Shelf progradation: Interpretation from seismic facies of eastern India

Amitava Bandyopadhyay
(Marine Wing, Geological Survey of India, 63, N. S. C. Bose Road, Calcutta-700 040, India
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Analyses of shallow seismic profiles on the outer continental shelf, between Krishna and Godavari valleys off central east coast of India, reveal prograding sedimentary sequences on the shelf as well as on the flanks of the valleys. The progradation on the outer shelf is associated with palaeovalleys. A non-depositional erosional unconformity surface has been recognised throughout the shelf at 20-25 m subsurface. This is followed by a transgressive sequence of progradational sediments deposited during rising eustatic sea level accompanied by subsidence of the sea floor.

Geophysical surveys out to the 200 m isobath were conducted by the Oil and Natural Gas Corporation (ONGC). The regional structure and tectonics of the Bay of Bengal have been discussed on the basis of observations along a few widely spaced traverses by a number of scientists. Owing to the importance of potential hydrocarbon deposits, a number of scout seismic surveys have been recently conducted by the Geological Survey of India and the ONGC, over the whole of the eastern continental shelf and slope. Seabed morphology of the Krishna-Godavari delta has been studied in detail. This paper evaluates seabed geomorphology and sedimentation history from shallow seismic profiles run on the outer shelf between Krishna and Godavari valleys in the Bay of Bengal. The results obtained are discussed in the context of Late Quaternary eustatic sea level change.

Methods

A 3.5 kHz Raytheon LSR on CESP mode recorded the bathymetry from the mothership R. V. Samudra Manthan (SM-34A) conducted by the Geological Survey of India during January '87. About 54000 km² was surveyed with a line run for 4197 km bounded by lat. 15° 16' to 14° 22'N and long. 84° 48' to 83° 24' E in the east and lat. 16° 16' to 15° 36'N and long. 82° 20' to 80° 54'E in the west. A surface-towed, Huntec Hydrosonde, shallow seismic system was deployed along a 338 line km traverse at 1/4 sweep scale. It started from A in the east moving northeastward in a sinuous pattern up to B and again turned towards southwest in the same sinuous way up to C from where it moved north up to D and took a turn east for reaching the terminating point E (Fig. 1). The position data were acquired through SATNAV. For bathymetric profiling regional transects were shot along the shelf almost parallel to the shelf edge thus providing coverage of about 200 m depth. The reflection profiles from A through B, C, D to E were used to classify and map echotypes occurring within the area.

Results

The echocharacter map (Fig. 2) of the study area covering the shelf reflects the acoustic character of the sea floor which is highly variable. This heterogeneity is the result of influence of a number of channels emerging from the land to cut across the sea. Ten distinctive echotypes are observed from the acoustic results after comparing with Damuth, Prats & Laine and McClennen. Representative records are shown in Fig. 3-11. The key patterns are summarised in Table 1.

Fig. 1 — Isobath map of the area (up to 200 m) showing cruise tracks and submarine valleys.
classes I, II and IV are based on earlier classification of Damuth\(^\text{10}\) while irregular echoes are tabled by Pratson & Laine\(^\text{11}\) and the fifth echocharacter class is newly included.

I. Distinctive echoes are characterised by sharp, continuous, strongly reflective echo and are divisioned into three echotypes on the basis of nature of subbottom reflectors — (IA) a single echo (Fig. 3), (IB) dipping subbottom undulatory reflectors (Fig. 4) and (IC) discontinuous parallel dipping subbottom reflectors (Fig. 5).

II. Indistinct echoes are acoustically semitransparent to transparent, semiprolonged bottom echo occur in areas of flat topography or within valley as sediment filling. Two echotypes could be identified, viz. (IIA) semiprolonged echo with intermittent subbottom reflectors with lowermost undulatory (Fig. 6) and (IIB) weak echo with discontinuous subbottom reflectors forming trough (Fig. 7).

III. Irregular echoes have either both surface and bottom irregular to rugged or smooth surface with undulatory bottom. Three distinct echotypes are classified, viz. (IIIA) sharp irregular hummocky top surface followed by lower reflectors (Fig. 8), (IIIB) irregular but sharp reflectors with irregular semiprolonged hyperbola character for top and bottom

<table>
<thead>
<tr>
<th>Echo class and type</th>
<th>Seismic properties</th>
<th>Microtopography</th>
<th>Interpretation</th>
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</thead>
<tbody>
<tr>
<td>I. DISTINCT</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>IA.</td>
<td>Strongly reflective single echo with subbottom reflectors</td>
<td>Gently sloping intervalley regions; shallow trough at lower part</td>
<td>Shallow marine with coarse sand</td>
</tr>
<tr>
<td>IB.</td>
<td>Strongly reflective echo with dipping lower undulatory reflectors</td>
<td>Gentle slope steepens sudden valleyward buried channels</td>
<td>Head of submarine valley, delta front,</td>
</tr>
<tr>
<td>IC.</td>
<td>Parallel subbottom reflectors discontinuous &amp; dipping lowermost reflectors</td>
<td>Gently sloping inter-valley region valley head</td>
<td>Shallow marine silty sand, prograding</td>
</tr>
<tr>
<td>II. INDISTINCT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IIA.</td>
<td>Indistinct semiprolonged echo with intermittent subbottom reflectors; undulatory bottom</td>
<td>Gently sloping generally in shallow basin areas; pinching structure</td>
<td>Turbidite/disturbed deposits</td>
</tr>
<tr>
<td>IIB.</td>
<td>Top indistinct wavy, subbottom discontinuous</td>
<td>Reflectors form trough abutting adjacent parallel reflectors</td>
<td>Channel &amp; inter-channel areas; late sedimentation</td>
</tr>
<tr>
<td>III. IRREGULAR</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>IIIA.</td>
<td>Top irregular hummocky, also subbottom</td>
<td>1-2m high mounds on basin floor</td>
<td>Outer shelf valley sediment creep</td>
</tr>
<tr>
<td>IIIB.</td>
<td>Top irregular, lower indistinct undulatory, intermediate irregular, intermittent</td>
<td>Gently sloping, 2-3m relief from average sediment surface</td>
<td>Channel with disturbed sedimentation</td>
</tr>
<tr>
<td>IIIC.</td>
<td>Sharp flat top surface with highly irregular bottom surface</td>
<td>Large scale hummocky structure</td>
<td>Intervalley erosional bottom surface</td>
</tr>
<tr>
<td>IV. WAVY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV.</td>
<td>Subbottom reflectors pinch and swell</td>
<td>Undulatory surface steeply dipping towards valley</td>
<td>Progressive accelleration of sediments valleyward, head of valley, levee</td>
</tr>
<tr>
<td>V. OTHER</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| V.                  | Lower reflectors abut falling reflectors, break | Sharp fall in depth-channel/canyon/shelf shelf head | Outer shelf, prograding valley/
reflections (Fig. 9) and (IIC) top surface sharp smooth and flat with highly irregular bottom surface (Fig. 10).

IV. Wavy echoes are described here as a regular wavy echo with migrating subbottom reflectors, i.e., migrating sedimentary waves (Fig. 11).

V. Other is a special class which is distinctively morphologic featured in the outer shelf area either at the point of shelf break or at the prograded valley head as lower reflectors abut against falling surface (Fig. 4, extreme right).

The overall pervasive fabric of the echotypes are normal to the continental margin. Traversing from west end a sharp continuous single echo (Type IA) is found to occupy a stretch of about 20 km indicating an area where the sediments being carried from continents are distributed onto the outershelf. The

Fig. 2 — Distribution of bottom and subbottom reflection characters in the survey area - key patterns are summarised in Table 1.

Fig. 3 — Sharp continuous strongly reflective single echo with subbottom reflectors (IA).

Fig. 4 — Sharp continuous echo with dipping subbottom undulatory reflectors (IB), top and bottom reflectors fall steeply at extreme right (V).
Fig. 5 — Distinct sharp echo with parallel discontinuous subbottom reflectors and dipping lower ones (IC).

Fig. 6 — Indistinct semiprolonged echo with lowermost highly undulatory reflectors (IIA).

Fig. 7 — Weak echo with discontinuous subbottom reflectors forming troughs, parallel reflectors on both sides abut trough (IIB).
Fig. 8—Irregular hummocky top surface with parallel subbottom reflectors (IIIA).

Fig. 9—Irregular sharp echo surface and intermittent subsurface; lowermost indistinct; incising channel cuts through valley floor (IIIB).

Fig. 10—Flat smooth top with highly irregular bottom reflectors (IIIC).
sediments are of coarse grained sand. This is followed by about 8 km wide zone having both top and subbottom irregular reflectors with a moderate hyperbole (Type IIIB) that might indicate an incising channel on the surface with a 2-3 m high levee on both the banks and a bifurcating valley floor on the surface. The fossil channel underneath is evident from lower reflectors. To its east again a sharp continuous single echo (Type IA) appears for about 10 km lateral extent. From the west end up to this point the area falls in between two submarine channels, seaward extension of two tributaries of the Krishna river. This is the area, in general, of sediment accumulation fed by the channels from both ends and the middle part is slightly disturbed by the influence of probable turbidity current flowing through a long-time standing channel which has small levee on banks. This channel may be an extension of another tributary shown in the land part of Fig. 1.

Western bank of the seaward extension of easternmost Krishna valley is represented following east by a sharp continuous echo with dipping truncated subbottom reflectors (Type IB). This acoustically fine transparent layers of clinoform character delineates prograding foreset bedding of valley edge in a delta front. The undulatory bottom reflector depicts burried fluvial channels. The lowermost recognisable strata on the banks occur at about 20 m subsurface (assessing a velocity of 1.8 m/sec for a mixed shelf sediment of sand and clay). This is a prograding sequence and the lowermost reflector defines a combination of very thin of sediments of which each film monoclinally drapes at the bank edge covering a part of the previous draping film (Fig. 4). This bottommost reflector depicts a horizon of nondeposition or erosion with persuasive evidence of truncated reflectors that are picked up in the records. The immediate overlying sediments were transported past this horizon and accumulated on the slope. The overlying reflectors are also progradational as the sloping beds extend into horizontal layers. In the classification of seismic facies of pro-fluvialite deltas and outer shelves, “progressive oblique” for the former and “progressive sigmoid” for the latter are termed. The part of the Krishna valley in submarine is of 7 km wide in the transect. This reflects in the echocharacter map. The eastern bank also bears the same character as its western one and therefore represented by Type IB. However, in between the valley walls and floor the exhibited reflectors have sharp top echo with either sudden steep fall or large hyperbola (Type V) and the lower reflectors abut the draped ones indicating a rugged valley wall and floor.

The Krishna submarine valley is followed east by a wide zone of Narsapur Bay. The area is characterised by a combination of echo characters comprising distinct sharp, acoustically semitransparent indistinct and irregular surface and bottom reflectors. Record of about 12 km length could not be picked up due to mechanical fault of the instrument. Distinct sharp multilayered parallel reflectors with discontinuous and dipping lower ones (Type IC) are characteristic of gentle sloping intervalley region with a likely prograded valley head but having silty sand sediment of shallow marine environment. There are valleys/troughs in the area having top with parallel discordant and discontinuous trough shaped reflectors. Horizontal parallel discontinuous layers on
both sides abut the trough reflectors. One such palaeovalley is shown in Fig. 7 (Type IIIB) located between Gautami Godavari and Vashishtha Godavari submarine channels. This valley is about 3 km wide. Distinct Type IA indicates a smooth undisturbed area for is a considerable space. Irregular surface and bottom reflectors (Type IIIB) and even sometimes with highly irregular bottom reflectors (Type IIIC) are found to be present further east and more precisely west of submarine channel of extended Vashishtha river. This indicates a highly erosional subbottom floor which comes as near as within 10 m below the sea floor. Thus the Narsupur Bay located between the two river valleys, the Krishna and the Godavari, records an overall near flat top surface and irregular bottom surface. The large scale irregular/hummocky/trough/ truncated pattern of the lower reflectors are indicative of unconformable surface having erosional or nondepositional character.

There is a small area showing rugged hyperbolic echo character of type V, an evidence of a channel in the area which is followed eastward by a 12 km wide zone of indistinct semiprolonged echo with intermittent subbottom reflectors and irregular undulatory lowermost surface (Type IIA). This is resulted from a disturbed depositional environment possibly due to combined effect of turbidite deposit and spilling over of the sediments onto the bank from the channel. This channel is the extended submarine part of the Vashishtha Godavari river whose west bank shows typical wavy echo with migrating subbottom reflectors (Type IV). The layers are dipping towards the valley and the reflectors are of pinch and swell character. Thus the lowermost truncated layer which is reflected from less than 20 m subsurface becomes an erosional or nondepositional surface. The valley floor also records migrating subbottom reflectors. The eastern bank is about 40 km wide with characteristic of sharp top irregular surface and irregular semiprolonged reflectors with a few hyperbole indicative of small submarine channels (Type IIIIB). At a few places echo characters of Type IB are found for the lowermost reflectors. The facies of such seismic reflectors is described as "progressive oblique". The immediate reflectors are inclined, irregular, wavy, commonly exhibiting moulded and draped patterns. These are the variety of off-lap seismic reflections where the reflections collectively compose a wedge to lensoid shaped unit that pinches out basinward. This type of off-lap is termed "oblique progradational seismic facies". The features of the eastern bank can be compared to "sigmoid progradational seismic facies". The top surface and subbottom reflectors of valley floor are highly irregular but parallel to each other.

The adjacent area exhibits indistinct semiprolonged echo with intermittent subbottom reflectors (Type IIA). This is again the effect of turbidite deposit on the western bank of seaward extended channel of Gautami Godavari river. At places, however, the lowermost surface records highly undulatory indicating an unconformable surface at about 25 m below the sea floor.

A seismic section, normal to the shelf break, extends between the 100 m and 150 m isobaths. Type IC echocharacter is observed with seaward progradational sediment wedge (Fig. 5) and found only on the shelf break. As the sloping beds extend into horizontal layers, the seismic facies becomes "progradational sigmoid".

**Discussion**

The study of the shallow seismic records of the area reveals that the banks of both the Krishna and Godavari river valleys are prograded towards their respective valley axes. The seismic profiles for the banks of the Krishna valley indicate progressive oblique facies for the lowermost recognisable layer and progressive sigmoid facies for the younger sediments. The banks of the Godavari valley depict offlap seismic reflections, typifying oblique progradational seismic facies for the western flank and progressive sigmoid for the eastern one. All the channels and palaeovalleys picked up in the records have a common seaward trend of their valley floor axis and they are also prograded. The shelf is identified as sigmoid progradational seismic facies.

Thus it is concluded that the shelf which includes the Krishna-Godavari delta, is a prograded one. Such a profluviatile delta is the result of fluvial deposits trapped when they arrive at the open sea. These deposits are later scattered by strong longshore drift during the southwest monsoon and thus form the prograded flanks for the submerged valleys in the area. The seismic facies as interpreted in the area is progressive sigmoid or oblique, and is related to subsidence for this case. The lowermost reflector is characteristic of the irregular, hummocky or wavy facies in most of the areas. Near the shelf break or valley mouth an oblique progradational facies is interpreted for the just overlying sediments indicating rapid deposition of sediments in sloping beds passing...
over the undulatory horizon. This undulatory horizon is considered to be an unconformity characteristic of either erosional or nondepositional environment. This distinctive surface feature has been observed in the whole studied area within 65 to 120 m water depth and at 20-25 m subsurface.

The basin is described as pericratonic divergent margin type and the shore as submerged protrudesent deltaic\(^7\). The entire region is within the active tectonic belt and has experienced relative sealevel changes due to subsidence or uplift in addition to the glacial effect during the Quaternary period.

The unconformity is a signature of the peak of the last glacial period (i.e., the Wurm glaciation or the Wisconsin glaciation) when the sea level fell maximum 120 m world wide\(^18\)\(^-\)\(^21\). A brief period of exposure of this unconformable horizon is followed by a transgression period when the sea level began to rise (Flandrian transgression). Therefore the last 20 - 25 m wedge of sediments got deposited during this trangression period in this area of subsidence.

However, further work will throw more light on the history of sedimentation and the behaviour of eustatic sea level change during the later phase of the Quaternary.

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References