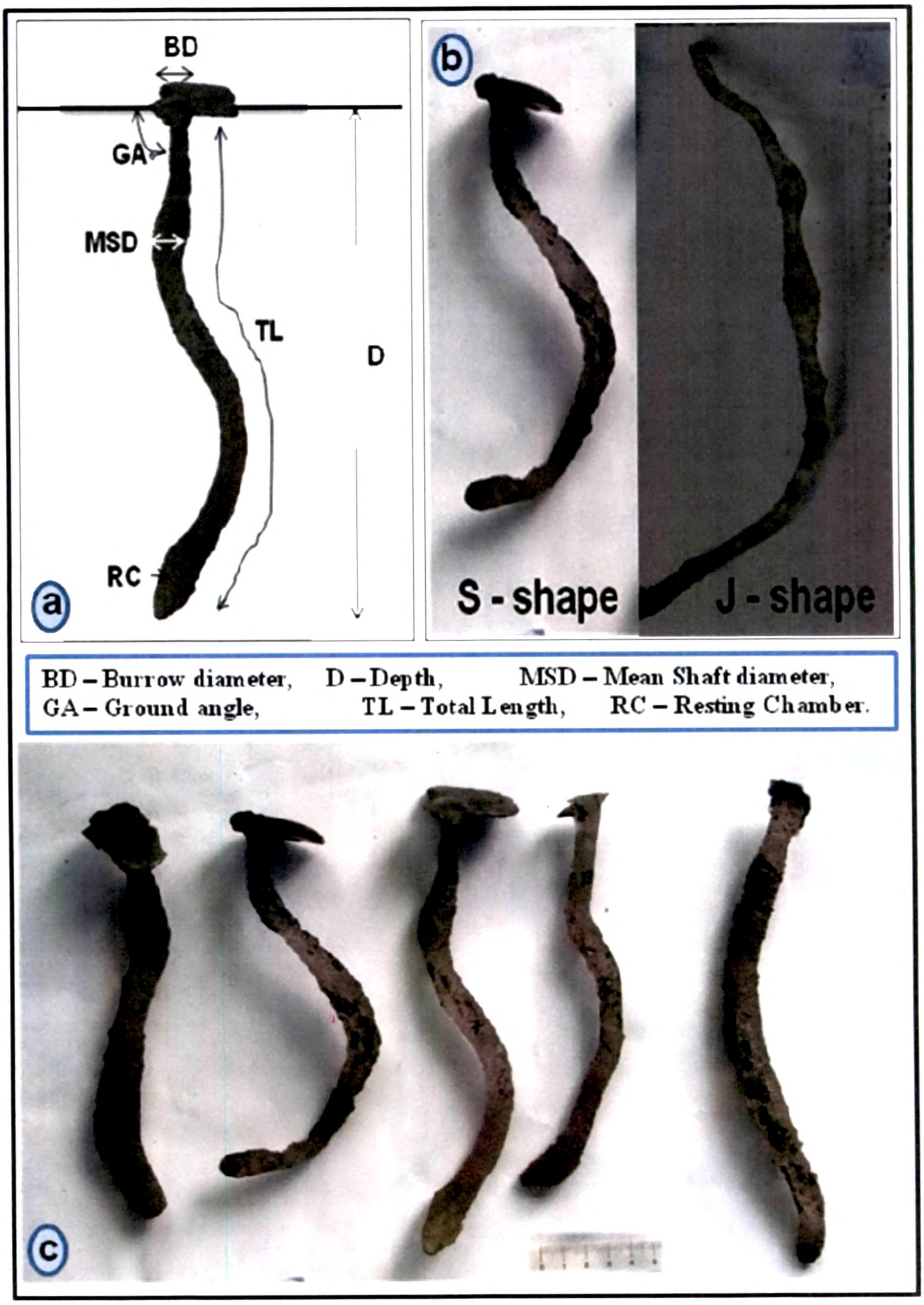

Plate 1: a. Morphometric burrow dimensions examined. b. S and J type of burrows. c. various type of burrow casts obtained from Zone 3.

Plate 2

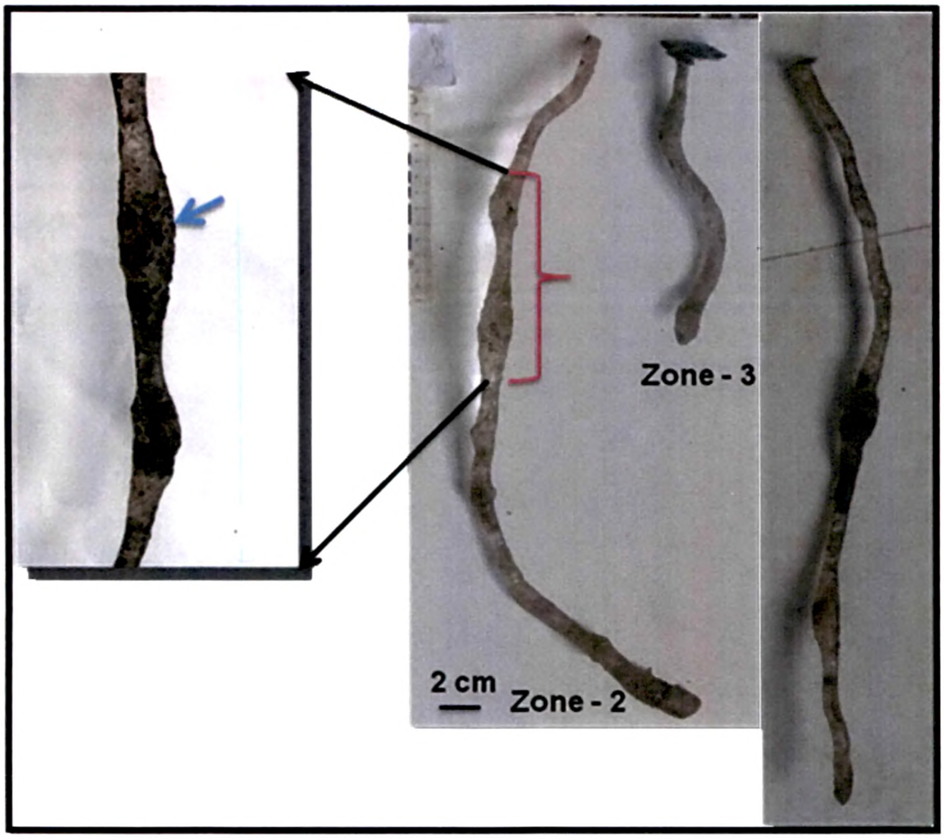

Plate 2: Size comparison of burrows in Zone 2 and 3. Inset showing close up view to resting chambers

Plate 3

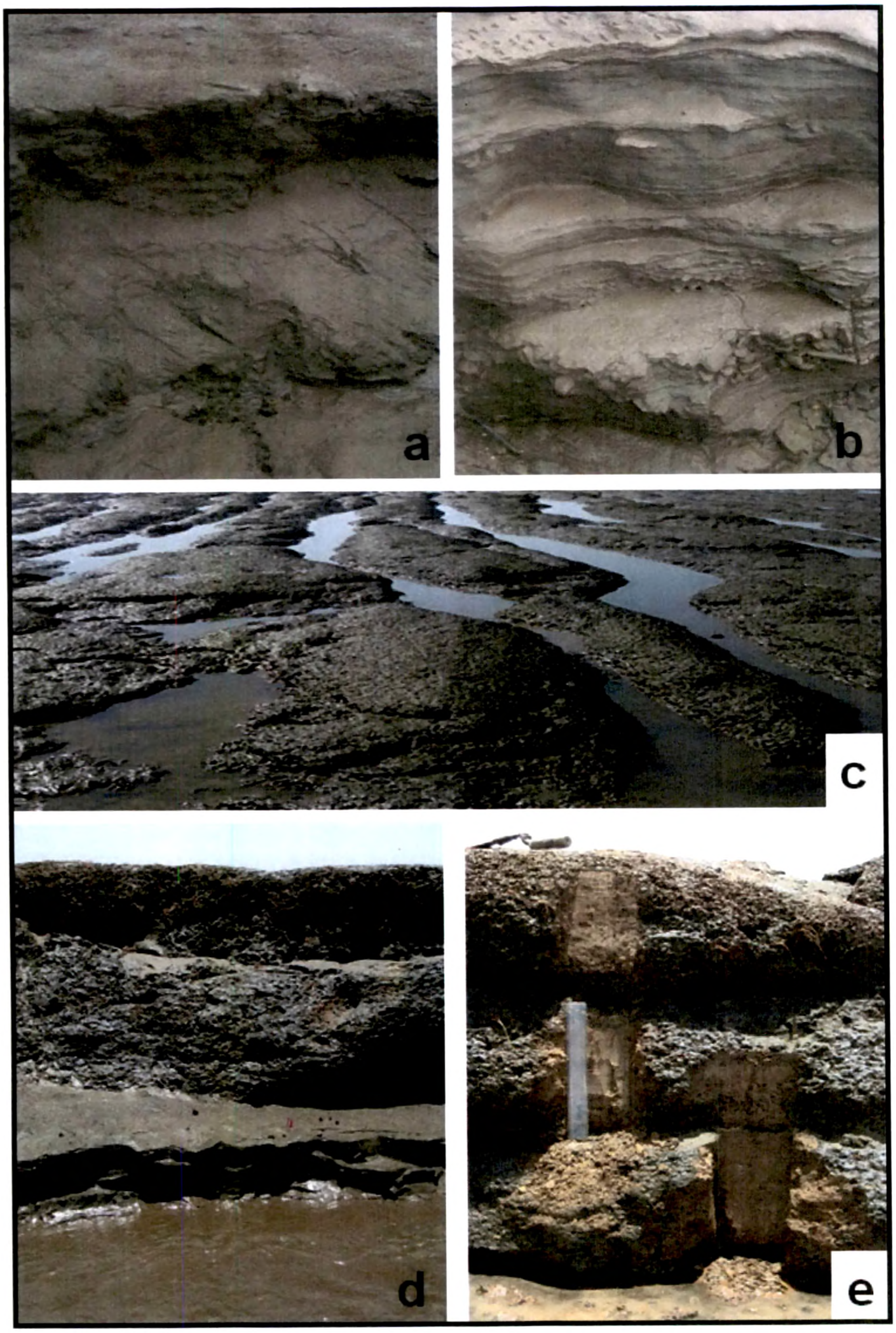

Plate 3: Features of hard calcritized sediment area. a, b. Formation of terraces and laminates of silt deposition over a period of time exhibiting reasons of sub surface compositional variations, c. tide pools in Zone 4, d, e. the habitat physical composition variations seen from upper to lower part as hard ground, soft ground and soup group in Zone 4.

Plate 4

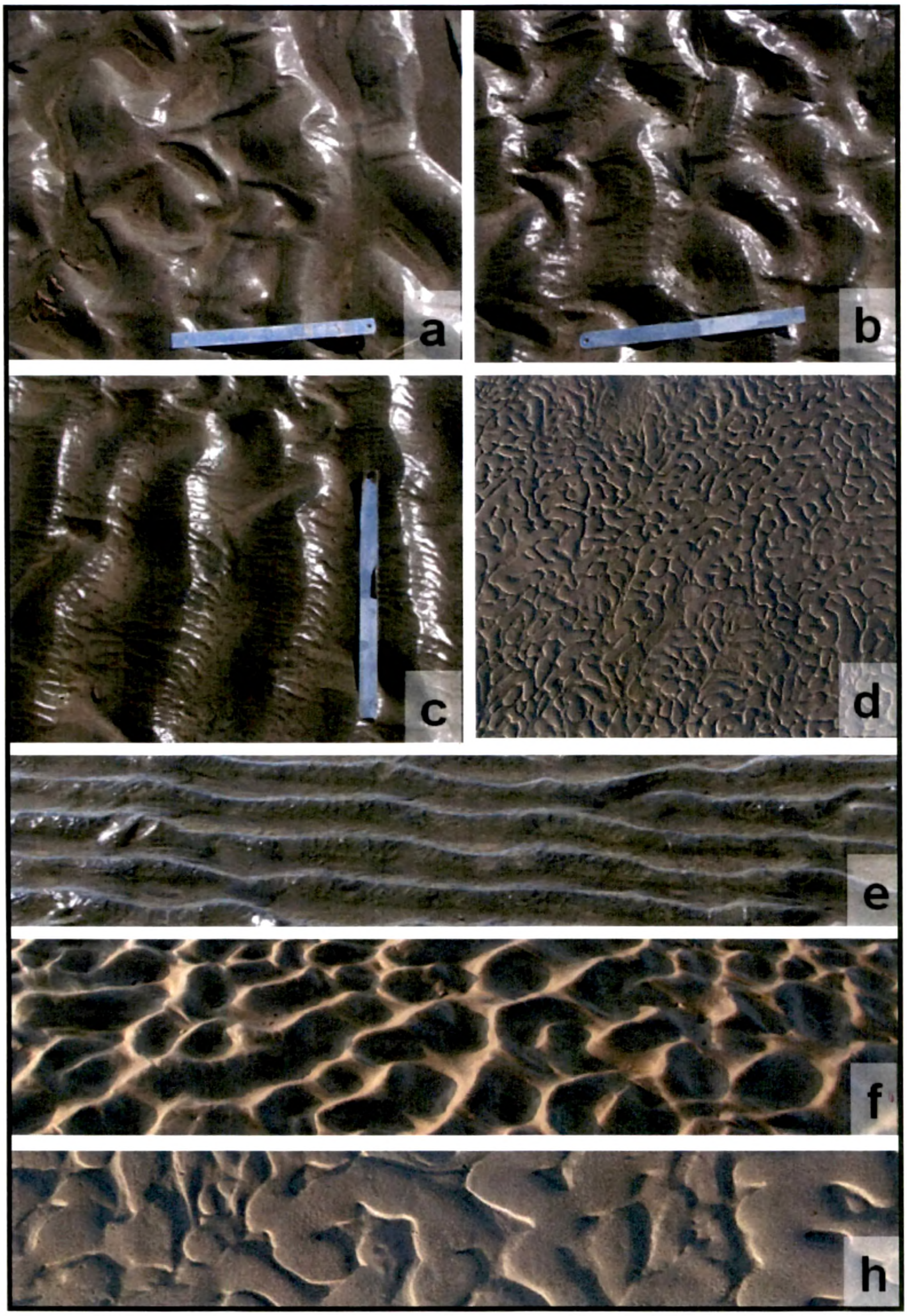

Plate 4: In Zone 5 the formation of ripples typically form microhabitat variations and allow fauna to select typical sub regions. These are formed by the waves and currents, their angularity as well as freshwater inflow directions. The trapping of sediments and nutrients define the distribution and sediment relationship of animals.

Plate 5

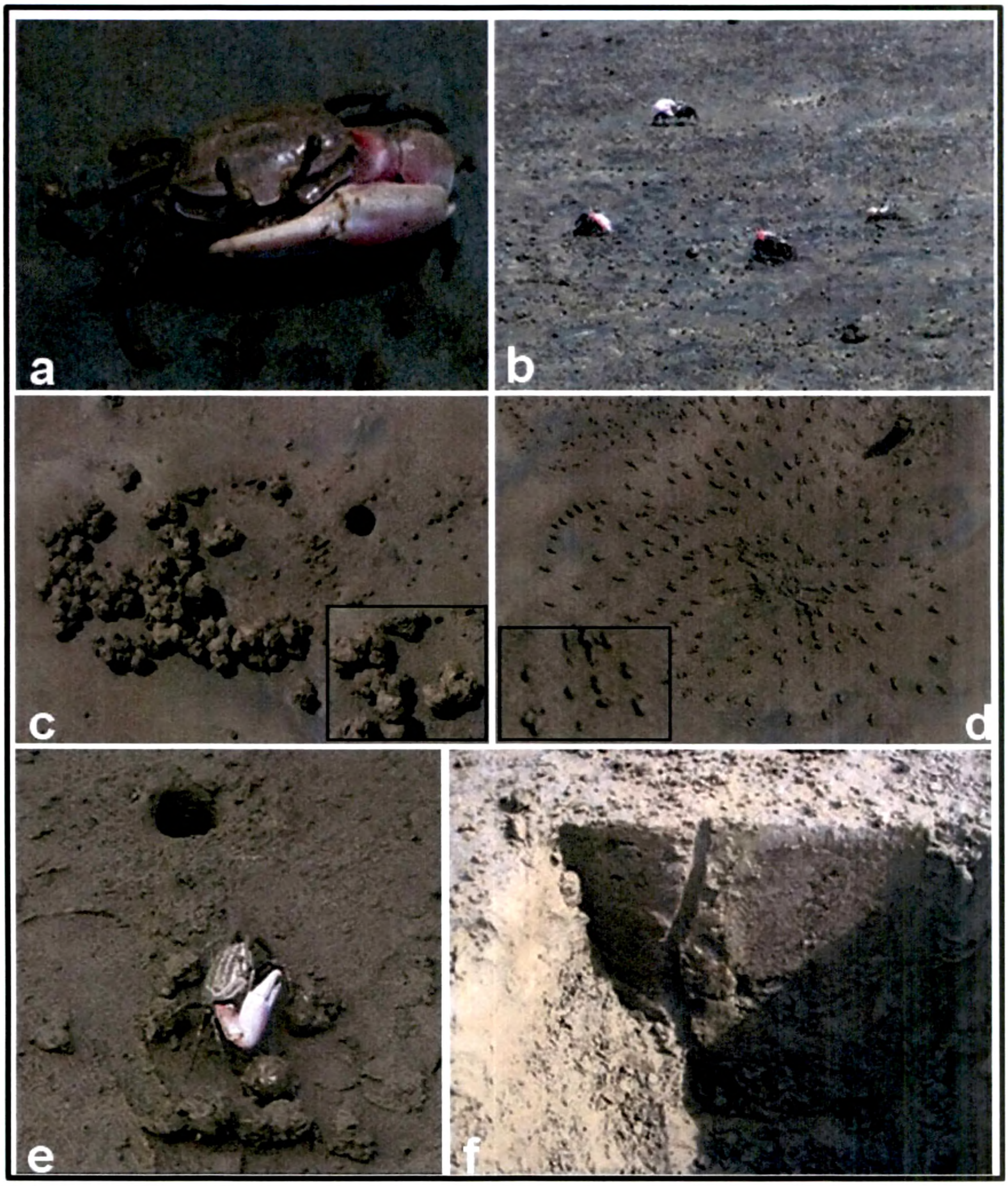

Plate 5: a. Uca lactea, male in field b. Foraging and displaying by male animals c. Larger and uneven burrowing pellets formed by male d. Roughly spindle shaped burrowing pellets of female animal e. Active burrow formation by male f. Side opened cross section through burrow of animal.

Plate 6

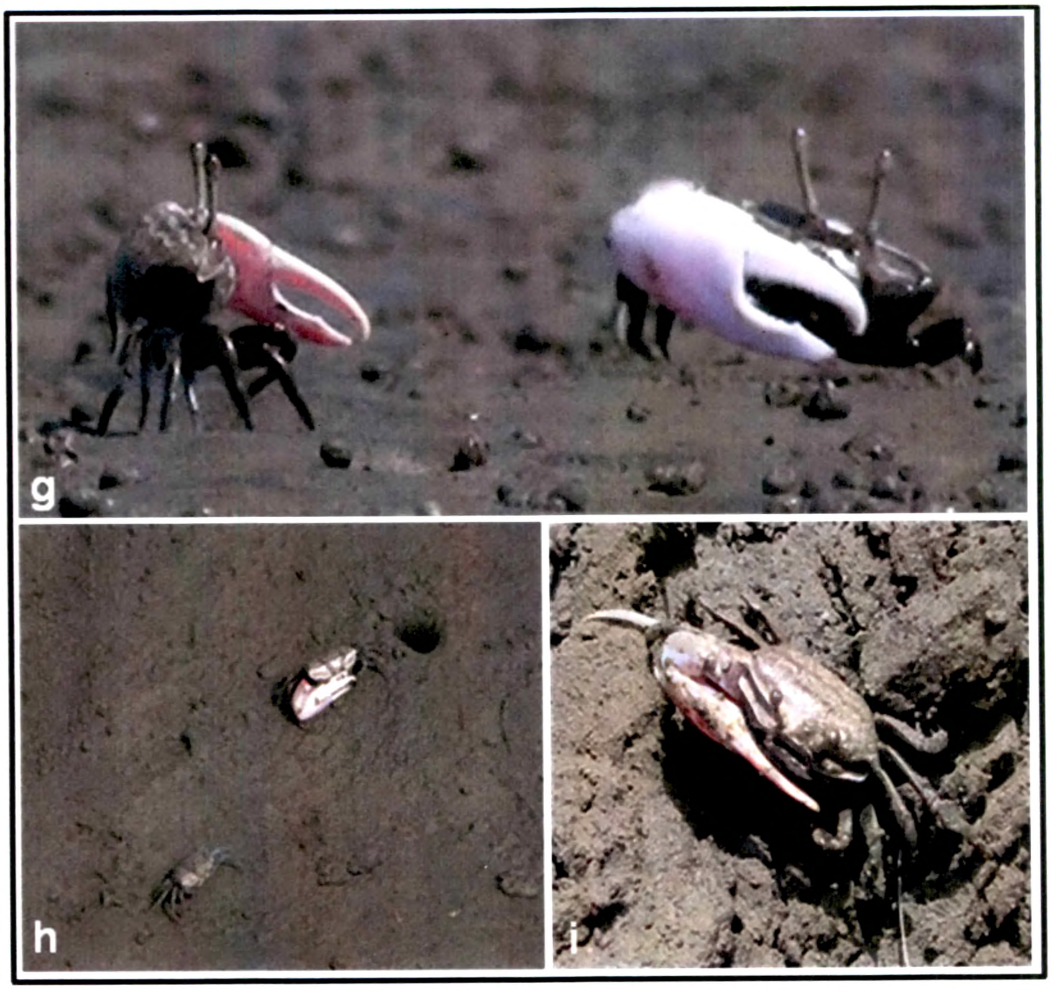

Plate 6: a. Territorial display by two males defending its own territory b. Typical mating display wherein male drives the female to its burrow by waving its larger chela c. A male specimen in alert position on being disturbed.

Plate 7

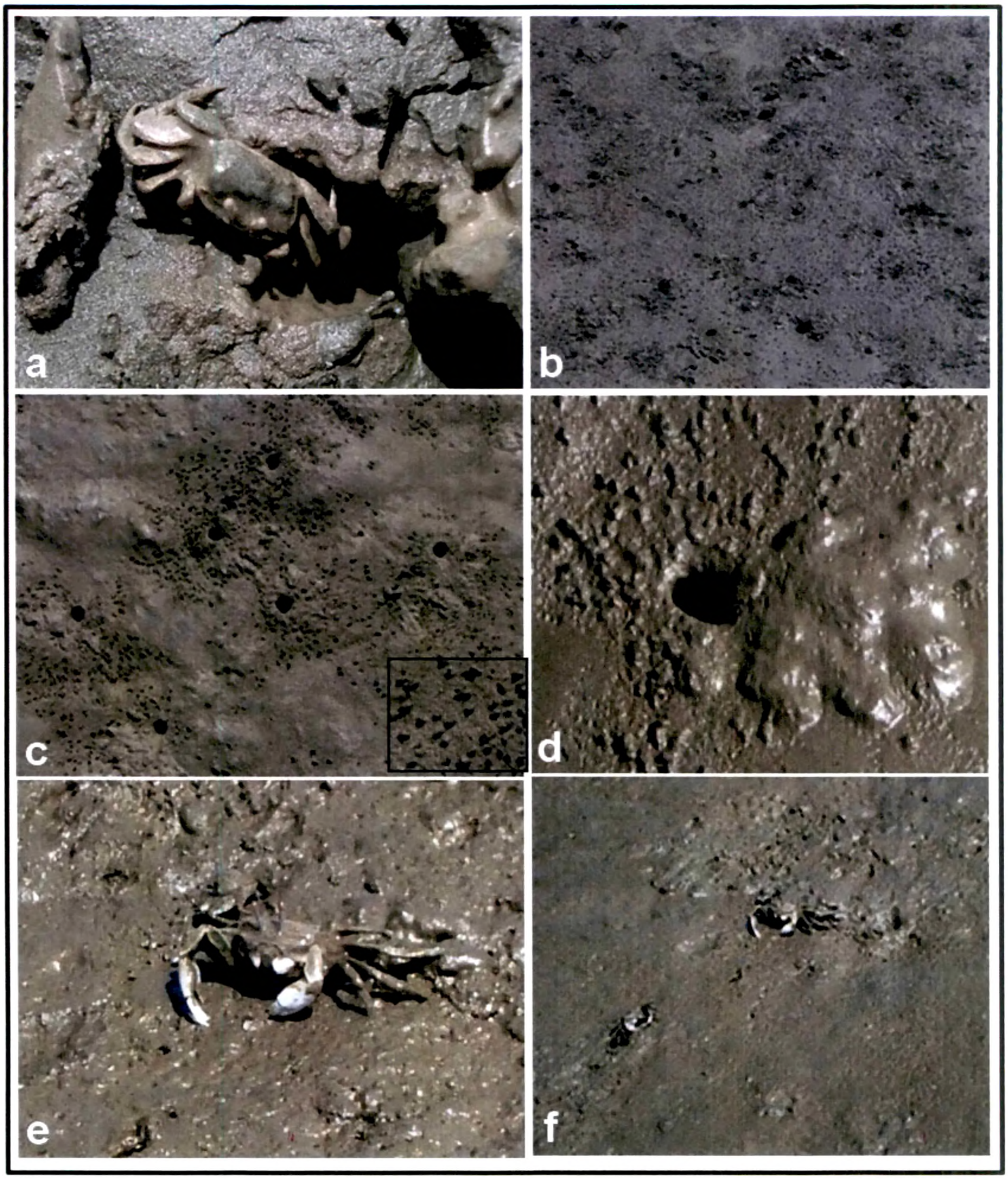

Plate 7: a. M. depressus coming out from a freshly built burrow b. Active crabs during lowtide. c & d. burrows of the animal reflecting their high density. e & f. Feeding by scraping the upper layer of sediments.

Plate 8

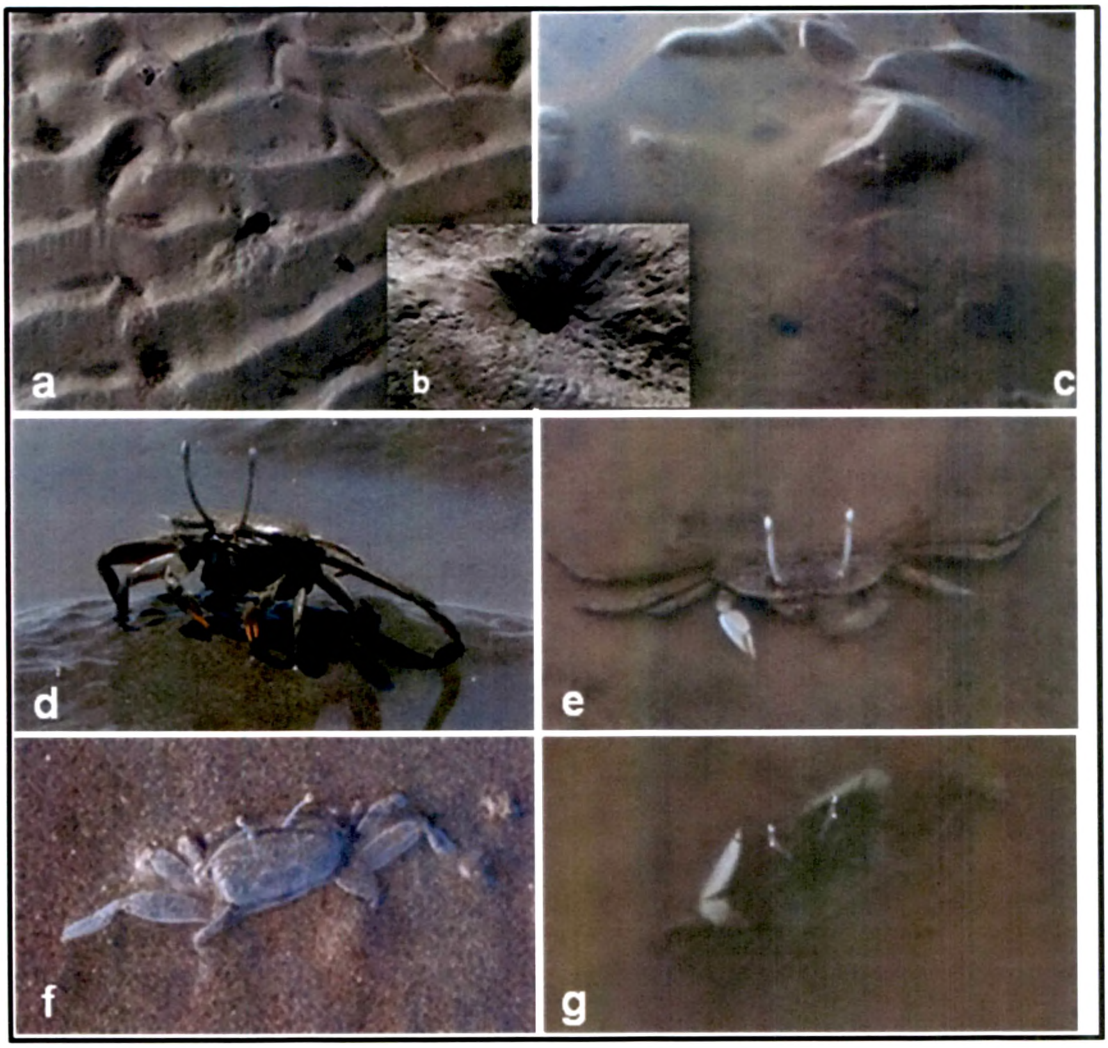

Plate 8: a. Habitat with ripples preferred by ***M. dilatatus,*** with its burrow b. Inset to the burrow opening c. Burrows at the base of the ripples inundated with water d & e. Feeding behavior in open area as well as in watery ground. f & g. Defensive behavior by trying to hide within loose sediment and under shallow water.

Plate 9

Plate 9: a., b & c. different type of burrow in distinct zones by same species with very high density of chimney formation. d. Chimney formed over the burrow. e. Sediment pellets used to form a chimney. f – h. characteristically built burrows on the ripple crest , few of them in groups.

Plate 10

Plate 10: i. Various type of feeding area exploration marks, j – k. Feeding and foraging in groups, l. Feeing nearby burrow leaving behind feeding pellets, m. Close up snap of scraping marks formed by the fingers of the crab during feeding.

Plate 11

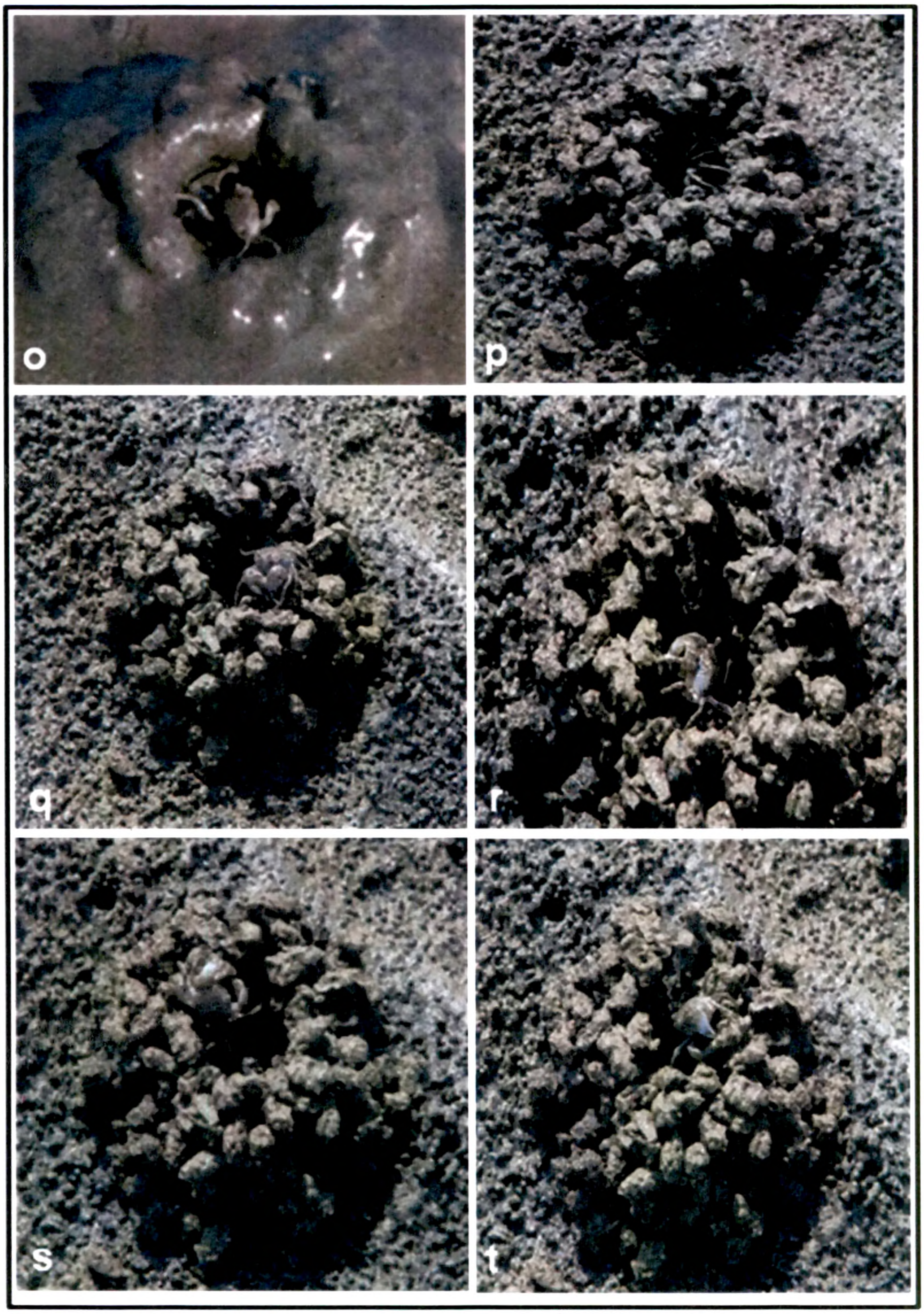

Plate 11: A sequential photographs of chimney formation by *D. crepsydrodactyla*.

Plate 12

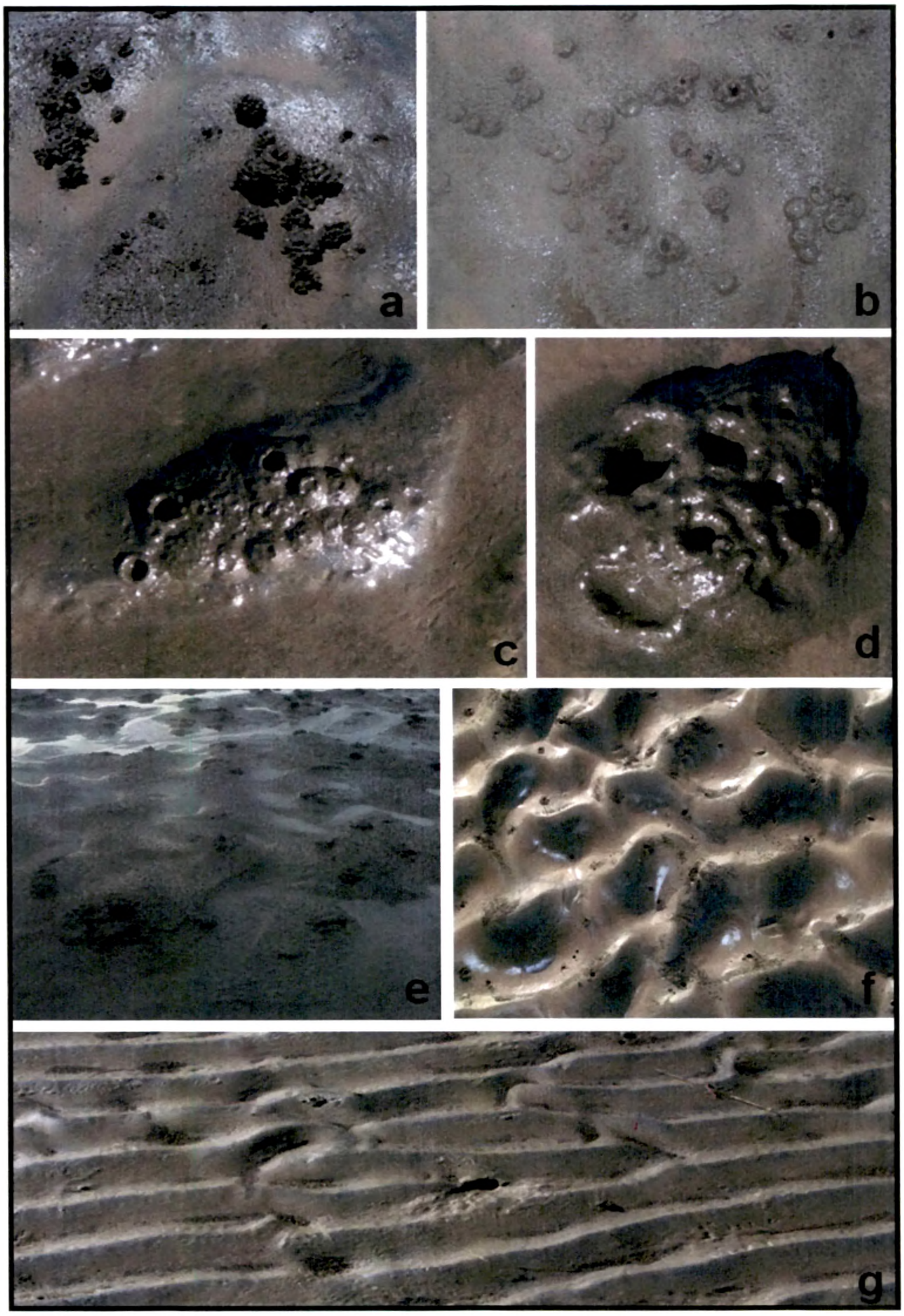

Plate 12: The sediment preference and burrowing of Dotilla. a. cluster of small chimneys, b. the closed burrows at the time of incoming tide, c and d. cluster of burrows on the ripple mound in soft ground, e and f. formation of the burrow on the ripple mounds and feeding explorations on sides of the mound, g. trapping of nutrients favouring burrowing of the crab in between ripples.

Plate 13

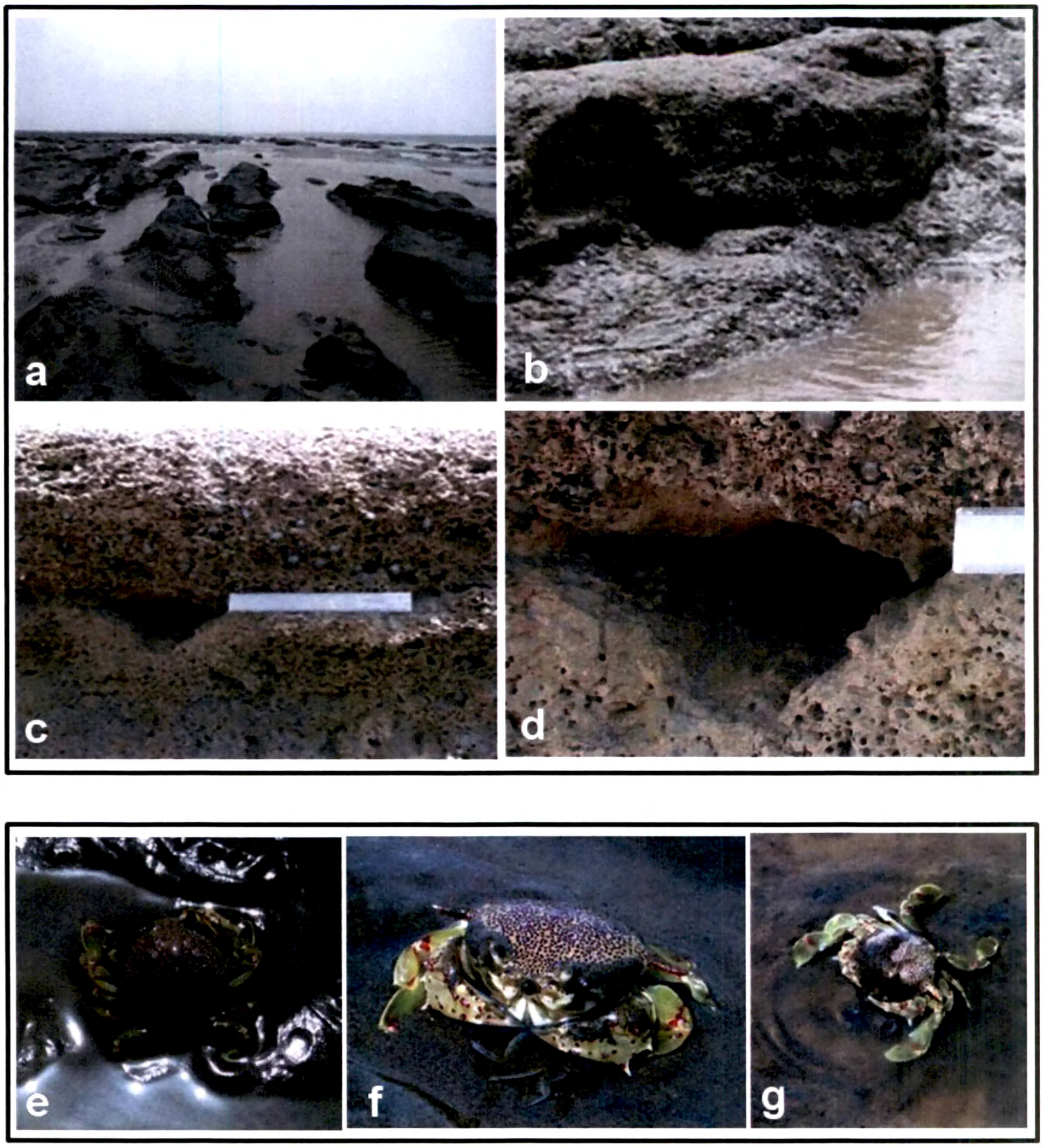

Plate 13: a –b. Habitat and substrata preferred by ***S. Serrata,*** c-d. Closer view to the burrow of ***S. serrata***.

e-g. Shows ***Matuta lunaris*** in the habitat. The later two shows the camouflage of the species and predating on other crab species.

Plate 14

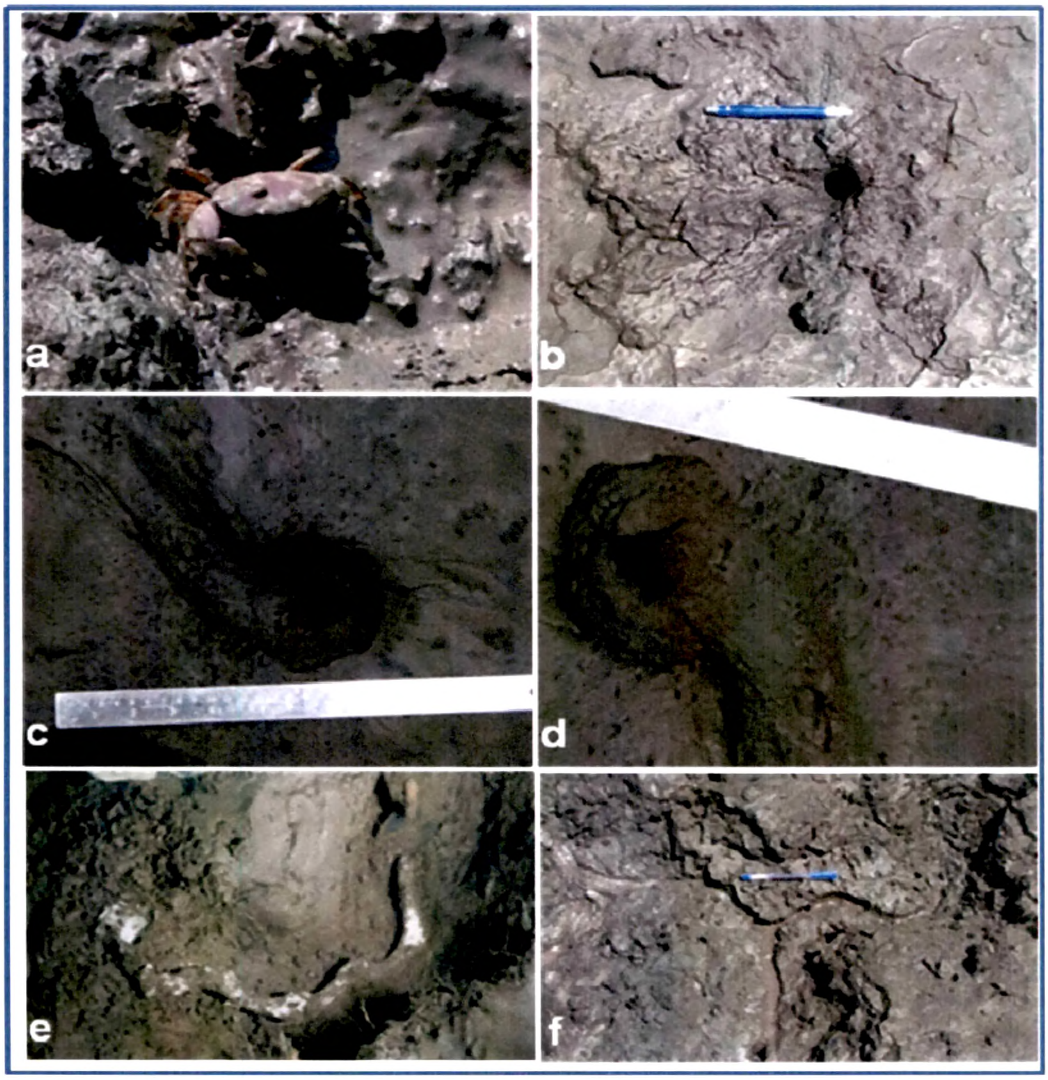

Plate 14: a. *C. carnifex* in its natural habitat, b. Burrow showing excavated sediments, c – d. burrow with passage on one of the side, e. partially traced wax cast of the burrow, f. Burrow in planar view. Open for upper side showing the subsurface spread and moist burrow lining.

Plate 15

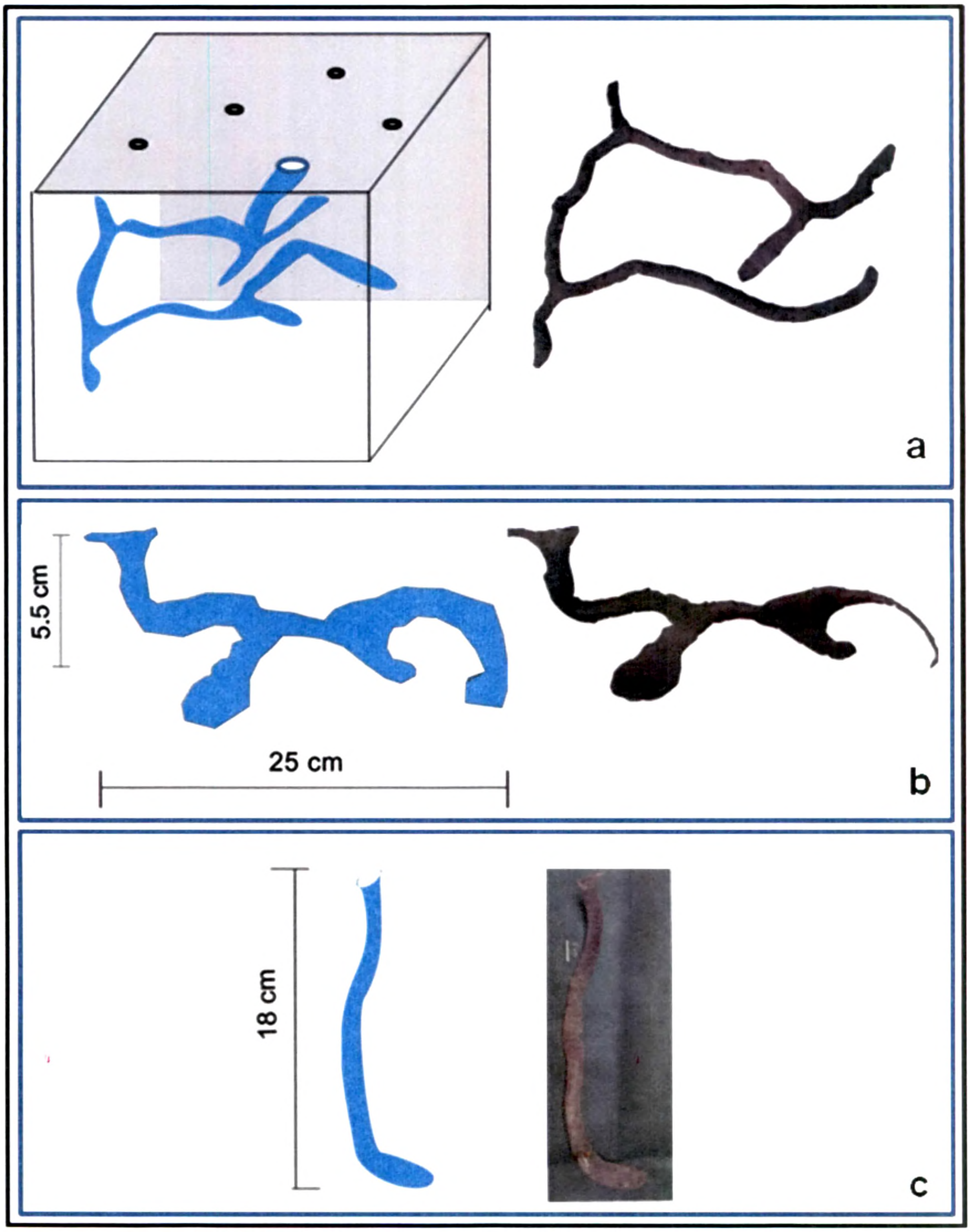

Plate 15: Burrow resin cast with its diagrammatic replica, a. ***C. carnifex*,**

b. mudskipper and c. ***M. depressus*.**

Plate 16

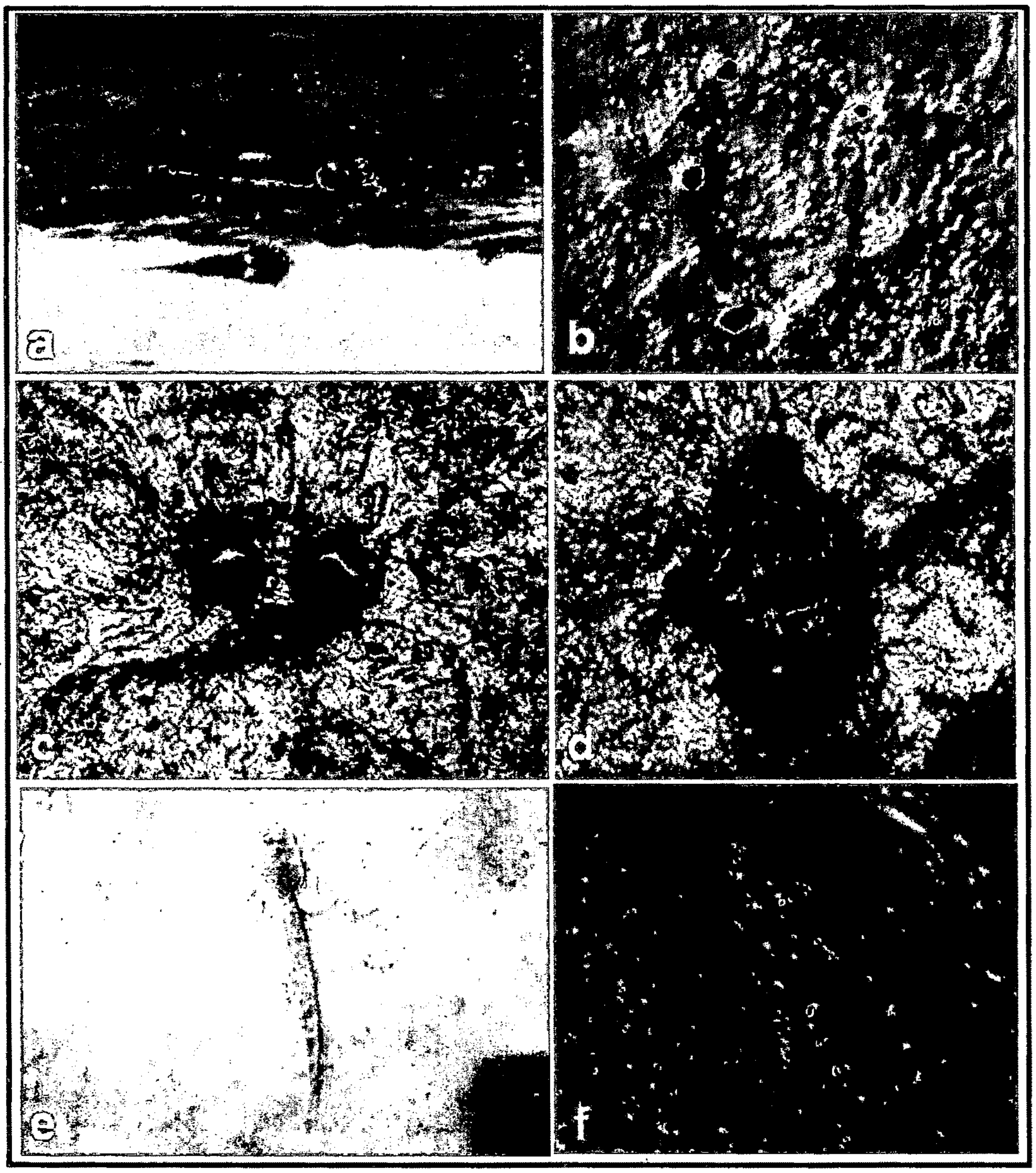

Plate 16: a. Foraging by mudskipper. b. Multi entrance burrow made by a mudskipper, c. Burrow filled with water with dual entrance, d. Mudskipper in its burrow, e. Young one of mudskipper in water pool and f. Fin marks of mudskipper evident of its presence.

Plate 17

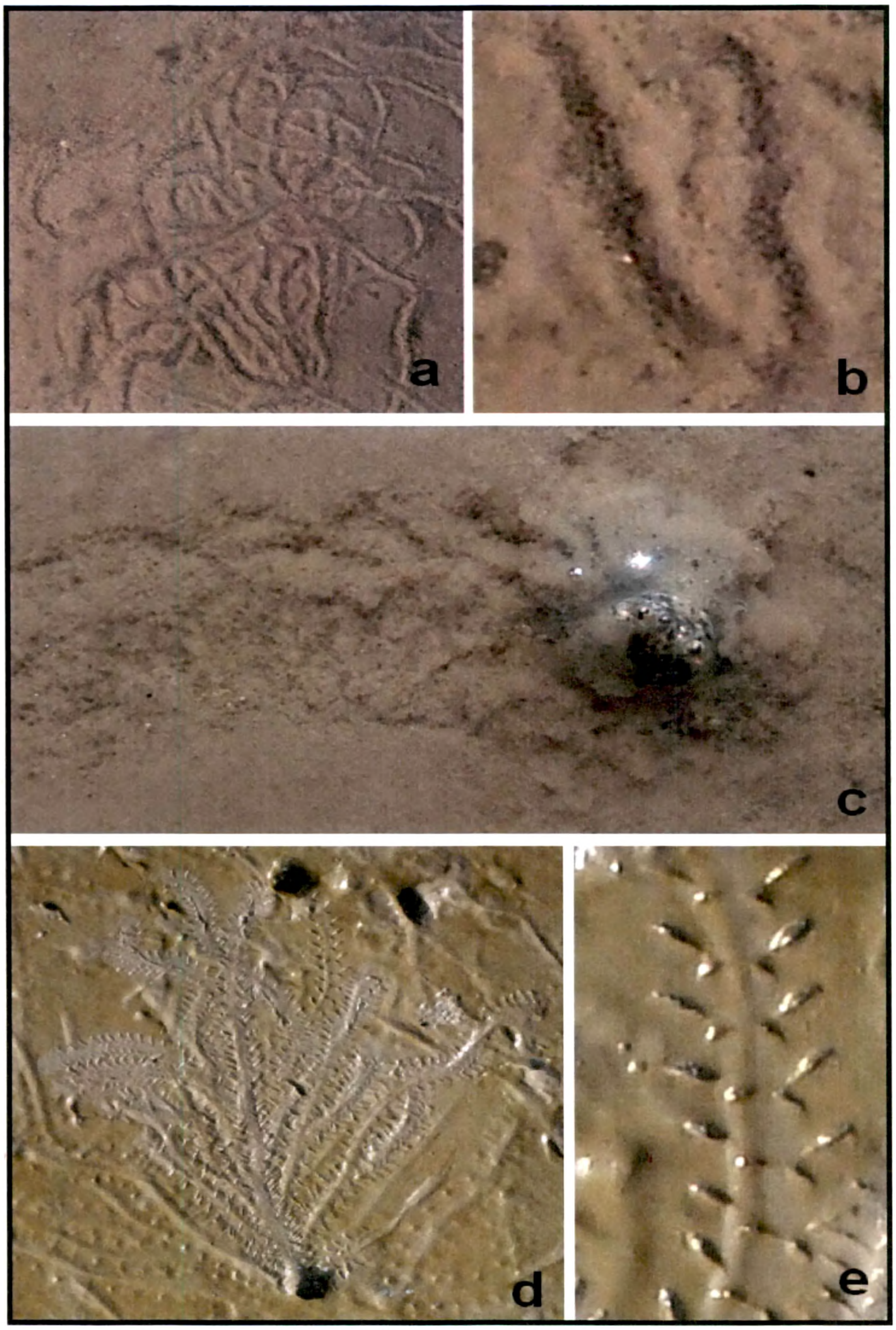

Plate 17: Locomotion marking of the mud shipper. a, b and c. Juveniles move with the loose upper sediments where fin markings are less conspicuous but whole body band marking is seen. d and e, The typical fin marking of adult fish. The distance between the fin marks is also indicative of size of the mud skipper.

Plate 18

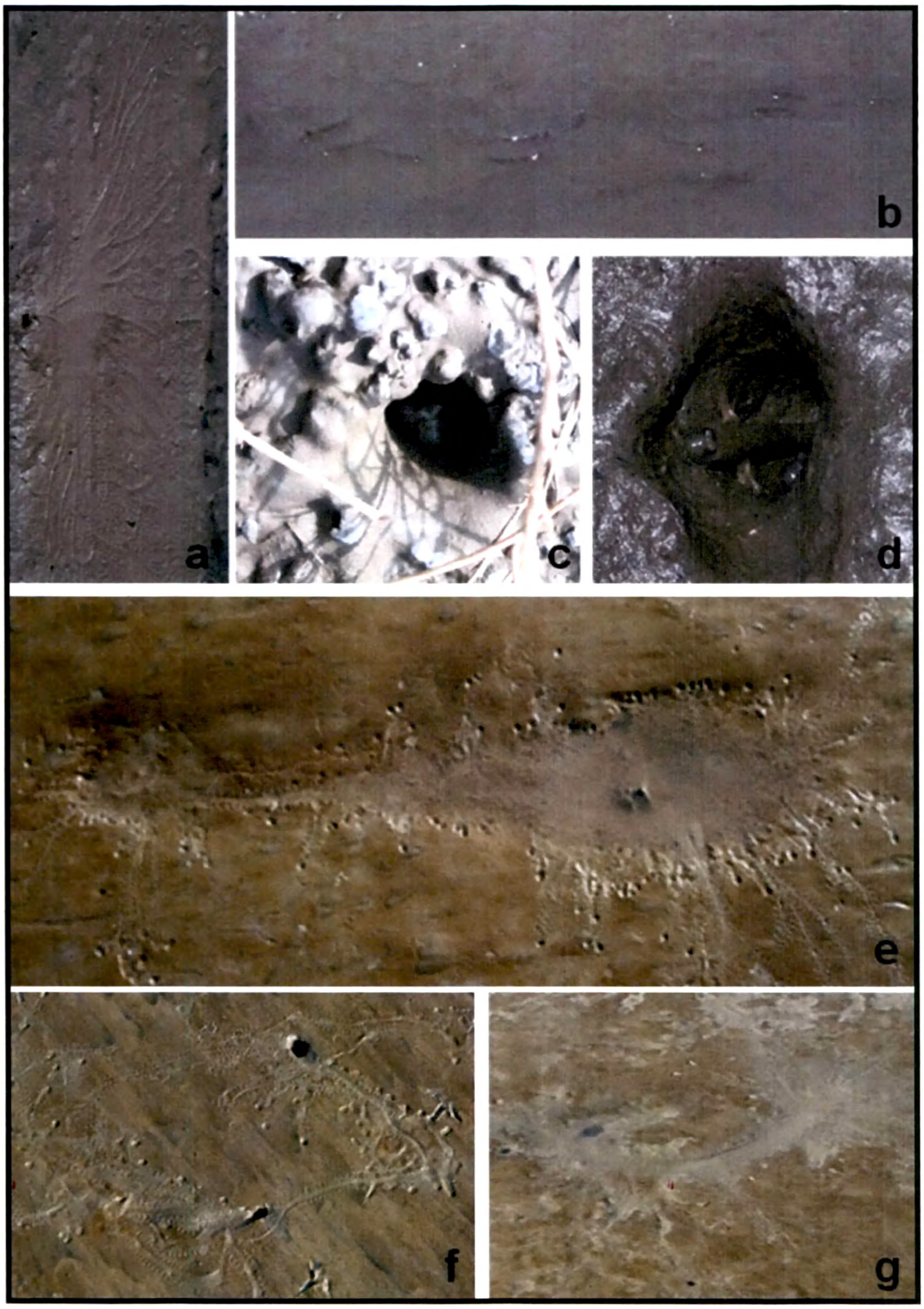

Plate 18: a. Extensive explorations by mud skipper in close vicinity of burrow, b. several fishes in the shallow water region, c and d. burrow pattern in the dried inter tidal area; Zone 2 and in the moist inter tidal area; Zone 3 on different moon days. Note the presence of burrowing balls at the periphery making boundary for the retention of water in c, e-g. Inter connected burrows made as shallow saucer for the retention of water in burrow as an adaptation against desiccation.

Plate 19

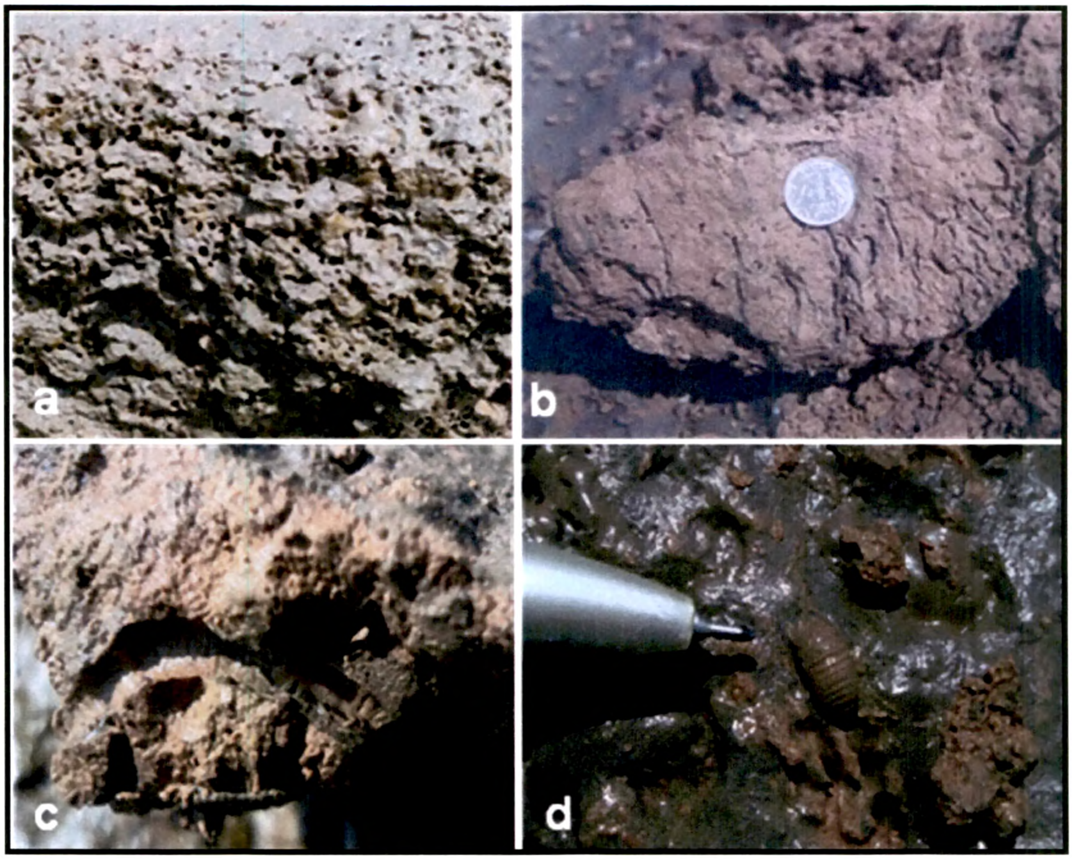

Plate 19: a. Highly perforated substrata as a niche of amphipod/isopod, b. broken sediment block with the fine tunnels of animals c. An amphipod in the fine burrow. d. isopod in its natural condition.

Plate 20

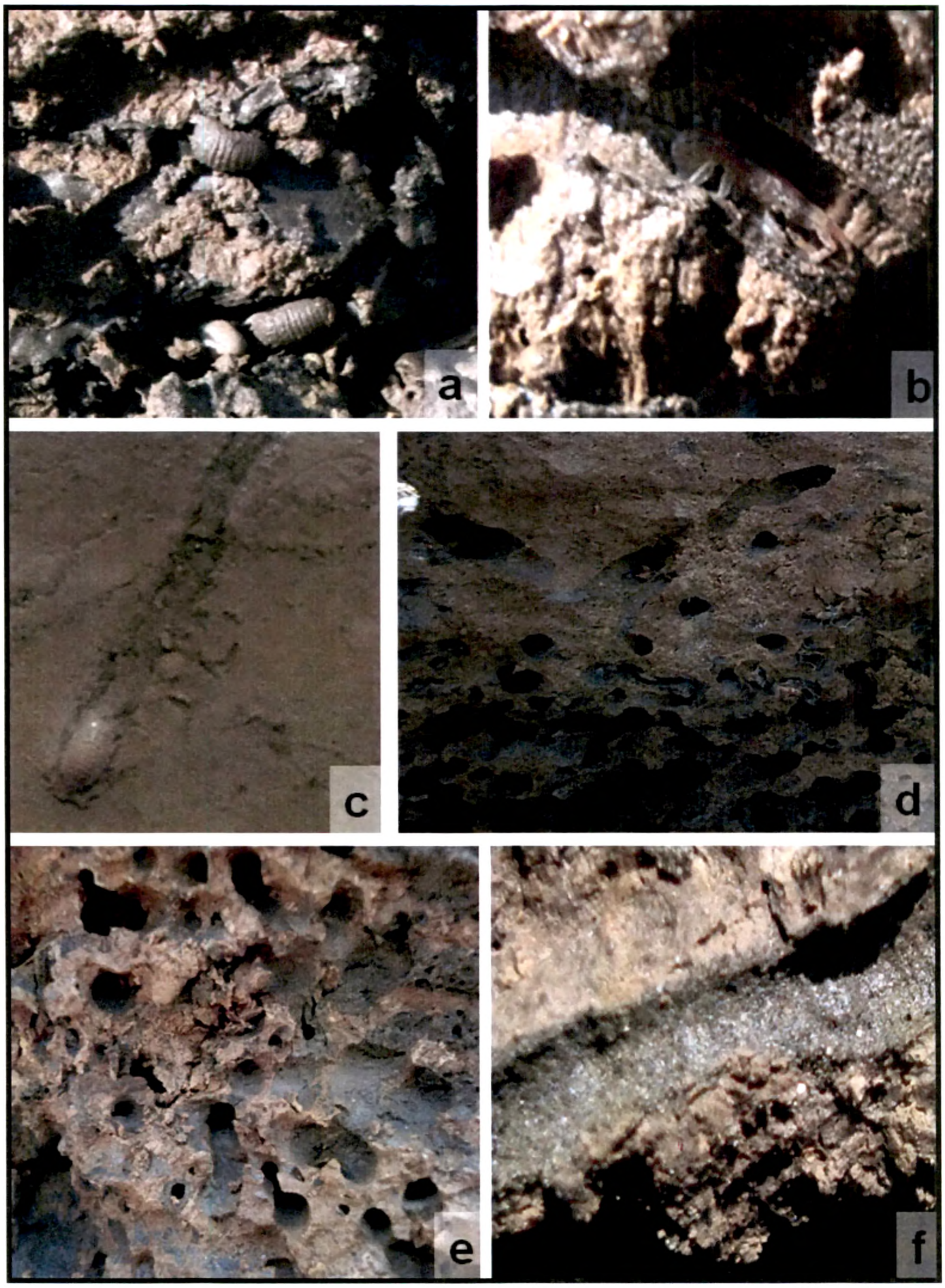

Plate 20: Burrowing of animals in the hard sediments, a and b. burrowing by Amphipod and Isopod, c. movement of an Amphipod in soft sediment, d and e. extensive burrowing in the suitable sediments; fewer burrows are seen in probable high density sediments in the right portion of photo e, f. soft inner margins of the burrow.

Plate 21

Plate 21: a-c. Burrowing by insect larva Megacephala, the burrow densities are shown in a and b, while in c the just superficial burrowing is clearly visible. d-e. Gastropod Assiminea erupting the sediment layers and emerging out for routine activity during low tides, f. excretory pellets of the animal.

Plate 22

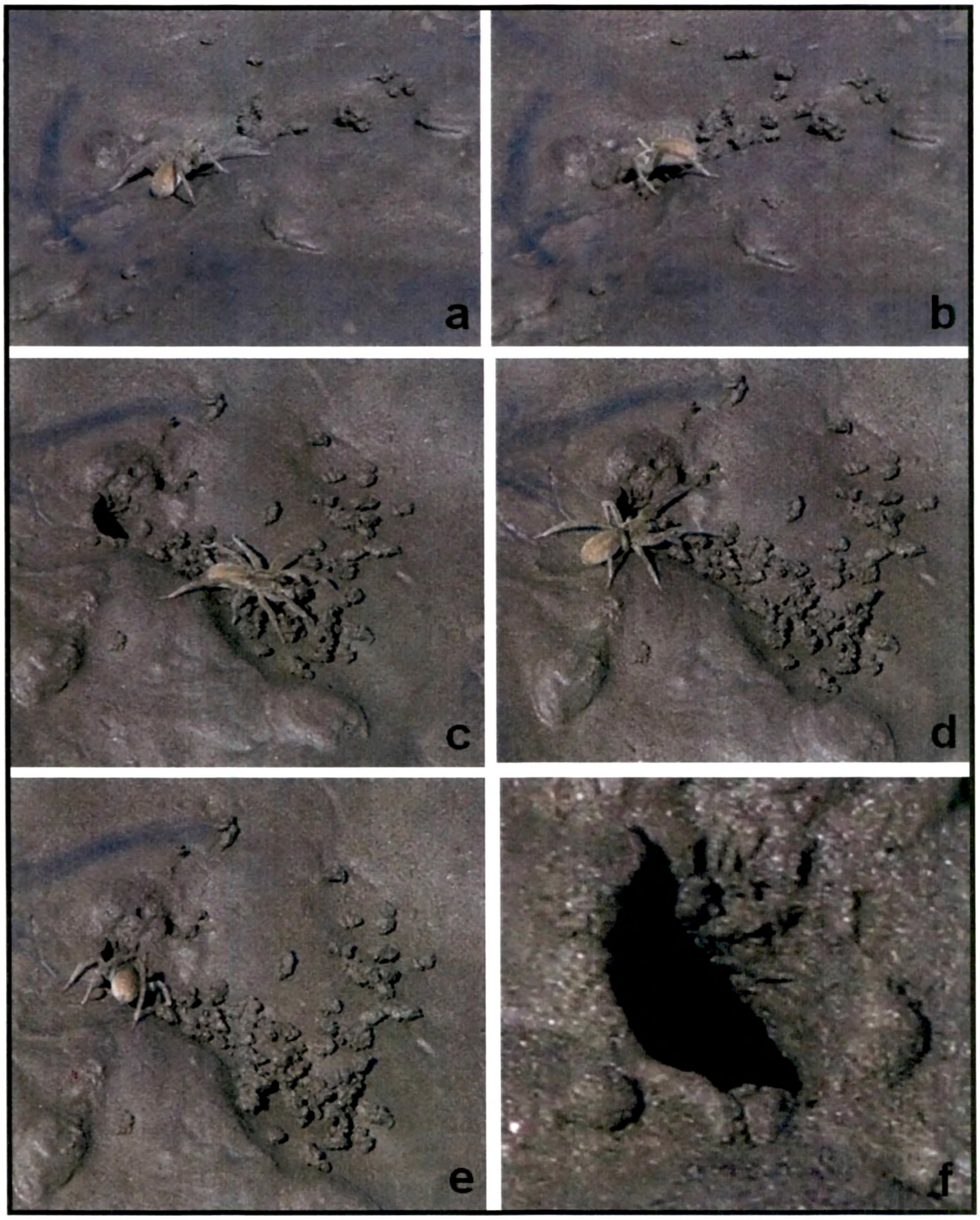

Plate 22: a-e. Sequence of burrowing by spider in Zone 3. They also exhibit typical spread and arrangement of the burrowing pellets, f. the margins of the burrow has distinct marking of the spider appendages and therefore can be distinguished from crab burrows.

Plate 23

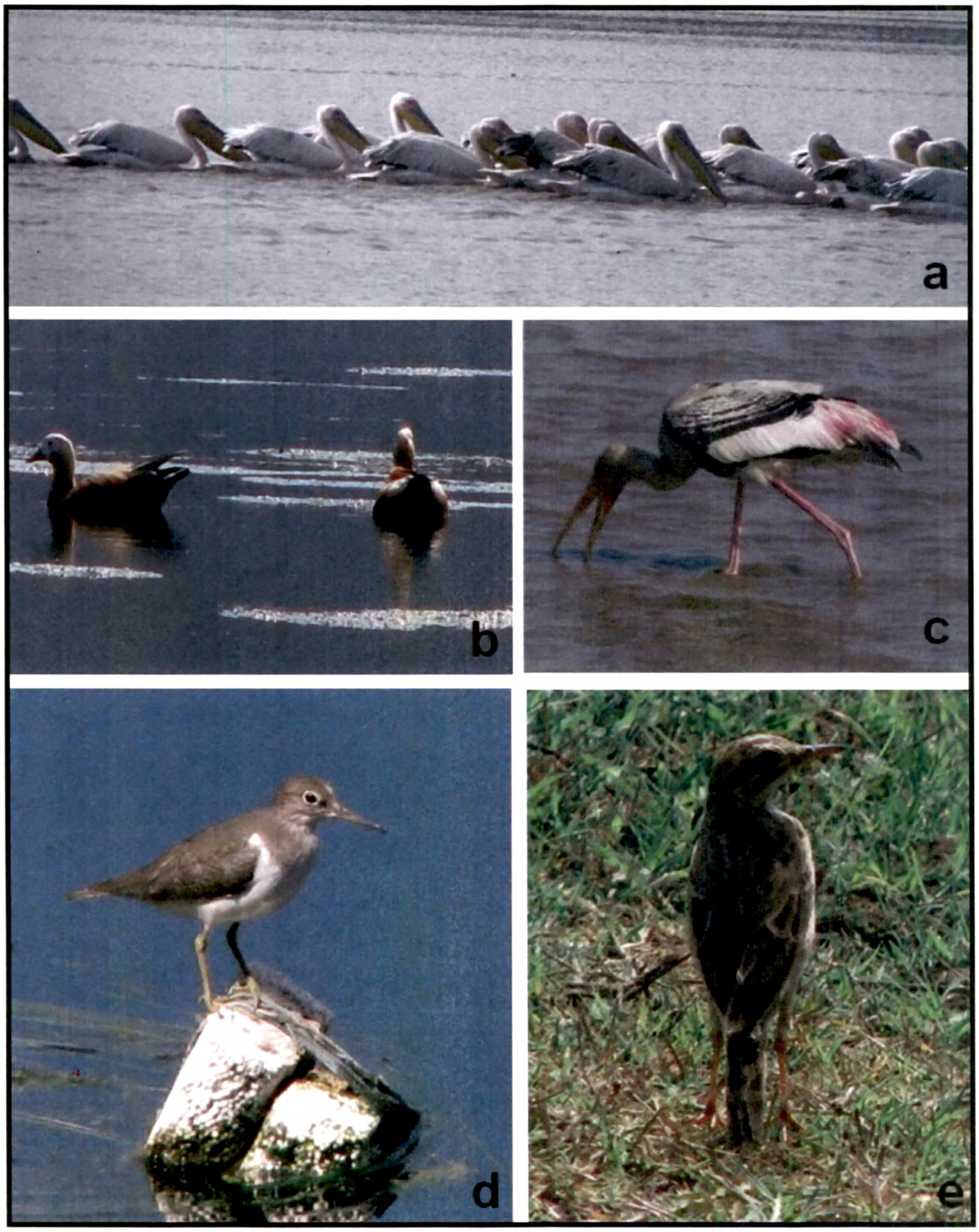

Plate: 23 a. Great white Pelicans (*Pelecanus onocrotalus*) at Midstream (Dabka) b. Ruddy shelduck (*Tadorna ferruginea*) in shallow waters at Mohammadpura c. Feeding by Painted stork (*Mycteria leucocephala*) during high tide at Kamboi d. Common sandpiper(*Tringa hypoleucos*) at upstream site e. Paddy field pipit (*Anthus rufulus*) in the surf region at Kamboi.

Plate 24

Plate 24 a. Foraging of Black winged stilt (***Himantopus himantopus***) and Common Red shank (***Tringa tetanus***) on Mudflat at Kamboi b. Common sandpiper (***Tringa hypoleucos***) on food hunt c. Indian pond heron (***Ardeola grayii***) in its striking position on Kamboi mudflat. d. Foot marks of foraging by birds on soft mud ground e. Beak marks of waders evidencing the feeding attempts on the mudflat.

Plate 25

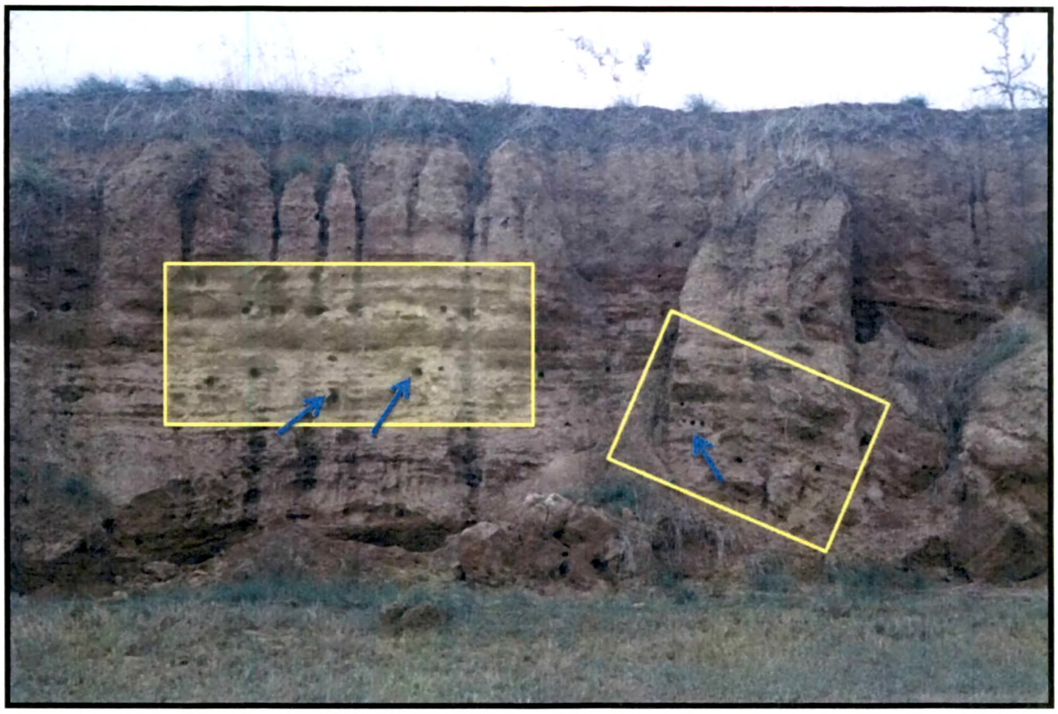

Plate 25: The ravines in the catchment of Mahi river estuary serve as a good habitat for many of the birds. The open cliff/faces at downstream and few places at upstream are used for excavating nest holes by Bank myna (***Acridotheres ginginianus)*** and Little green bee eaters (***Merops orientalis***).

Plate 26

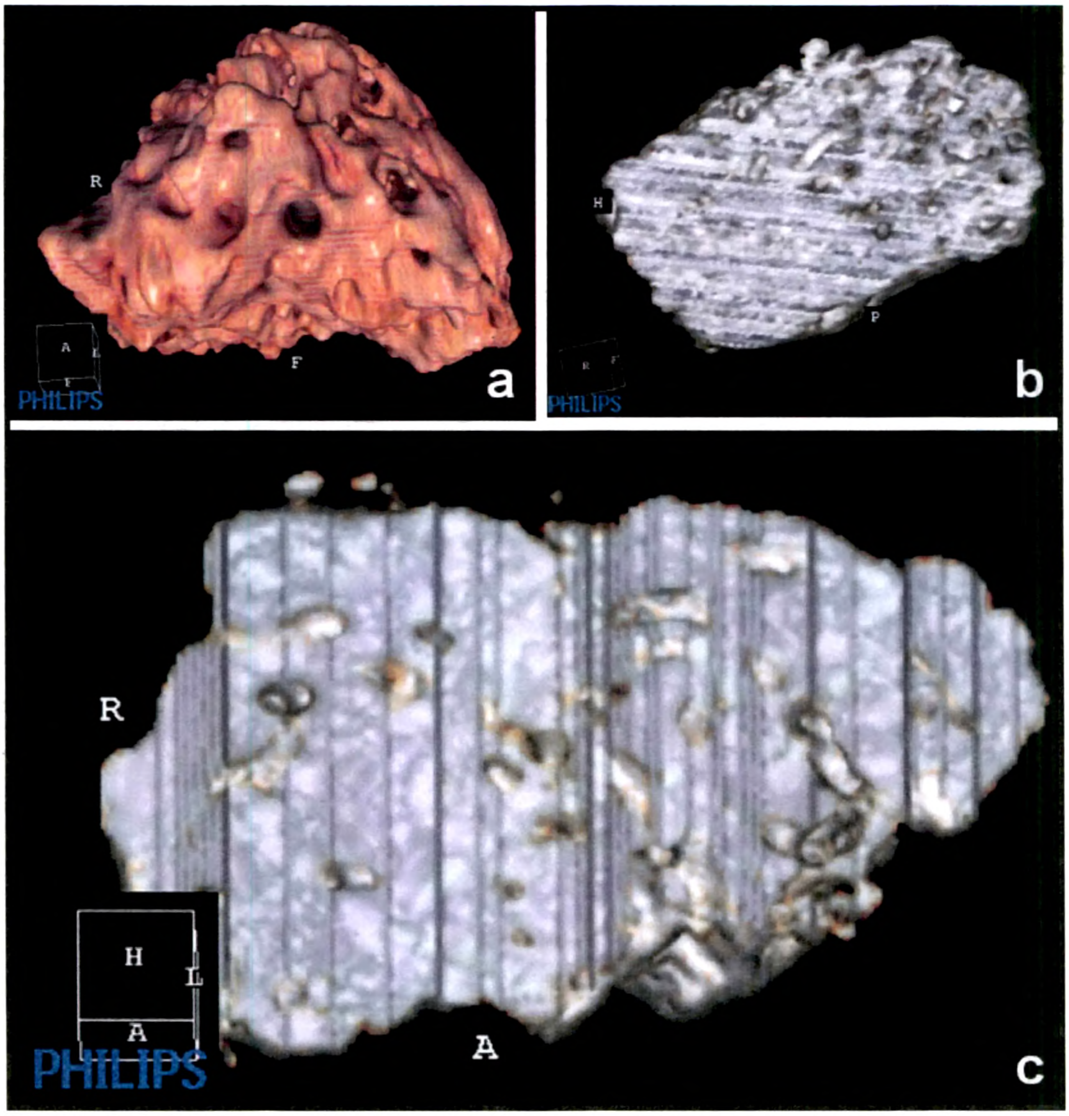

Plate 26: CT scanning of the hard sediment block from Zone 4. a. Showing the external morphology details, b and c. the transverse sectional views of the block. In b single layer view shows burrowing density while multi layered 3-D view in c demonstrate occupancy by different animals.

Plate 27

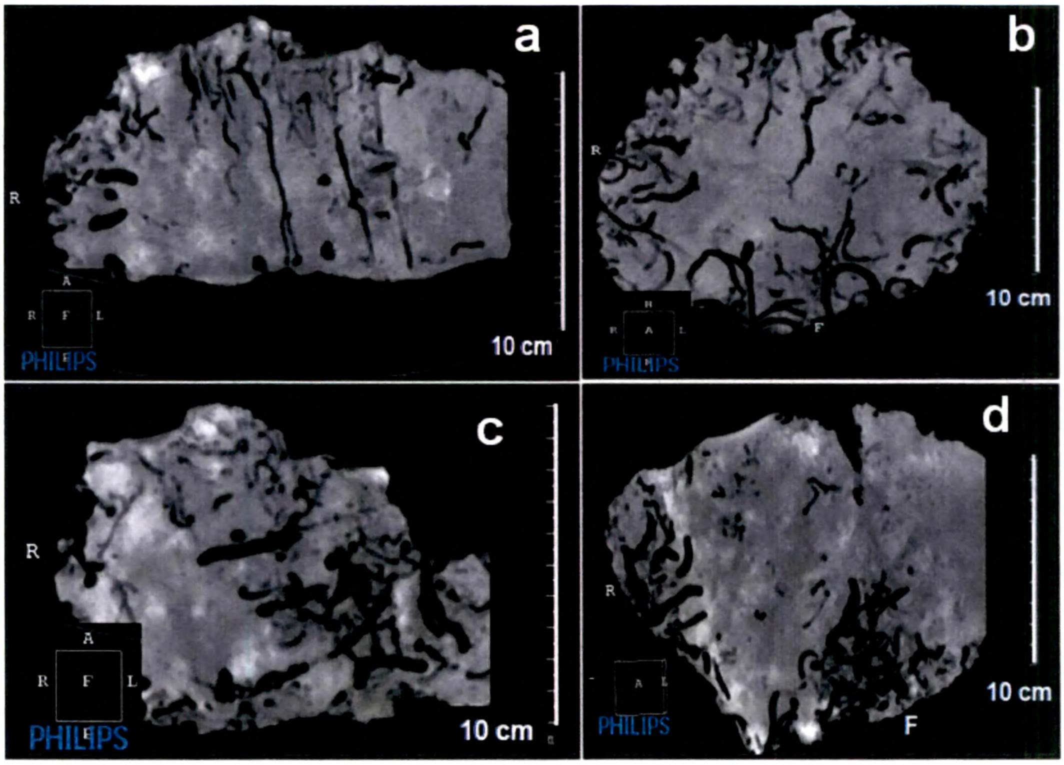

Plate 27: The CT Scanning of sediment block at different angles and orientations shows the size and density of burrows in different regions. The burrow interconnections are also visible.

Plate 28

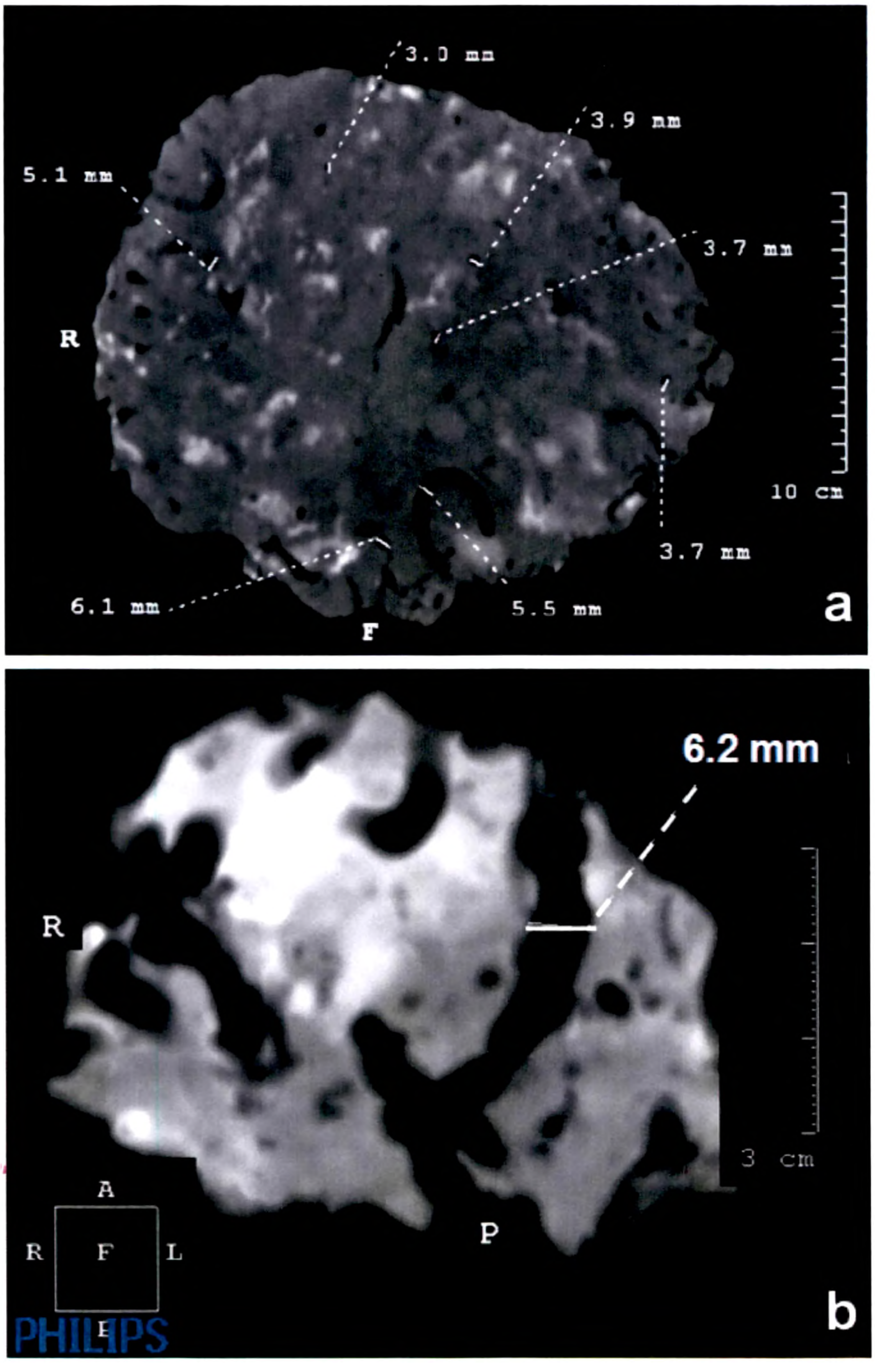

Plate 28: Determining the diameter of the burrow in the CT Scan images. The larger burrows are those of Sipuncula. The smallest ones are those of polychetes.

Plate 29

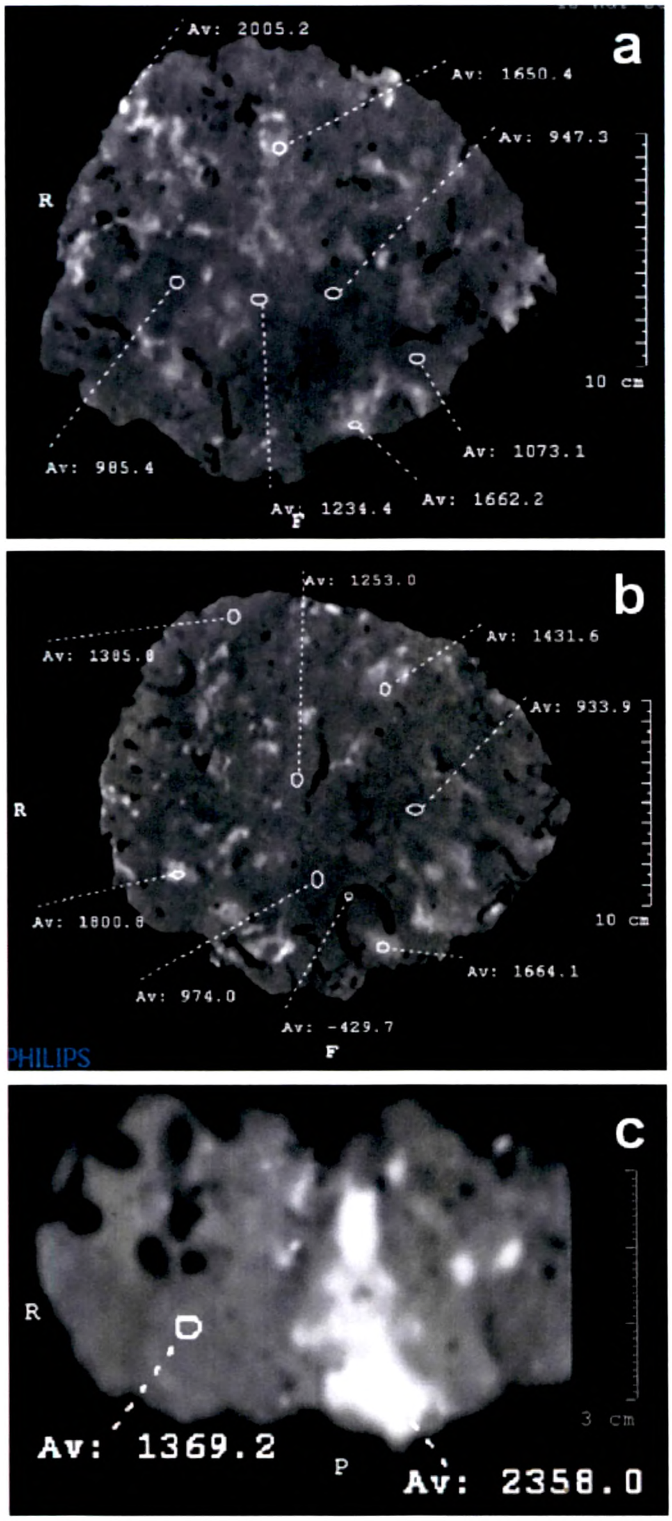

Plate 29: Demarking the sediment density of the block using specific software. The calcritized areas have higher densities and these are not preferred by the burrowing forms.

Plate 30

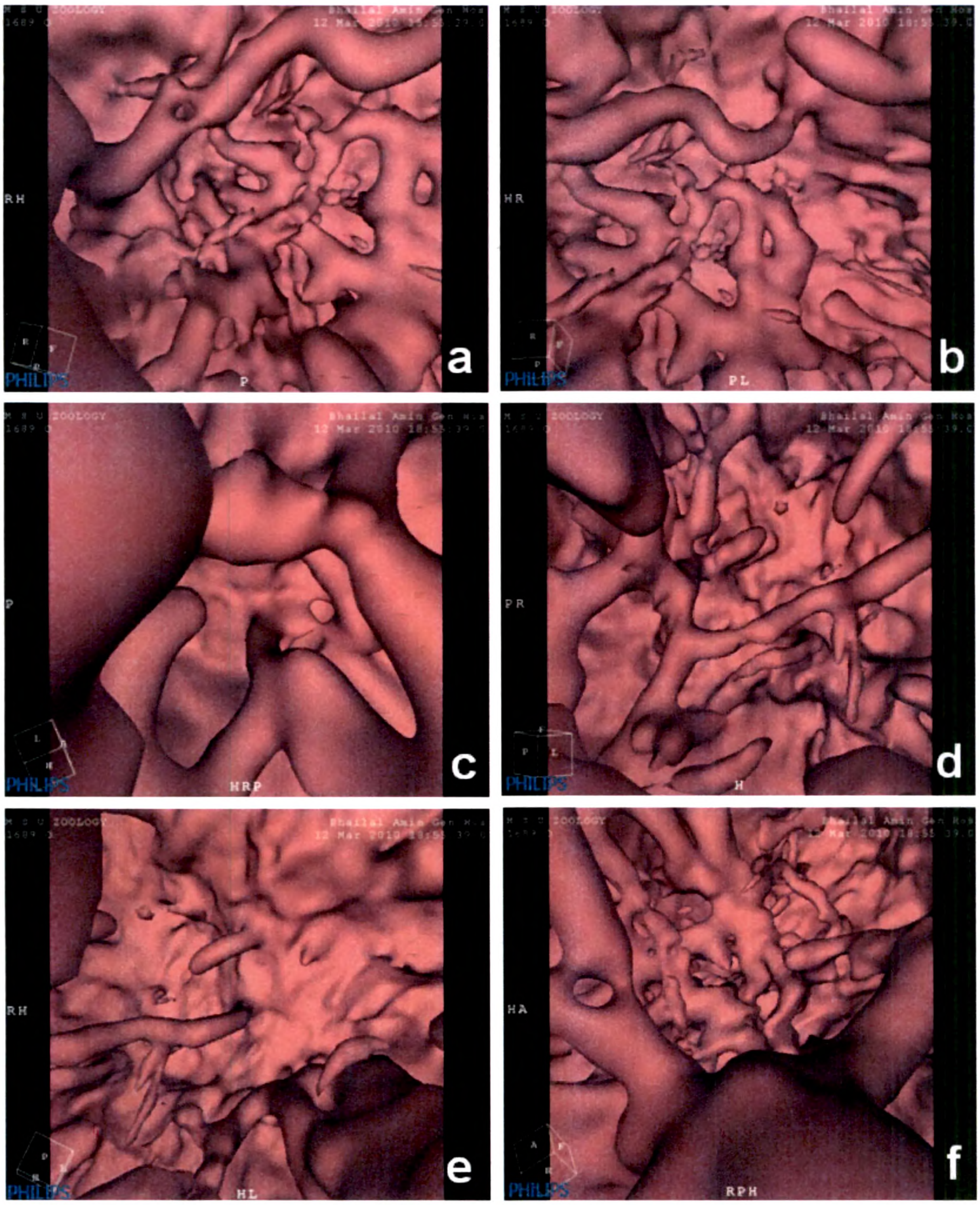

Plate 30: Endoscopic view of the CT Scan images using specific software to show the interior of the sediment block showing burrow architecture. The inverted (negative) image formation shows the burrows as tubes and the actual sediment filled area as the open regions here.

The pictures describe extensive branching, inter connections and burrow chamber areas (bulged portions) as well as the burrow ends (in e).

Plate 31

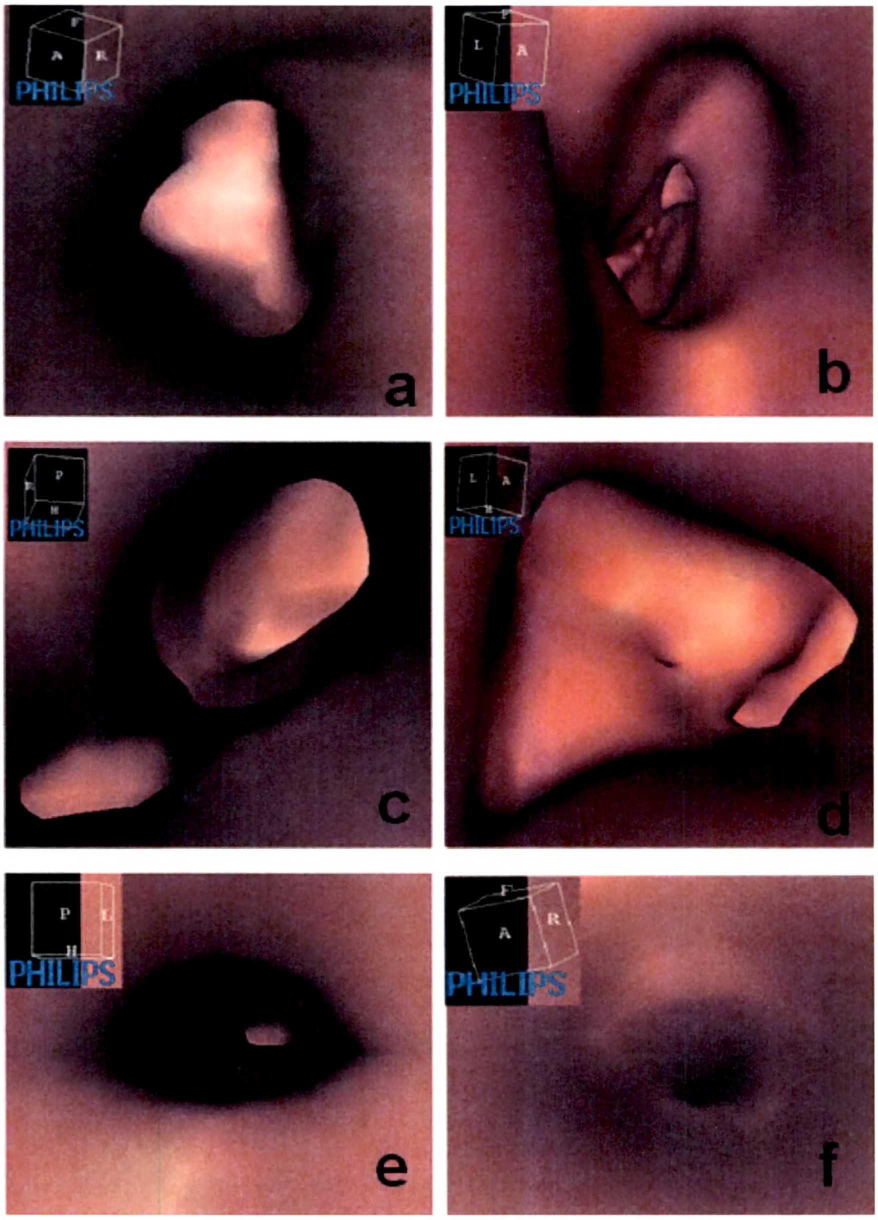

Plate 31: The CT Scan images were visited internally using endoscopy software and the pictures were taken at different intervals to show the burrow architecture. The endoscopy path started with burrow mouth in a, leading to branching into two in b, One of the branch was wider while the other was narrow in diameter as shown in c, in d the further branching is visible as well as the dead end in the centre is also seen. The architecture depict that this is one of the bulged portion of the burrow. In e the narrowing of distal end of burrow is seen while in f the burrow has ended into a dead end.