[PS]Stratigraphy of Linked Submarine Minibasins in Laboratory Experiments*

Enrica Viparelli[1], Tzu-hao Yeh[1], Alessandro Cantelli[2], Edgar Leslie[1], Alec Robertson[1], and Gary Parker[3]

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[1]Department of Civil and Environmental Engineering, University of Illinois Urbana-Champaign, Urbana, IL (viparell@engr.sc.edu)
[2]Shell, Houston, TX
[3]Department of Civil and Environmental Engineering and Department of Geology, University of Illinois Urbana-Champaign, Urbana, IL

Abstract

Minibasins in the deep sea on the North Slope of the Gulf of Mexico are prime locations for the deposition by turbidity currents of sediment with the potential to form hydrocarbon reservoirs. Laboratory experiments on two linked submarine minibasins with three-dimensional geometries and non-uniform sediment have been performed at the University of Illinois, Urbana-Champaign to study: (1) the role of the geometry on the deposition of coarse sediment in the updip portion of the first (or updip) basin, (2) the fate of both the sand and the mud as the updip basin fills, and (3) the evolution of the deposit in the downdip (or second) basin as the first basin fills. Salt-induced subsidence has not been modeled. Three sets of experiments have been performed with different inflow discharges, i.e. high, medium, and low. In each set, repeated and sustained turbidity currents have been released to fill the updip basin. A downdip-migrating entrance deposit, which might be interpreted as the analog of an apron, formed in the updip portion of the first basin, while the deposit in its downdip part can be reasonably characterized as ponded. At the end of each experiment the deposit in both the basins has been dried and sliced, and core samples have been taken to quantify the stratigraphy.

At the moment, data have been processed for the experiments with medium and high inflow rate, showing that: (1) the deposit in the updip basin in the experiment with the high inflow rate is coarser than the deposit in the experiment with the medium inflow rate, (2) as the updip basin fills, the pattern of trapping of coarser sediment in the apron deposit causes a mild tendency for upward fining in the ponded zone, and (3) the apron deposit shows a downstream fining profile. Finally, detailed measurements of one event in the first basin show a massive ponded deposit (i.e. no significant vertical variation of grain size distribution) bounded by two thin layers of fine drape. The deposit in the downdip basin is mostly fine-grained and draped, but its grain size distribution is coarser for the experiment with the high inflow rate.

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STRATIGRAPHY OF LINKED SUBMARINE MINIBASINS IN LABORATORY EXPERIMENTS

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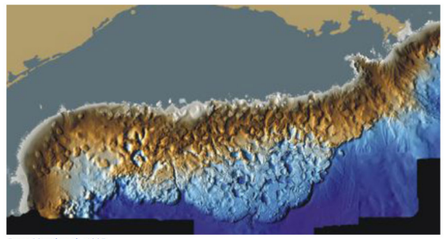
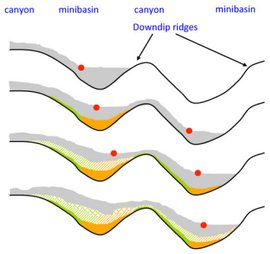
MINIBASINS OF THE GULF OF MEXICO ON A SEAFLOOR MAP



From Diegel et al., 1995

HOW ARE THE MINIBASINS FILLED?



The turbidity currents enters the minibasin, hits the downdip ridge, and an updip migrating hydraulic bore forms (red dot in the figure). Sediment is deposited in a ponded fan (solid green and orange deposits). In case of a sustained current, the system can reach a quasi-steady state, in which the planform position of the hydraulic bore very slowly changes in time.

As the minibasin fills, turbidity currents spill over the lowermost point of the basin flanks (i.e. the spill point) and reach the next empty minibasin downslope. In this stage, the first basin is filled up to its spill point, stacked lobes and channels may form, and fine sediment may be delivered downdip (green and orange striped deposit).The quasi-steady planform position of the hydraulic bore migrates downdip.

The current spilling in the next minibasin downslope can
a) die down emplacing a draped deposit;
b) reach the downdip ridge, be reflected, and emplace a ponded deposit.

When a minibasin is filled, turbidity currents bypass it through channel-levee systems. In this phase, slope adjustments occur with the erosion of the spill point, knickpoint migration, and channel bed aggradation/degradation (net green and orange deposits). Finally, a drape of mud is deposited at the end of the cycle. (Prather,1998)

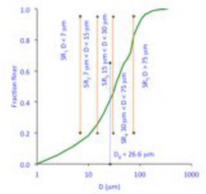
HOW CAN WE ACCOUNT FOR THE NON-UNIFORMITY OF THE SEDIMENT AND THE 3-DIMENSIONAL GEOMETRY OF THE SYSTEM?

3 LABORATORY EXPERIMENTS

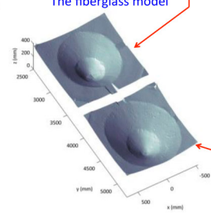
Experiment	Run	Q (l/s)	C	Duration (min)
1	12	0.30	0.05	20 (5(; 30 (2); 40 (1); 55 (4)
2	9	0.45	0.05	15 (4); 25 (1); 35 (4)
3	9	0.20	0.05	30 (6); 20 (3)

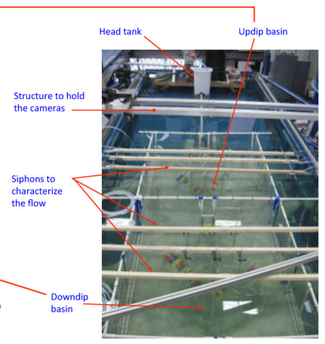
Experiment 1: base case, coarse sediment (SR_3-SR_6) trapped in the updip basin, just fine sediment spilling downdip (SR_1-SR_2);
Experiment 2: large turbidity current entering the updip minibasin, higher spilling in the distal basin;
Experiment 3: small but fast turbidity current entering the updip basin, small spilling in the downdip basin.

The parent material: 5 size ranges SR_1-SR_5



The fiberglass model





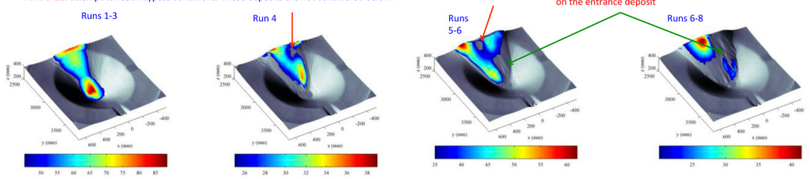
EXPERIMENT 1: Q = 0.3 l/s, C = 0.05

In the updip minibasin

Runs 1-3: preferential deposition of sediment in the central part of the basin and on the proximal flank.

Runs 4-8: channels and lobes form on the entrance deposit;

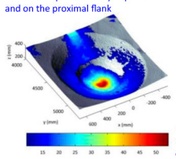
Runs 9-12: attempt to reach bypass conditions. These deposits are not considered below.



The color scales represent the thickness of the deposit emplaced during the runs in millimeters. The red arrows point at the channels.

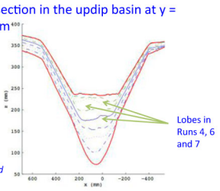
In the downdip minibasin

Sediment is preferentially deposited in the center and on the proximal flank

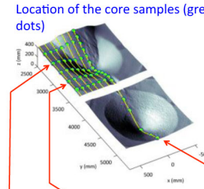


The color scale represents the thickness of the deposit emplaced during the runs in millimeters.

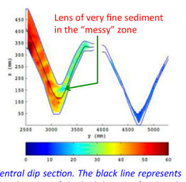
Strike section in the updip basin at y = 3000mm



Location of the core samples (green dots)



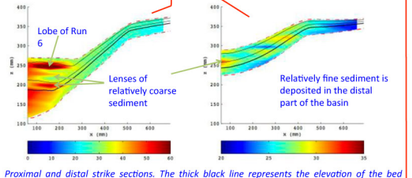
Dip and strike sections



The coarse sediment is trapped in the updip basin and just the fine components, i.e. SR_1 and SR_2, spill downdip.

When lobes are deposited, the stratigraphy is characterized by lenses of coarse and fine sediment, highlighted with green arrows in the cross sections.
Lobes are made of very coarse sediment, i.e. SR_6;
Lenses of moderately coarse sediment, i.e. SR_5 and SR_4, and very fine sediment, i.e. SR_3 and SR_1, are deposited on the sides of the lobes.

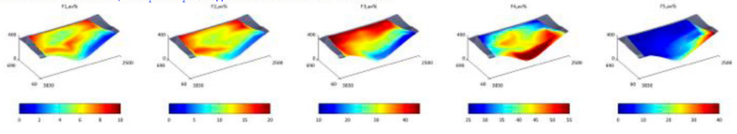
Central dip section. The black line represents the elevation of the bed deposit after Run 3. The color scale denotes the geometric mean diameter of the deposit in microns.



Proximal and distal strike sections. The thick black line represents the elevation of the bed deposit after Run 3, the thin black lines denote the elevation of the bed deposit after Run 4 and Run 6. The color scale represents the geometric mean diameter of the deposit in microns.

Average grain size distribution of the deposit in the updip minibasin in Runs 1-3, i.e. when lobes are not emplaced.

SR_3 sediment is preferentially deposited on the proximal flank, SR_4 sediment is deposited in the central part of the basin and high fractions of SR_5 sediment are deposited on the lateral flanks. Very small fractions of fine sediment, i.e. SR_1 and SR_2 are trapped on the lateral flanks of the minibasin.

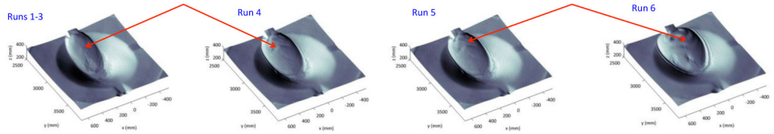


The color scales denote the percent of sediment in the SR_1-SR_5 size ranges, i.e. F_1-F_5, in the deposit emplaced in Runs 1-3.

EXPERIMENT 2: Q = 0.45 l/s, C = 0.05

In the updip minibasin

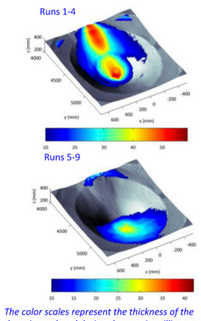
Preferential deposition of coarse sediment occurs on the proximal flank and in the central part of the minibasin. Laboratory analogs of trains of cyclic steps form on the entrance deposit in Runs 3-7. As the basin fills, the steps form on a wider area, revealing that in the later stages of the experiment the ponded zone becomes smaller and confined in the distal part of the basin. As the basin fills, the position of the hydraulic jump at quasi-steady state migrates downstream and the jump occupies a wider area.



The arrows point at the laboratory trains of cyclic steps.

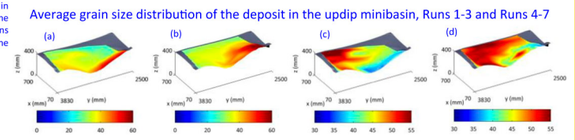
In the downdip minibasin

The depositional pattern changes during the experiment: in Runs 1-4 preferential deposition of sediment occurs on the proximal flank and in the center of the minibasin. In Runs 5-9 preferential deposition occurs in the distal part of the minibasin.



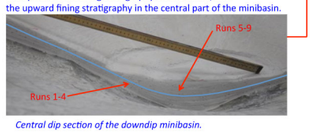
The color scales represent the thickness of the deposit emplaced during the runs in millimeters.

Average grain size distribution of the deposit in the updip minibasin, Runs 1-3 and Runs 4-7



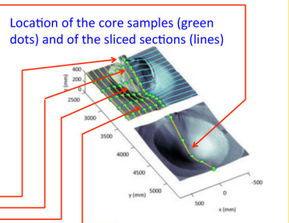
The color scales represent 1) the geometric mean diameter in microns (a) Runs 1-3, (b) Runs (4)-(7); and 2) percent of sediment in the SR4 size range in (c) Runs 1-3, and (b) Runs 4-7.

In Runs 1-3, SR_5 sediment is deposited in the central part of the basin, while SR_4 sediment is preferentially deposited on the lateral flanks in the distal part of the minibasin. Finer sediment, i.e. SR_2 and SR_1, is deposited on the proximal lateral flanks. The SR_4 sediment is deposited in the ponded zone, while the finer components are transported updip in the upper part of the water column (a and c).
In Runs 4-7 more SR_5 sediment is trapped on the entrance deposit. The fraction of SR_4 sediment deposited in the central part of the basin increases. SR_3 sediment is deposited on the lateral flanks of the basin (b and d), showing that as the basin fills, it is transported updip in the upper part of the water column. This is most likely the consequence of the downdip migration of the quasi-steady state position of the hydraulic jump , or in other words of a smaller ponded zone.
This results in
1) the change in depositional pattern in the downdip minibasin;
2) the upward coarsening stratigraphy on the flanks, and
3) the upward fining stratigraphy in the central part of the minibasin.



Central dip section of the downdip minibasin.

Location of the core samples (green dots) and of the sliced sections (lines)



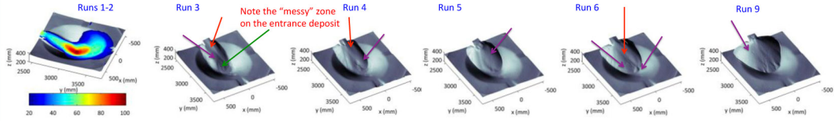
Dip sections in the updip minibasin. The black dotted circle denotes what might be interpreted as the position of the hydraulic jump at quasi-steady state. The red arrows point at what might be described as trains of cyclic steps

EXPERIMENT 3: Q = 0.2 l/s, C = 0.05

In the updip minibasin

Runs 1-2: preferential deposition of sediment in the central part of the basin. Due to the higher velocity of the entering turbidity current compared to the other experiments, the flank deposits have comparable thicknesses;

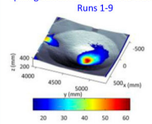
Runs 3-9: preferential deposition on the proximal flank and in the central part of the basin. Channels and lobes form on the entrance deposit.



The color scale represent the thickness of the deposit emplaced during the runs in millimeters. The red arrows point at the channels, and the purple arrows at the lobes.

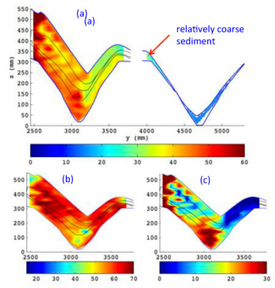
In the downdip minibasin

Preferential deposition of sediment occurs at the exit of the connecting canyon, where the relatively coarse sediment spilling in Runs 1-5 is preferentially deposited. In all the experimental runs the spilling current is too weak to travel through the basin. It dies down right at the exit of the canyon emplacing a hemipelagic deposit.



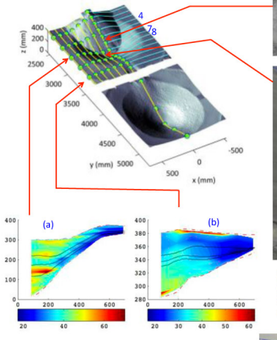
The color scale represent the thickness of the deposit emplaced during the runs in millimeters.

Central dip section of the downdip minibasin.

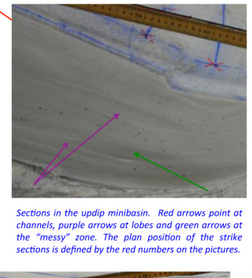


Spatial variation of (a) the geometric mean diameter (in microns) , and of the percent of sediment in the SR4 (b) and SR5 (c) size ranges in the central dip section.

Location of the core samples (green dots) and of the sliced sections (lines)



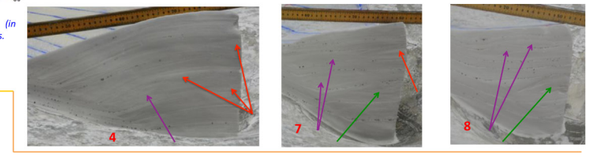
Spatial variation of the geometric mean diameter (in microns) in the proximal (a) and distal (b) strike sections.



Sections in the updip minibasin. Red arrows point at channels, purple arrows at lobes and green arrows at the "messy" zone. The plan position of the strike sections is defined by the red numbers on the pictures.

Although experiment 3 is characterized by the smallest inflow rate, due to the faster turbidity current entering the updip minibasin compared to experiment 1,
a) the deposit in the central part of the updip minibasin emplaced in the first runs is coarser than in experiment 1 (very high fractions of SR_6 sediment);
b) the sediment spilling in the downdip minibasin in the early stages of the experiment is relatively coarse. This coarse sediment is deposit at the exit of the connecting canyon;

In the updip minibasin during Run 3, a lens of very fine sediment is deposited downdip of the lobe, as in Runs 6-8 of experiment 1. These lenses of very fine sediment are associated to the "messy" bathymetry observed in the distal part of the minibasin.
In the proximal strike section, clear lenses of coarse material are associated with the emplacements of lobes.
A clear pattern of upward fining is observable in the distal strike section, revealing an increasing trapping of coarse sediment in the entrance deposit during the late experimental runs.



CONCLUSIONS

1) When the turbidity current enters the minibasin, it becomes laterally unconfined and tends to flow over a wider area compared to the section of the canyon. Consequently, when the current decelerates, preferential deposition of sediment on the proximal flank of the basin occurs. In particular,
a) preferential deposition of coarse sediment occurs on the proximal flank of the minibasin;
b) a thick and coarse deposit is emplaced in the central and deep part of the minibasin;
c) a relatively coarse and thin deposit is emplaced in the central part of the distal flank, i.e. updip of the canyon connecting the two basins; and
d) relatively fine sediment is deposited on the lateral flanks.

2) When a relatively large turbidity current enters the updip minibasin (i.e. experiment 2),
a) preferential deposition of coarse sediment occurs on the proximal flank. The coarse sediment that reaches the distal part of the minibasin is mostly trapped in the ponded deposit. The reflected current transports fine sediment updip. This sediment is deposited on the basin flanks;
b) as the minibasin fills, more and more coarse sediment is trapped in the entrance deposit. Part of the coarse sediment that arrives in the ponded zone is deposited, and part is transported updip by the reflected current. It then deposits on the lateral flanks of the basin.

Due to the preferential deposition of coarse sediment on the entrance deposit and on the lateral flanks,
a) the ponded deposit in the deeper part of the basin is characterized by an upward fining stratigraphy; and
b) upward coarsening is observed on the proximal lateral flanks, i.e. on the sides of the entrance deposit.

3) When a relatively small and fast current enters a "nearly empty" basin (early stages of experiment 3),
a) preferential deposition of coarse sediment is always observed in the proximal zone, but the fraction of coarse sediment that reaches the distal zone is larger than in the case of a slower and larger current entering the same basin (i.e. experiment 1);
b) due to the mixing in the ponded zone, the deposit on the distal flank and the spilling current are coarser than in the base case.

As the updip basin fills, more coarse sediment is trapped in the entrance deposit, and consequently the distal ponded deposit and the spilling current become progressively finer in time.

4) In the early stages of the experiments, the emplaced deposits are symmetric respect to the central dip section of the basin. As the updip basin fills,
a) the flow becomes asymmetric, and stacked lobes and channel form in the proximal part of the basin for low and moderate inflow rates (experiments 1 and 3); and
b) in the case of a large inflow rate (experiment 2), the flow remains symmetric, stacked lobes are not emplaced, and laboratory analogs of cyclic steps form and migrate on the entrance deposit.

5) The stratigraphy of the deposit in the case of stacked lobes presents lenses of coarse sediment in correspondence of the lobes and of the channels, surrounded by a relatively fine matrix.
Lenses of very fine sediment may form in the distal part of the basin when the current deposits most of the bed material in the lobe, and just the very fine component of the mixture reaches the distal part of the basin.

When lobes are not emplaced, the stratigraphy of the deposit does not present lenses of coarse and fine sediment. Preferential deposition of sediment is observed in the proximal part of the basin, and an upward fining profile characterizes the ponded zone.

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Prather B. E., J. R. Booth, G. S. Steffens, and P. A. Craig (1998). Classification, Lithologic Calibration, and Stratigraphic Succession of Seismic Facies of Intraslope Basins, Deep-Water Gulf of Mexico, AAPG Bulletin, v. 82(5A), 701-728.

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ADDITIONAL INFORMATION:

1) Additional information on the experimental set up is given on the right panel of the booth;
2) Additional information on the flow characteristics is presented on the left panel of the booth;
3) Videos and pictures of the experiments can be seen on the laptop.