An Investigation of the origin and evolution of Mima mounds in California's Central Valley

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Figure 1 – View of project area northeast of Merced, California.

Survey Parameters

This LiDAR survey was conducted on Sunday, September 17, 2006 (GPS day 260) on the project polygon northeast of Merced in Merced County, California. LiDAR data were collected with a (rented) Optech 1233 ALTM (serial# 99B112) mounted in a turbocharged twin engine Cessna 337 (tail number N86539). The survey required one flight about four hors in duration. Figure 2 (below) shows the location and size of the project polygon.

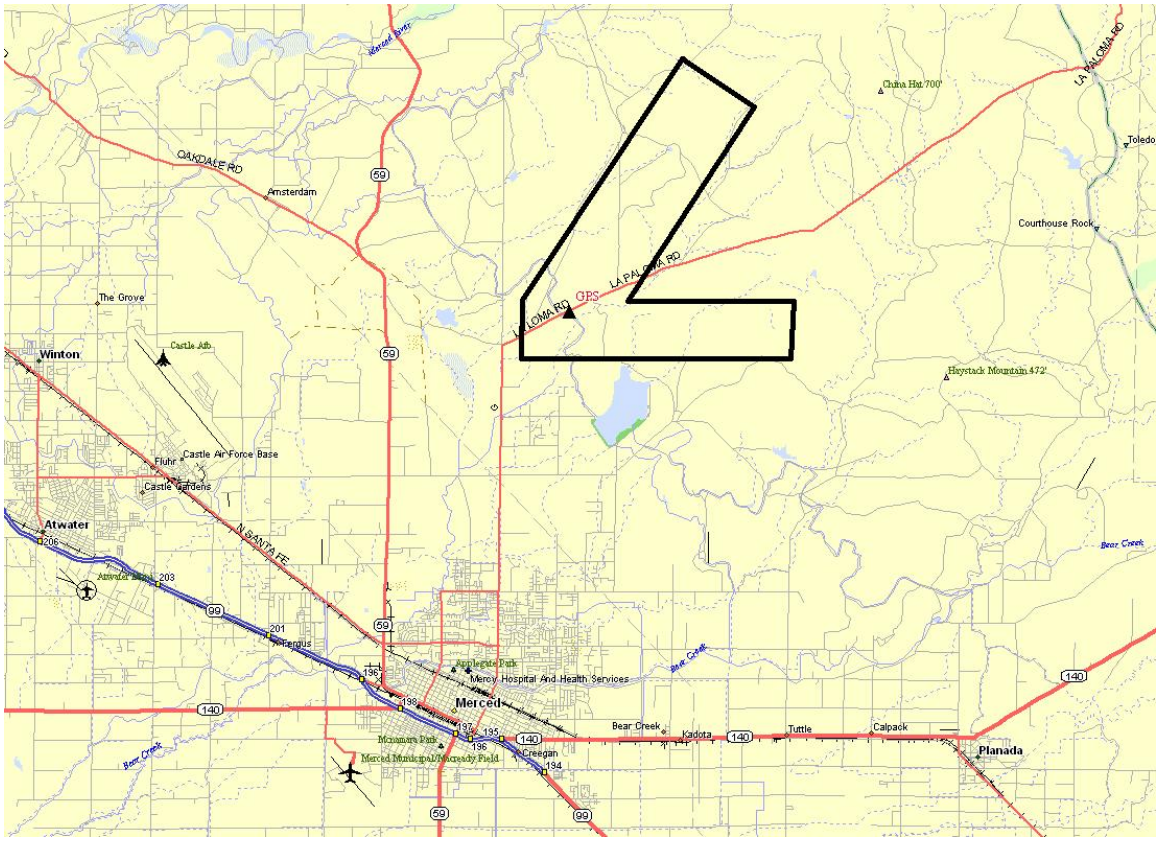

Figure 2 – Project polygon (30 square kilometers) GPS reference station (REED) location is shown as the black triangle.

LiDAR settings were held constant as follows: the flight line spacing was fixed at 212 meters. This fixed line spacing resulted in 50 percent overlap. The scan angle was held constant at +/- 20 degrees, and scan frequency (mirror oscillation frequency) was fixed at 28 Hz for the flight.

Figure 3 (below) is a map showing the 21 planned flight lines for polygon along with the LiDAR parameters.

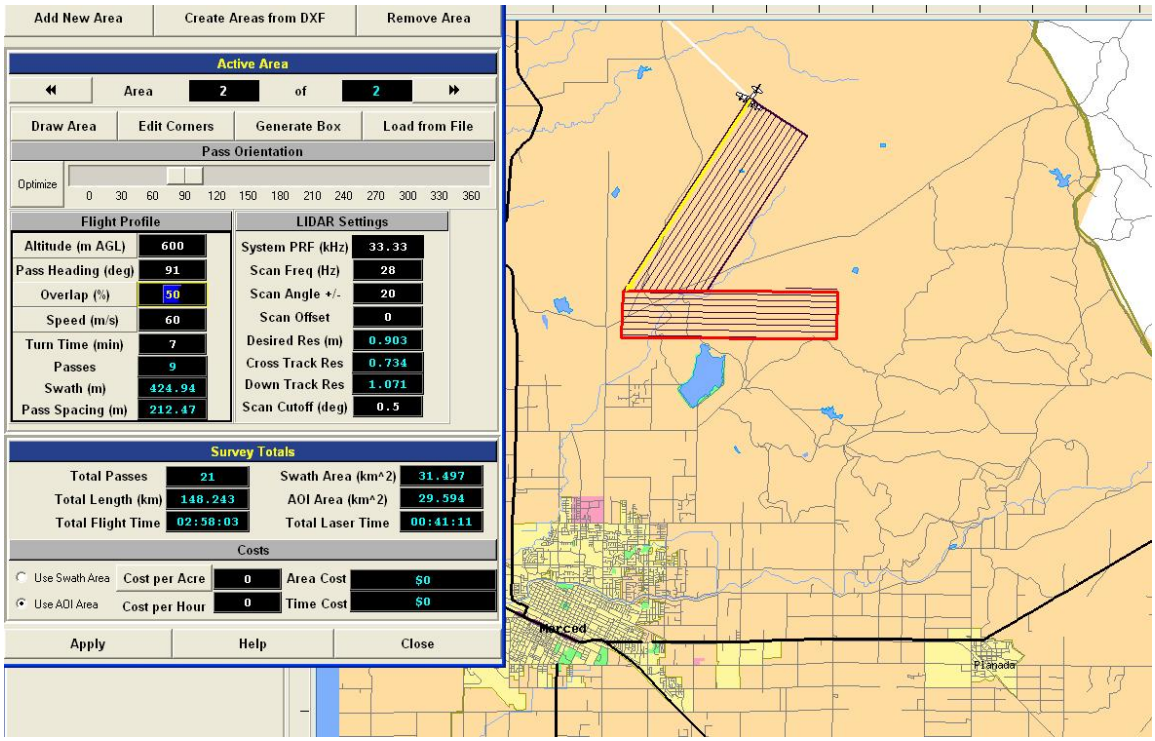

Figure 3 - LiDAR setting and project flight lines.

As shown above, at flying height 600 meters Above Ground Level (AGL) the cross-track point spacing is 0.73 meters. At 116 knots (60 m/s) along track point spacing varies from 1.07 meters at nadir to 2.14 meters at the edge of the swath. The swath is 425 meters wide. Swath overlap is 212 meters. Laser spot size is 0.18 meters.

GPS Reference Stations

Two locations were selected and occupied as GPS reference stations for the flight. One station (MPI_) was set at the Mariposa Airport about 35 Km distant, and the other (REED) was set inside the project area on LaPaloma Road. Both stations were occupied for at least four hours. Equipment included Ashtech dual-frequency Z-Extreme receivers with choke-ring antennas (ASH700936.D) on 1.500 meter fixed height tripods.

All observations were submitted to the NGS on-line processor OPUS with solution files included as Appendix A. Final control coordinate values (NAD83) were obtained from the OPUS solutions and referenced to the CORS network. For further information on OPUS see http://www.ngs.noaa.gov/OPUS/ and for more information on the CORS network see http://www.ngs.noaa.gov/CORS/ .

Navigation Processing

Normally, airplane trajectories are processed using KARS (Kinematic and Rapid Static) software written by Dr. Gerry Mader of the NGS Research Laboratory. KARS software yields ionosphere-free differential GPS solutions that are based on carrier phase double-differences with fixed integer ambiguities. This software requires good quality dual frequency GPS observations and these solutions are preferred. They have demonstrated accuracy of a few centimeters over long baselines – 60 to 100 kilometers.

Occasionally it becomes necessary to use a different processing engine such as REALM (Optech proprietary software), or POSGPS (APPLANIX software). Both REALM and POSGPS provide a robust means of differential GPS processing when only the L1 frequency observations are high quality and both software packages have demonstrated accuracy similar to KARS over short baselines - 0 to 15 kilometers.

It was necessary to use APPLANIX L1 POSGPS processing on this flight survey due to a bad aircraft GPS antenna that failed to collect high quality L2 observations – making processing with KARS impossible. Baseline lengths from station REED for this flight were less than 10 kilometers long while baselines from station MPI_ averaged 35 kilometers – too long for a high quality trajectory to be processed with L1 observations only. The final post-processed trajectory for this survey was, then, processed from station REED, but no redundant high quality trajectory exists.

After GPS processing was completed for all flights, the GPS and the raw IMU (Inertial Measurement Unit) data collected during each flight were input into APPLANIX software POSPROC. This software employs a sophisticated Kalman Filter algorithm to combine the 1-Hz final differential GPS solutions with the raw 50-Hz IMU data and their respective error models. The final result is a smoothed and blended solution of both aircraft position and orientation at 50 Hz, in SBET format (Smoothed Best Estimated Trajectory).

Calibration and Laser Point Processing

The SBET, raw laser range, and mirror-angle data were combined using Optech's REALM processing suite to generate the laser point dataset. System calibration was then performed as a 2-step process: step one (relative calibration) is to adjust the bore sight values of heading, roll, pitch, and scanner mirror scale such that systematic positional errors are minimized; and step two is an absolute calibration such that the laser DEM will match the height values of ground truth collected by vehicle-mounted GPS.

Step 1: Relative calibration was performed in TerraMatch software please see (**http://terrasolid.fi/ENG/Products.htm**) for detailed information.

A general description of the relative calibration procedure follows.

1. Cross-lines are flown for every flight with a heading perpendicular to the project flight line heading.
2. Small polygons containing these cross lines along with project flight lines are processed using approximate calibration values for heading, roll, pitch, and scanner mirror scale. Each line is processed separately.
3. Continuing to process each line separately, all lines are filtered to remove vegetation; then individual flight line surfaces are created.
4. TerraMatch uses an iterative algorithm to compute the best-fit between the individual flight line surfaces: simultaneously solving for the optimal changes to bore sight values of heading, roll, pitch, and scanner mirror scale.
5. These changes to the calibration values are updated in REALM; then output is checked for all flights using each flight's cross lines.
6. Complete and final output is run using the optimized calibration values for each flight.

This project consisted of only one flight and there were multiple sets of cross lines at the angle point of the project polygon. A TerraMatch calibration was performed using several lines of different heading at this angle point and an optimal set of bore sight corrections was computed. These values were then input into REALM and a different set of cross lines was again checked with TerraMatch. Results showed no significant change in any bore sight calibration value.

Step 2: Absolute calibration is done by comparing the height of the nearest neighbor laser point to the height of a set of check points that are collected by vehicle-mounted GPS.

Using a set of 727 check points spread over the project roads – see Figure 4 below - a height bias was found to average +98 mm (Laser - Ground). This bias is viewed as statistically significant and was applied to the final output heights computed by REALM – all output was lowered by 0.098 meters. The standard deviation of the laser – check point differences was 0.073 meters, which is fairly typical.

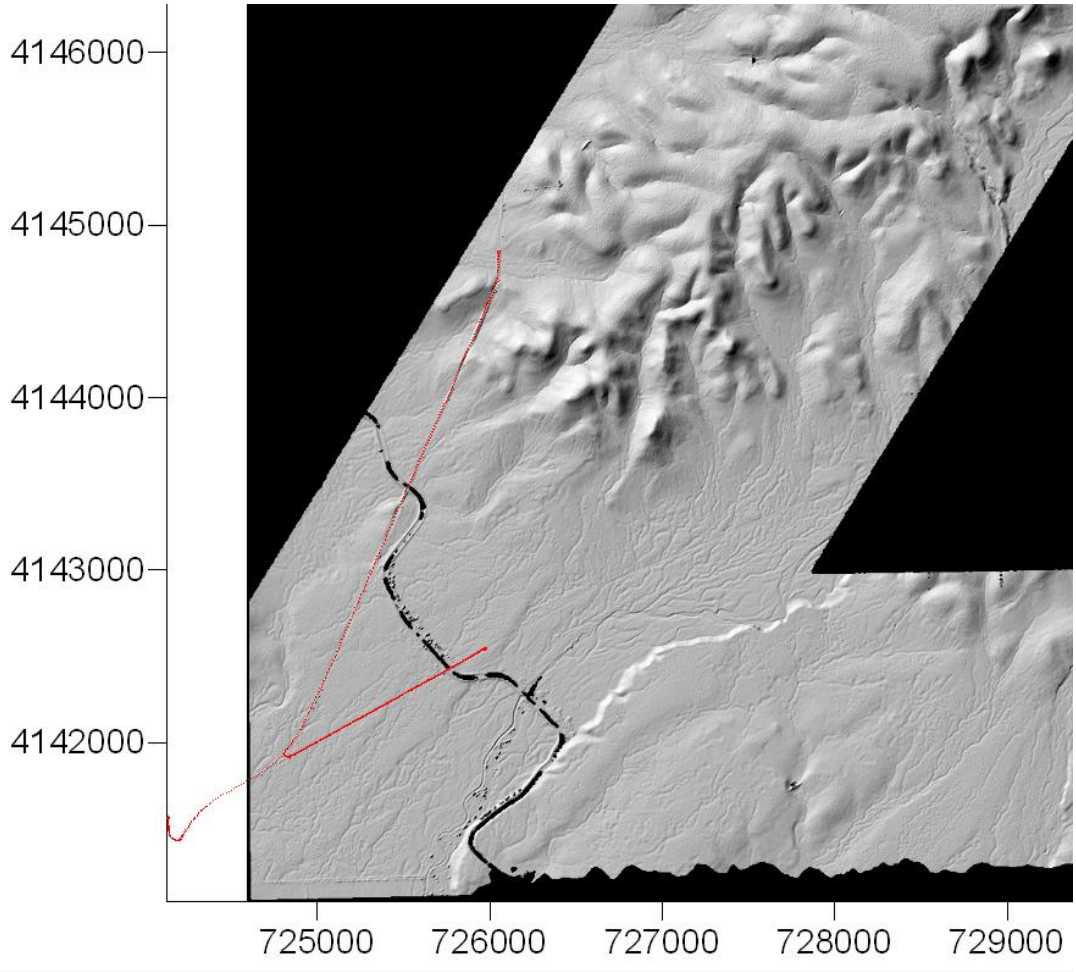

Figure 4 - Ground truth points (red) plotted onto a shaded relief of the project area.

All coordinates were processed with respect to NAD83 and referenced to the national CORS network. The 9-column output provides ellipsoid heights in UTM Zone 10, with units in meters.

The last return data was extracted from the 9-column format and ellipsoid heights were converted to orthometric heights in NAVD88 using NGS GEOID03 model with Corpscon v6.0 (Corps of Engineers Coordinate Conversion).

The complete output format is a 9-column ASCII file (space delimited), one file per flight strip. The nine columns are:

1. GPS time (seconds of week)
2. Easting last return
3. Northing last return
4. Height last return
5. Intensity last return
6. Easting first return
7. Northing first return
8. Height first return
9. Intensity first return

Note that in these 9-column files height values are ellipsoid heights which do NOT match orthometric heights (elevations) found in the 3-column files or 1-meter DEM grid nodes.

Filtering and DEM Production

No filtering was performed on this dataset due to the sparse presence of vegetation. The last return NAVD88 point data was binned in 2km x 2km tiles using TerraSolid's TerraScan software. The tiles were outputted with 60m overlap in ASCII format (XYZ) and gridded at 1m cell size using Golden Software's SURFER v. 8.01.

The tiles need to overlap in order to obtain consistent transitions from one tile to the adjacent ones.

Gridding parameters:

```
Gridding Algorithm: Kriging
Variogram: Linear
Nugget Variance: 0.07 m
MicroVariance: 0.00 m
SearchDataPerSector: 10
SearchMinData: 5
SearchMaxEmpty: 1
SearchRadius: 40m
```

The resulted Surfer grid tile set was exported to ESRI ArcInfo floting point binary format and using an in-house C++ application the overlap was trimmed from each tile. The trimmed tiles were exported to ESRI ArcInfo GRID format and merged into one seamless raster dataset.

Appendix A – OPUS Solutions

```
                                NGS OPUS SOLUTION REPORT
                                ========================

     USER: michaels@ufl.edu                       DATE: October 09, 2006
RINEX FILE: mpi_260r.06o                          TIME: 20:31:49 UTC


  SOFTWARE: page5  0601.10 master22.pl            START: 2006/09/17  17:04:00
 EPHEMERIS: igs13930.eph [precise]                 STOP: 2006/09/17  23:30:00
  NAV FILE: brdc2600.06n                      OBS USED: 12622 / 12779   :  99%
  ANT NAME: ASH700936D_M    NONE            # FIXED AMB:    51 /    51   : 100%
ARP HEIGHT: 1.500                           OVERALL RMS: 0.008(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)           ITRF00 (EPOCH:2006.7119)

        X:     -2536340.853(m)   0.014(m)          -2536341.583(m)   0.014(m)
        Y:     -4385599.386(m)   0.021(m)          -4385598.080(m)   0.021(m)
        Z:      3862884.431(m)   0.012(m)           3862884.454(m)   0.012(m)

      LAT:   37 30 37.77317      0.006(m)        37 30 37.78887      0.006(m)
    E LON:  239 57 27.89651      0.007(m)       239 57 27.84417      0.007(m)
    W LON:  120  2 32.10349      0.007(m)       120  2 32.15583      0.007(m)
   EL HGT:          651.179(m)   0.027(m)               650.586(m)   0.027(m)
 ORTHO HGT:          680.370(m)   0.037(m) [Geoid03 NAVD88]

                       UTM COORDINATES    STATE PLANE COORDINATES
                        UTM (Zone 10)         SPC (0403 CA 3)
Northing (Y) [meters]     4155616.281          612244.079
Easting (X)  [meters]      761429.354         2040468.324
Convergence  [degrees]     1.80201319           0.28024862
Point Scale                1.00044194           0.99993795
Combined Factor            1.00033972           0.99983578

US NATIONAL GRID DESIGNATOR: 10SGG6142955616(NAD 83)


                              BASE STATIONS USED
PID       DESIGNATION                       LATITUDE    LONGITUDE DISTANCE(m)
AF9702 MHCB MT HAMILTON BARD CORS ARP      N372029.501 W1213833.227  142901.7
DH7211 P242 FRAZIERAIRCN2004 CORS ARP      N365714.136 W1212747.402  140412.7
DG8529 P304 MENDOTA___CN2004 CORS ARP      N364420.399 W1202123.702   90067.7

                   NEAREST NGS PUBLISHED CONTROL POINT
DF4550      O68 A                          N373041.671 W1200226.194     188.5
```

NGS OPUS SOLUTION REPORT
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USER: michaels@ufl.edu DATE: October 09, 2006
RINEX FILE: reed260s.06o TIME: 20:21:05 UTC

SOFTWARE: page5 0601.10 master13.pl START: 2006/09/17 18:23:00
EPHEMERIS: igs13930.eph [precise] STOP: 2006/09/17 22:18:30
NAV FILE: brdc2600.06n OBS USED: 7772 / 7822 : 99%
ANT NAME: ASH700936D_M NONE # FIXED AMB: 33 / 33 : 100%
ARP HEIGHT: 1.500 OVERALL RMS: 0.009(m)

REF FRAME:	NAD_83(CORS96)(EPOCH:2002.0000)		ITRF00 (EPOCH:2006.7119)	
X:	-2570738.073(m)	0.015(m)	-2570738.803(m)	0.015(m)
Y:	-4373463.382(m)	0.015(m)	-4373462.083(m)	0.015(m)
Z:	3852960.671(m)	0.014(m)	3852960.690(m)	0.014(m)
LAT:	37 24 7.31001	0.013(m)	37 24 7.32527	0.013(m)
E LON:	239 33 10.18439	0.005(m)	239 33 10.13204	0.005(m)
W LON:	120 26 49.81561	0.005(m)	120 26 49.86796	0.005(m)
EL HGT:	47.011(m)	0.021(m)	46.427(m)	0.021(m)
ORTHO HGT:	78.357(m)	0.033(m)	[Geoid03 NAVD88]	

	UTM COORDINATES (Zone 10)	STATE PLANE COORDINATES SPC (0403 CA 3)
Northing (Y) [meters]	4142531.167	600109.335
Easting (X) [meters]	725958.998	2004677.279
Convergence [degrees]	1.55125455	0.03234361
Point Scale	1.00022897	0.99994763
Combined Factor	1.00022159	0.99994025

US NATIONAL GRID DESIGNATOR: 10SGG2595942531(NAD 83)

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE(m)
AF9702	MHCB MT HAMILTON BARD CORS ARP	N372029.501	W1213833.227	106112.2
DH7211	P242 FRAZIERAIRCN2004 CORS ARP	N365714.136	W1212747.402	103020.8
DH9030	P301 LILPANOCHECN2004 CORS ARP	N364822.632	W1204434.935	71154.5

NEAREST NGS PUBLISHED CONTROL POINT

HS1222	H 718	N372357.	W1202936.	4094.7