Chapter 10

Gandhera Quarry, A Unique Mammalian Faunal Assemblage From the Early Eocene of Baluchistan (Pakistan)

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1. Introduction

A newly discovered fossil locality, Gandhera Quarry, is yielding the most complete evidence to date on the structure of mammalian communities on the Indo-Pakistan subcontinent during the early Eocene. Gandhera Quarry is located in

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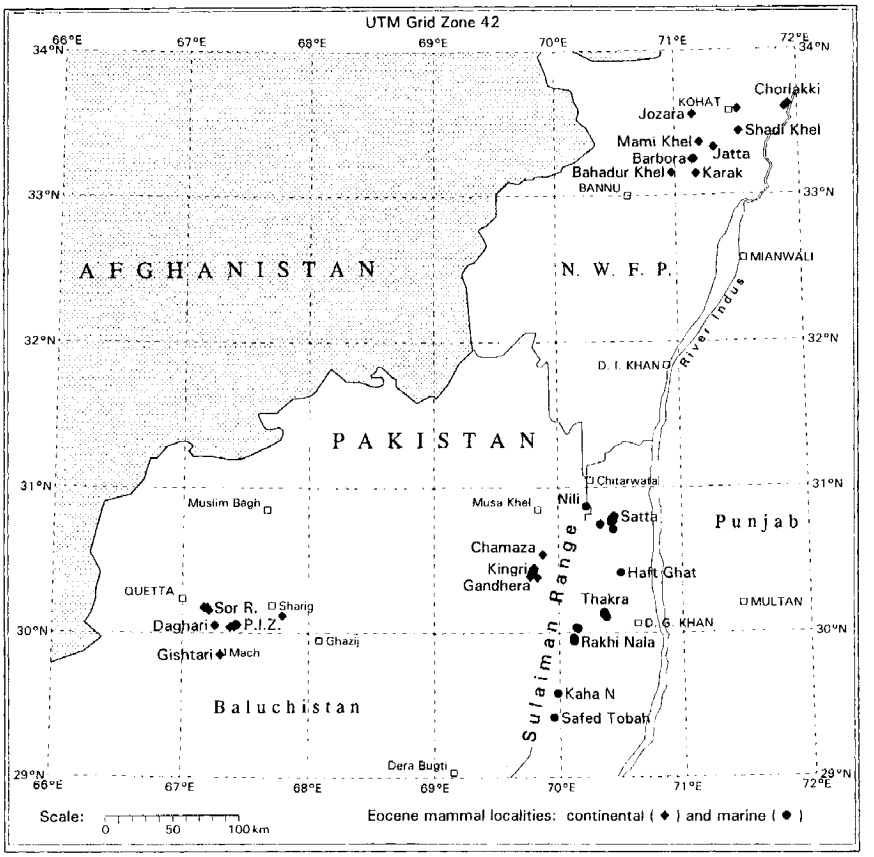

FIGURE 1. Map of northwestern Pakistan showing the location of Gandhera southeast of Kingri in eastern Baluchistan.

Musa Khel District, Baluchistan Province, Pakistan (Figures 1–3). The locality was discovered by Munir-ul-Haq in April, 1999, while prospecting for new localities with a Geological Survey of Pakistan-University of Michigan (GSP-UM) field party. The purpose of the present paper is to provide preliminary findings concerning the depositional environment, taphonomic characteristics, and taxonomic composition of Gandhera Quarry and its faunal sample. More complete taxonomic treatment is in progress and the paleobiogeographic implications of the Gandhera faunal assemblage will be discussed elsewhere (Gingerich *et al.*, in preparation).

2. Geologic Setting

Gandhera Quarry is located in the uppermost part of the mammal-bearing, fluvial, upper Ghazij Formation (Gingerich *et al.*, 1997, 1998, Figure 2). The

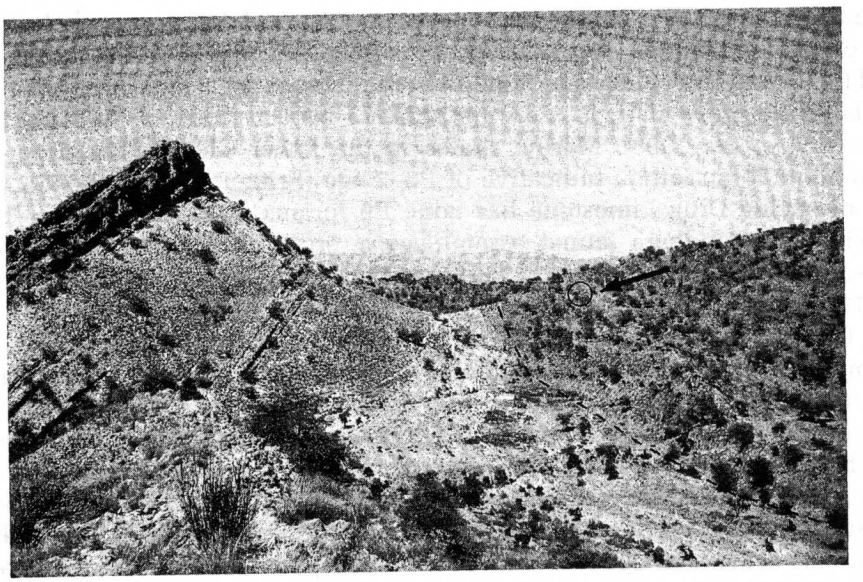

FIGURE 2. Photograph showing location of Gandhera Quarry in the upper part of the fluvial upper Ghazij Formation. View is to north. Collector standing in center of circle gives scale. Arrow points up-section. Dashed line approximates contact with overlying Drug Limestone forming bluff at left.

FIGURE 3. Gandhera Quarry. Fossil producing level is at the top of the slightly overturned flaggy sandstone (arrow). Hammer is shown for scale. Arrow points up-section. View is to north.

Ghazij Formation is a shallowing-upward sequence of: (1) marine shales in the lower part; (2) paludal coal-bearing sandstones and shales in the middle part; and (3) fluvial sandstones and floodplain mudstones with well developed paleosols in the upper part. It is on the order of 2600 m thick in the Kingri area (Warwick *et al.*, 1998). Marine shales in the lower Ghazij Formation yield planktonic foraminifera indicative of P6–7 age (Fritz and Khan, 1975), while the overlying Drug Limestone has zone P9 forams at the top (Afzal, 1996), making the Gandhera faunal assemblage a probable zone P7–9 equivalent (51–50 Ma) or late early Eocene (late Ypresian on the time scale of Berggren *et al.* 1995; Figure 4).

Gandhera Quarry is a 65 meter long sandstone-clay interface rich in small mammal jaws, teeth, and postcrania. The sequence is slightly overturned (Figure 3) so that the sandstone is now on top of the clay but the reverse was true during deposition. Well preserved dentitions and postcrania are cemented in a hard calcarenite matrix in the top 2–3 cm of the sandstone. This calcarenite facies is commonly preserved as a lag deposit in upper Ghazij sandstones and is largely composed of reworked carbonate nodules and less abundant lithic fragments cemented together with a carbonate/quartz cement. The calcarenite layer at Gandhera contains relatively coarse grains and larger bone elements at the northern end of the deposit and fines laterally to the south where grain size and bone elements are smaller. Above this hard layer, the shale is much softer and more friable and contains relatively more incomplete remains of small mammals. Above the shale is a greenish sandy clay that contains fewer bone elements.

3. Collecting Techniques

A variety of collecting techniques were undertaken at Gandhera Quarry in order to assess the best ways to approach future work. First, the small valley and drainage beneath the quarry layer were intensively surface prospected resulting in the collection of 187 maxillae and dentaries, 81 isolated whole teeth, and 1918 identifiable postcranial elements. Large blocks of the calcarenite layer were extracted and transported to the preparation laboratory at the University of Michigan where they are now being prepared. The shale layer above the calcarenite was quarried and dry screened resulting in collection of 41 maxillae and dentaries, 112 isolated whole teeth, and 1004 identifiable postcranial elements. Fresh samples of the shale layer were also collected ($\approx$ 5 kg) and transported to Michigan for wet screening. Nested screens of decreasing size (1000, 710, and 500 μm) were used, which resulted in the procurement of 13 additional maxillae and dentaries, 257 isolated whole teeth, and 918 identifiable postcranial elements. Quarrying produced some nearly complete bone elements but is very time consuming as, even when relatively intact, bones are microfractured making extraction difficult. Table 1 summarizes the identifiable elements collected at Gandhera Quarry in four days of field work and Figure 5 summarizes relative bone abundance.

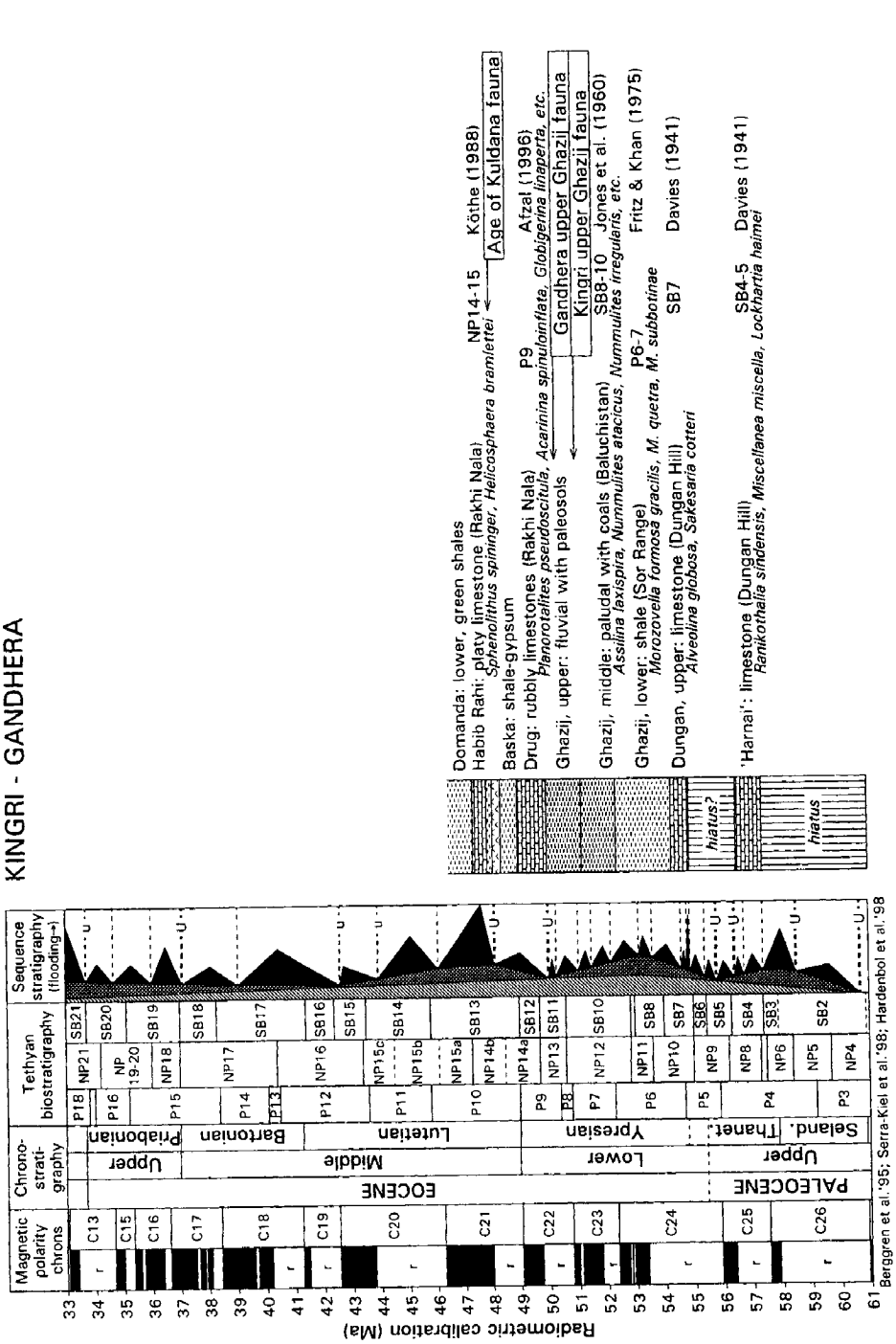

FIGURE 4. Correlation chart showing the stratigraphic position and age of Gandhera Quarry relative to earlier mammal-bearing units in the Ghazij Formation and the later Kuldana Formation faunas.

Table 1. Identifiable mammalian elements at Gandhera Quarry

Source	Maxillae/Dentaries	Whole Teeth	Tooth Fragments	Postcrania
Surface	187	81	98	1,198
Dry Screen	41	112	522	1,004
Wet Screen	13	257	2,387	918
Totals	241	450	3,007	3,840

Total of all identified elements = 7,538.

4. Taxonomic Composition

Three intervals within the Ghazij Formation of Baluchistan have produced mammalian remains (Gingerich *et al.*, 1997, 1998). The lowest interval is in the middle part of the Ghazij Formation and has produced two taxa of quettacyonids, an archaic family of condylarths, from coal and overlying mudstone lithologies (Gingerich *et al.*, 1997, 1999), and a possible anthracobunid from the coal unit (Ginsburg *et al.*, 1999). A second interval is in the lower part of

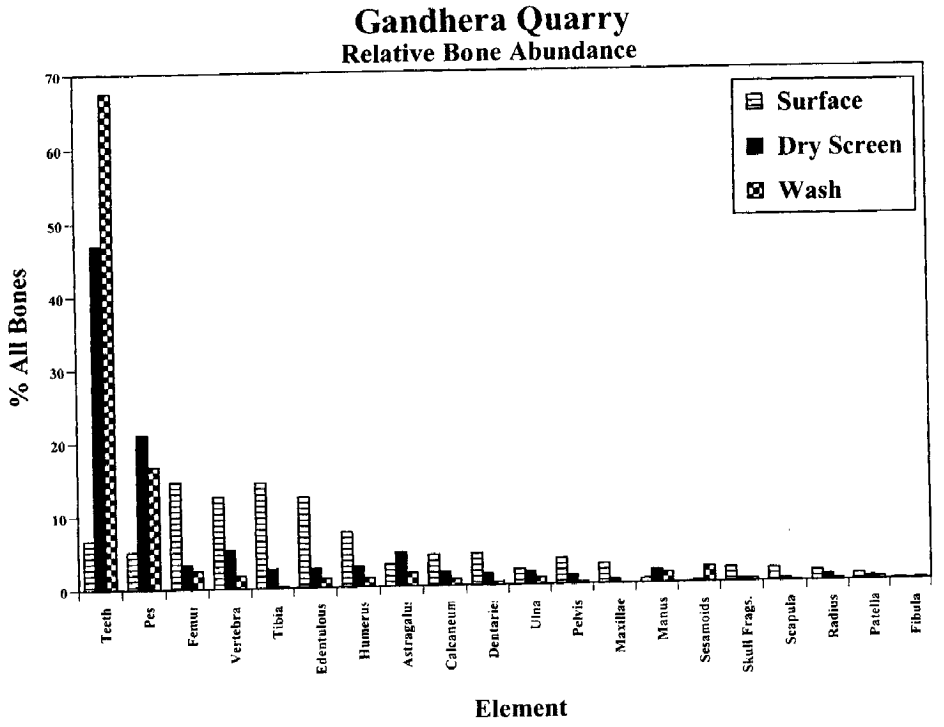

FIGURE 5. Relative bone abundance by collecting technique at Gandhera Quarry.

the upper Ghazij and has produced a more extensive faunal sample consisting of primitive perissodactyls, tillodonts, and quettacyonids, from calcarenite and mudstone. Gingerich, *et al.*, 1998. The upper part of the upper Ghazij Formation has produced the most diverse fauna and includes the Gandhera Quarry sample. The fauna from the upper part of the upper Ghazij is more typical of other holarctic early Eocene faunas known from North America, Europe, and Asia in that it includes primates, artiodactyls, perissodactyls, rodents, and hyaenodontid creodonts (Figure 6). Table 2 summarizes taxonomic composition through the Ghazij Formation.

5. Bones at Gandhera Quarry

5.1. Preservation

The calcarenite layer preserves relatively complete, solid elements, but otherwise bones tend to be broken and fractured in the rest of the sequence at Gandhera Quarry. Much of the breakage may be due to tectonic alteration as the sequence was overturned and compacted. Bones tend to be abraded and polished with few sharply preserved broken surfaces. Bones found in place in the calcarenite or in the shale directly above the calcarenite exhibit more freshly broken surfaces but even within these lithologies abraded and polished surfaces dominate. There is little evidence for any articulation or association of bones within the Gandhera sequence and there is no direct evidence of predator activity (bite marks, etching of teeth or bones due to gastrointestinal acids).

5.2. Distribution

Bones are scattered throughout the sequence with no dominant orientation. Within the calcarenite, bones are inter-laced and tightly juxtaposed with both horizontal (with respect to the bedding plane) and vertical orientations. The most substantial portion of the calcarenite layer is composed of bone, with only a small fraction made up of the silicified cementing matrix. Most bones found at Gandhera have nearly equivalent hydraulic properties (Voorhies Groups II and III, see Table 3). Somewhat larger elements are concentrated at the northern end of the quarry where sediments are coarser, and elements decrease in size southward as the sediments fine. Table 3 shows the distribution of bone elements by Voorhies group at Gandhera.

6. Summary

Much work remains to be done at Gandhera Quarry and any firm conclusions would be premature at this time. Table 4 summarizes sedimentary and taphonomic features at Gandhera as they are now understood. Based on these

Table 2. Ghazij Formation faunal list
(* - known from Gandhera Quarry; ** - only known from Gandhera Quarry)

Upper part of upper Ghazij
- Primates
  - Adapiformes
    - 1-2 taxa**
- Perissodactyla
  - Brontotheriidae
    - 3 taxa
  - Isectolophidae or Helaletidae
    - 4 taxa*
  - Chalicotheriidae
    - 1 taxon
  - New Family?
    - Large, bunodont taxon
- Artiodactyla
  - Dichobunidae
    - 3-4 taxa*
- Rodentia
  - Ctenodactylidae
    - 1-2 taxa**
- Mesonychia
  - Mesonychidae
    - 1 taxon
- Creodonta
  - Hyaenodontidae
    - 1-2 taxa**
- Insectivora/Proteutheria
    - 3-4 taxa**

Lower part of upper Ghazij
- Condylarthra
  - Quettacyonidae
    - *Sororocyon usmanii*
    - *Obashtakaia aeruginis*
- Perissodactyla
  - Families Uncertain
    - 3-4 taxa (includes large, bunodont taxon)
- Tillodontia
  - New Family
    - 2-3 taxa

Middle part of Ghazij Fm.
- Condylarthra
  - Quettacyonidae
    - *Quettacyon parachai*
    - *Machocyon abbasi*
- Order Uncertain
  - Anthracobunidae?
    - *Nakusia shahrigensis*

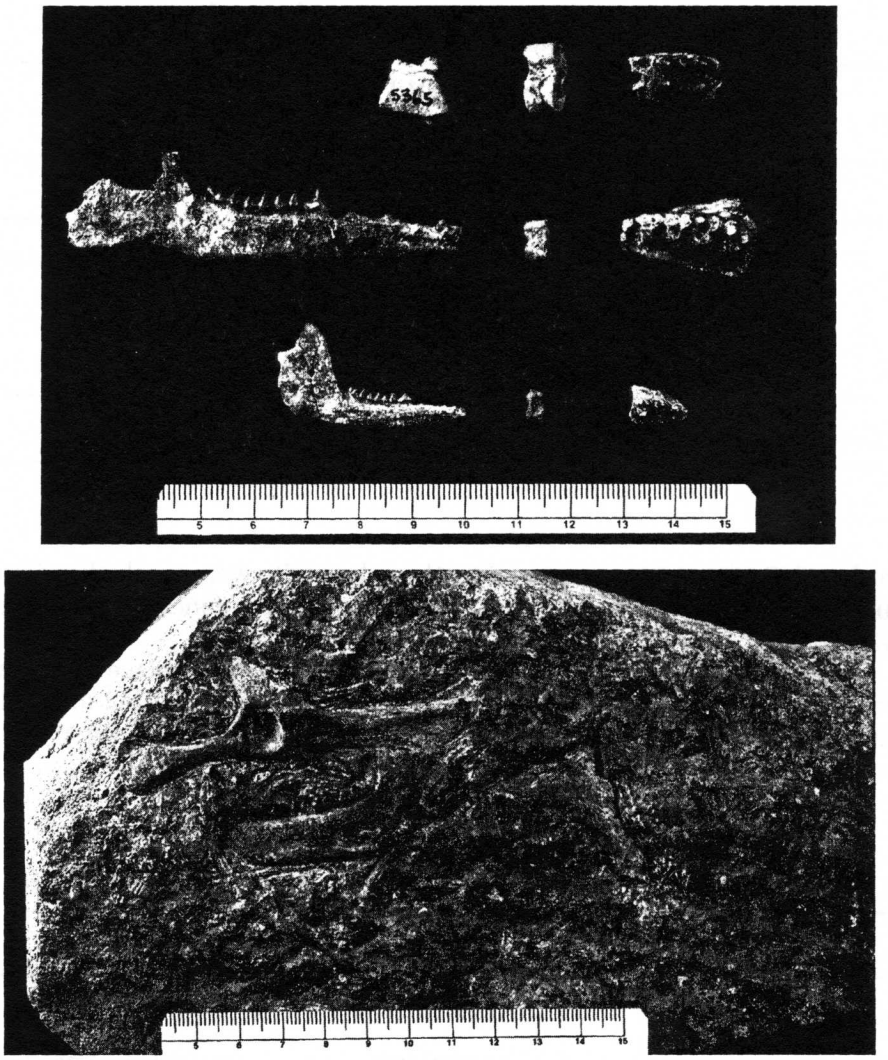

FIGURE 6. Top—Artiodactyl dentitions, maxillae, and astragali of three sizes found at Gandhera Quarry; Bottom—Two perissodactyl dentitions and a pelvis in a block of Gandhera Quarry sandstone matrix.

features, a channel or splay depositional system is favored over an overbank floodplain interpretation. The fact that many of the bones at Gandhera are abraded and polished suggests that they were transported or reworked to some degree before being preserved. Their abundant preservation alongside reworked carbonate nodules suggests that they were hydraulically sorted and concentrated within an active (or reactivated) lag of a channel or splay. Once deposited, bones that were at the sand-shale contact were cemented and

Table 3. Gandhera quarry—voorhies dispersal groups (based on Voorhies, 1969; Dodson, 1973; Korth, 1979)

	GROUP (with element and number of specimens)			
Low Settling Velocity		⇔		High Settling Velocity
I	I/II	II	II/III	III
	Radius (56) Ulna (125) Scapula (59) Pelvis (128) Vertebrae (552)	Maxillae (104) Teeth (450) Humerus (312) Femur (555) Astragalus (208)	Tibia (467) Skull Frags. (65) Calcaneum (184)	Dentaries (579)
Totals By Group	920	1,629	716	579

hardened. Bones not encompassed by the calcarenite were cracked and broken further as strata were over-turned, producing the sequence now exposed at Gandhera.

The taxonomic composition of the mammalian assemblage at Gandhera will be important for interpreting the sequence of events that led to the diversification of many modern orders of mammals. The high diversity within

Table 4. Gandhera Quarry—sedimentary and taphonomic features (condition present at Gandhera in bold type; modified after Badgley, 1986)

Taphonomic/Sedimentary	Expected Channel/Splay	Floodplain
Sediments coarsen laterally	**YES**	NO, OR LESS
Stratigraphic Distribution	**RESTRICTED HORIZONTALLY**	MORE HORIZONTAL DISPERSAL
Articulated skeletal elements	**NO**	OCCASIONALLY
Spatial Distribution	**SCATTERED**	SOME CLUSTERING
Dominant Voorhies Groups	**II-III**	I-III
Hydraulic Equivalence	**MOSTLY EQUIVALENT**	LESS EQUIVALENT
Tooth-Vertebra Ratio	**HIGH (Above 3.00 – Gandhera = 5.14)**	LOWER (Between 1-2)
Bone Damage	**ABRADED, POLISHED**	BROKEN, LESS ABRASION

families is surprising given the early Eocene age of the deposits. Much more study is required before these issues can be addressed in detail.

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