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SETTLING VELOCITIES OF UNCONSOLIDATED CARBONATE SEDIMENTS OF

BUCK ISLAND NATIONAL PARK, ST. CROIX, U.S.V.I.

Submitted by:

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ABSTRACT

In classifying the settling velocities of sediment grains in a fluid medium, it is important to consider grain shape as well as grain size and density. For example, a spherical granule and a second platy granule of similar size and properties will settle at distinctly different rates, (Krumbein and Sloss, 1963).

This experiment was designed to gain insight into the settling properties of marine carbonate sediments of various shapes and sizes. Carbonate sediment samples extracted from areas surrounding Buck Island National Park, St. Croix, U.S. Virgin Islands, were examined to determine the ratio of round grains to platy grains (R:P ratio) within samples sieved at $\frac{1}{4}$ phi intervals. Each of the fifteen samples taken underwent standard sieve analysis as well. Settling velocities were then determined for each grouping for comparison with terrigenous grains of similar size.

The results enable settling velocities of carbonate sediments to be accurately predicted, and subsequent terrigenous hydraulic equivalents be evaluated, with visual observation of a carbonate sample size and respective R:P ratio. With this information, physical grain sizes of the sieved Buck Island samples were adjusted to their hydraulic equivalent for correlation to current energy flow of the study area. Before adjusting the samples to terrigenous hydraulic equivalents (T_e), the mean physical grain size of the fifteen samples was calculated to be 1.170 (0.44mm) with an average standard deviation of 1.100 ($\pm .67$ mm). After the samples were adjusted to hydraulic values the mean size and standard deviation from that sized decreased to 1.790 (0.28mm) and .570 ($\pm .130$ mm) respectively.

Introduction:

Although marine carbonate sediments span the same size range as marine terrigenous sediments (Ginsburg, 1974) they differ significantly in relationship to their respective hydraulic properties, (Marine Geology, West Indies Lab, 1978). Carbonate sediments differ not only with comparable terrigenous samples, but with other carbonate samples of dissimilar shapes as well. The more any particle departs from a spherical shape, the more resistance it will offer in a fluid medium, (Krumbein and Sloss, 1963).

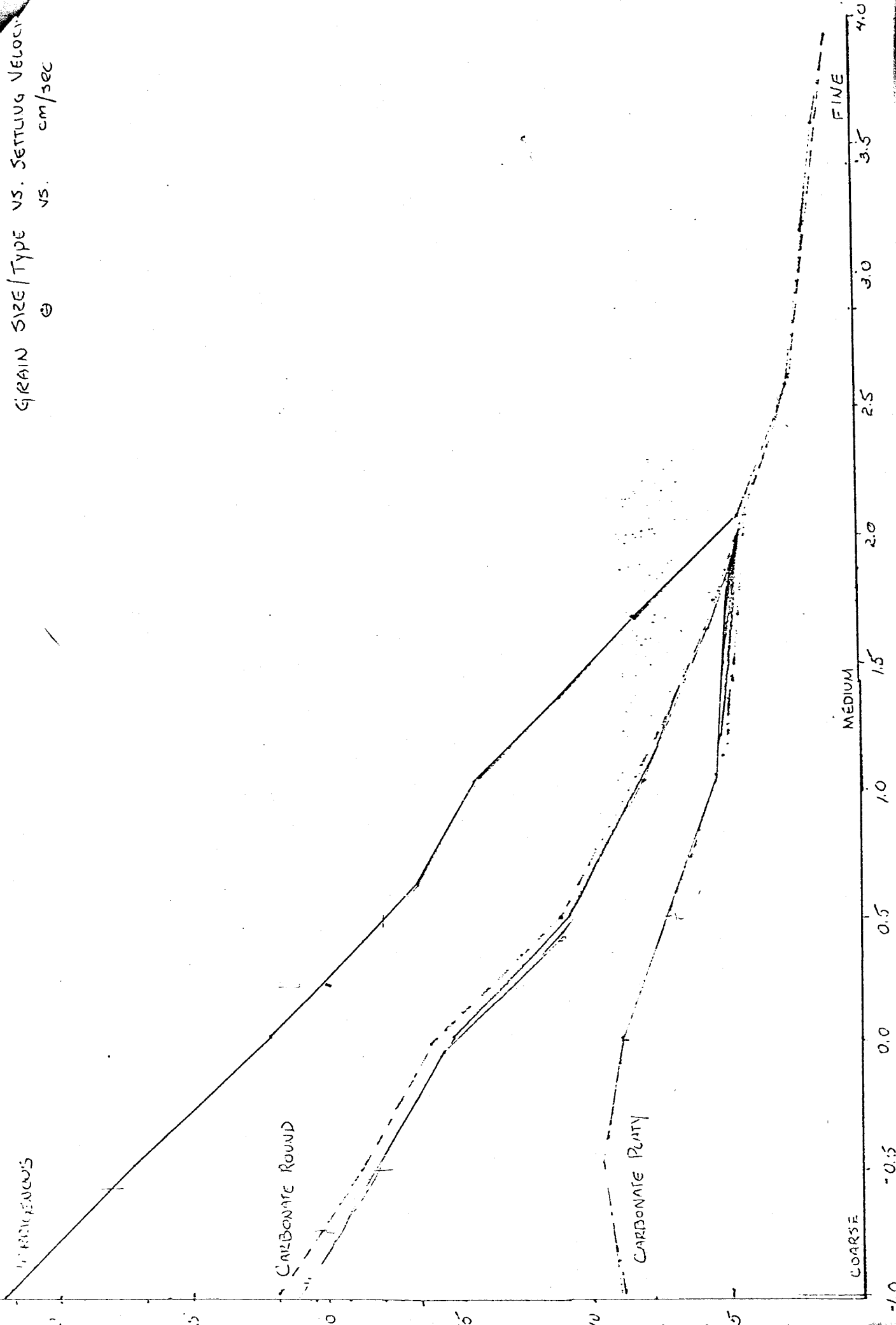
Fundamentally, sedimentation in a marine environment depends upon the interactions of gravity, the fluid medium, and its effects on the particular grains settling. Further, basic theories state that the larger and heaviest of grain types will settle more rapidly than smaller, lighter types, (Sternberg, 1875, as cited by Krumbein and Sloss, 1963). Marine sedimentation, as stated by Pettijohn, 1958, also depends on the actual sediment types, i.e. carbonate, terrigenous, etc. Until recently, these analysis have not considered the importance of shape, i.e. platy, round, cylindrical, etc., and their resulting effects in dealing with settling velocities in a viscous environment, (Pettijohn, 1958), (Hubbard, pers. comm.). Sediment transport studies have generally assumed grain shape as spherical, (Krumbein and Sloss, 1963). In a carbonate setting, finding spherical grains occurring naturally is an exception rather than the rule, (Ginsburg, 1973). Therefore the validity of using classic settling velocities in direct correlation with sieve analysis of carbonate sediments is questioned.

Preliminary studies (figure 1) indicated that coral and terrigenous grains of equivalent sizes behave similarly, but NOT identically in relationship to their relative settling velocities. Coral carbonate grains of 2.50mm (2.00) or larger,

Figure 1

R.P.T. curve w/ predicted
of intermitten R:P ratios.

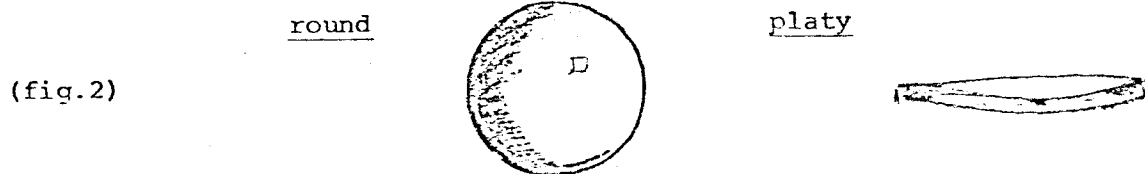
GRAIN SIZE/TYPE VS. SETTLING VELOCITY
vs. cm/sec



settle more slowly than similar sized terrigenous material. This difference is probably due to density differences and surface irregularities of the carbonate grains. Grains finer than 0.250mm (2.60) were found to settle at equal velocities regardless of terrigenous or carbonate composition.

Experimentation with platy carbonate material further indicated that carbonate sediment grains should be reevaluated to determine their hydraulic characteristics with respect to size and shape. (fig.1) Platy carbonate grains were determined to behave hydraulically similar to equivalent terrigenous grains of .354mm (1.50) or less, regardless of physical sizes. Hence, this study was initiated to generate information by which carbonate material could be compared to existing sedimentological models which classically quantify terrigenous quartz spheres.

As figure #1 illustrates, both round and platy carbonate grains can be correlated to the terrigenous curve to determine their respective terrigenous equivalent. However, natural carbonate sediments will tend to vary in contents from pure round constituents to pure platy constituents, and various combinations of such in between. Round grains designate a particle of generally spherical nature. Platy was assigned to flattened, flaky grains, (fig.2). These ratios depend on many



variabilities within an ecosystem, such as current energies, and grain parent.

It was further hypothesized that as the round to platy ratio decreased from 10:0 down to 0:10, average settling velocities of the round to platy ratios, (R:P), would decrease accordingly. Further, the curves generated in relation to

the R:P ratio would vary predictably, as shown in figure 3. The predicted curves were proposed to enable carbonate samples of any sample to be correctly evaluated in relationship to hydraulically equivalent terrigenous grain sizes. This would prove to be an invaluable tool for determining actual current energies of a given carbonate marine environment, as found on Buck Island National Park, St. Croix, U.S. Virgin Islands.

The ensuing experimental observations were designed to determine the validity of the settling velocity predictions, and subsequent terrigenous equivalents, of carbonate samples of varying R:P ratios. Secondly, using the hydraulic equivalents, an analysis of the current energy flow around Buck Island will be made.

Study Area

Buck Island National Park is located off of the Northeastern coast of St. Croix, U.S. Virgin Islands, at 37° 0' N latitude, 72° 30' longitude. The island is 1.8 kilometers long on its East to West axis, and .5 kilometers in width at its maximum on its North-South axis. The island's maximum elevation is 329 feet.

Morphologically, it is characterized by a tapered shape, thin on the East end and proportionately thicker on the West end. (figure 4) The south shore is further characterized by a vertical wall of eroded Cretaceous, Caledonian material. This vertical wall suggests that Buck Island has undergone a general uplift and tilting on the South side. The Southwestern portion of Buck Island is fringed by natural beach. (fig.4) The Northern shores of the island are characterized by a relatively steep 35° slope. This slope further indicates tilting of the bed formation underlying Buck Island.

The significance of studying this area centered around the fact that the

R.P.T. curve w/ predicted values of intermissions R:P ratios:

GRAIN SIZE / TYPE VS. SETTING

✓ 37 ✓ 32

TERRIGENOUS

2
2:8
1:6
20:0

2
+
6
+
8
+
1
+
1

76

1

100

2

0.10

CARBONATE ROUND

CARBONATE PLATY

FIVE

COARSE

MEDIUM

—

!

1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27. 28. 29. 30. 31. 32. 33. 34. 35. 36. 37. 38. 39. 40. 41. 42. 43. 44. 45. 46. 47. 48. 49. 50. 51. 52. 53. 54. 55. 56. 57. 58. 59. 60. 61. 62. 63. 64. 65. 66. 67. 68. 69. 70. 71. 72. 73. 74. 75. 76. 77. 78. 79. 80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90. 91. 92. 93. 94. 95. 96. 97. 98. 99. 100. 101. 102. 103. 104. 105. 106. 107. 108. 109. 110. 111. 112. 113. 114. 115. 116. 117. 118. 119. 120. 121. 122. 123. 124. 125. 126. 127. 128. 129. 130. 131. 132. 133. 134. 135. 136. 137. 138. 139. 140. 141. 142. 143. 144. 145. 146. 147. 148. 149. 150. 151. 152. 153. 154. 155. 156. 157. 158. 159. 160. 161. 162. 163. 164. 165. 166. 167. 168. 169. 170. 171. 172. 173. 174. 175. 176. 177. 178. 179. 180. 181. 182. 183. 184. 185. 186. 187. 188. 189. 190. 191. 192. 193. 194. 195. 196. 197. 198. 199. 200. 201. 202. 203. 204. 205. 206. 207. 208. 209. 210. 211. 212. 213. 214. 215. 216. 217. 218. 219. 220. 221. 222. 223. 224. 225. 226. 227. 228. 229. 230. 231. 232. 233. 234. 235. 236. 237. 238. 239. 240. 241. 242. 243. 244. 245. 246. 247. 248. 249. 250. 251. 252. 253. 254. 255. 256. 257. 258. 259. 260. 261. 262. 263. 264. 265. 266. 267. 268. 269. 270. 271. 272. 273. 274. 275. 276. 277. 278. 279. 280. 281. 282. 283. 284. 285. 286. 287. 288. 289. 290. 291. 292. 293. 294. 295. 296. 297. 298. 299. 300. 301. 302. 303. 304. 305. 306. 307. 308. 309. 310. 311. 312. 313. 314. 315. 316. 317. 318. 319. 320. 321. 322. 323. 324. 325. 326. 327. 328. 329. 330. 331. 332. 333. 334. 335. 336. 337. 338. 339. 340. 341. 342. 343. 344. 345. 346. 347. 348. 349. 350. 351. 352. 353. 354. 355. 356. 357. 358. 359. 360. 361. 362. 363. 364. 365. 366. 367. 368. 369. 370. 371. 372. 373. 374. 375. 376. 377. 378. 379. 380. 381. 382. 383. 384. 385. 386. 387. 388. 389. 390. 391. 392. 393. 394. 395. 396. 397. 398. 399. 400. 401. 402. 403. 404. 405. 406. 407. 408. 409. 410. 411. 412. 413. 414. 415. 416. 417. 418. 419. 420. 421. 422. 423. 424. 425. 426. 427. 428. 429. 430. 431. 432. 433. 434. 435. 436. 437. 438. 439. 440. 441. 442. 443. 444. 445. 446. 447. 448. 449. 450. 451. 452. 453. 454. 455. 456. 457. 458. 459. 460. 461. 462. 463. 464. 465. 466. 467. 468. 469. 470. 471. 472. 473. 474. 475. 476. 477. 478. 479. 480. 481. 482. 483. 484. 485. 486. 487. 488. 489. 490. 491. 492. 493. 494. 495. 496. 497. 498. 499. 500. 501. 502. 503. 504. 505. 506. 507. 508. 509. 510. 511. 512. 513. 514. 515. 516. 517. 518. 519. 520. 521. 522. 523. 524. 525. 526. 527. 528. 529. 530. 531. 532. 533. 534. 535. 536. 537. 538. 539. 540. 541. 542. 543. 544. 545. 546. 547. 548. 549. 550. 551. 552. 553. 554. 555. 556. 557. 558. 559. 560. 561. 562. 563. 564. 565. 566. 567. 568. 569. 570. 571. 572. 573. 574. 575. 576. 577. 578. 579. 580. 581. 582. 583. 584. 585. 586. 587. 588. 589. 590. 591. 592. 593. 594. 595. 596. 597. 598. 599. 600. 601. 602. 603. 604. 605. 606. 607. 608. 609. 610. 611. 612. 613. 614. 615. 616. 617. 618. 619. 620. 621. 622. 623. 624. 625. 626. 627. 628. 629. 630. 631. 632. 633. 634. 635. 636. 637. 638. 639. 640. 641. 642. 643. 644. 645. 646. 647. 648. 649. 650. 651. 652. 653. 654. 655. 656. 657. 658. 659. 660. 661. 662. 663. 664. 665. 666. 667. 668. 669. 670. 671. 672. 673. 674. 675. 676. 677. 678. 679. 680. 681. 682. 683. 684. 685. 686. 687. 688. 689. 690. 691. 692. 693. 694. 695. 696. 697. 698. 699. 700. 701. 702. 703. 704. 705. 706. 707. 708. 709. 710. 711. 712. 713. 714. 715. 716. 717. 718. 719. 720. 721. 722. 723. 724. 725. 726. 727. 728. 729. 730. 731. 732. 733. 734. 735. 736. 737. 738. 739. 740. 741. 742. 743. 744. 745. 746. 747. 748. 749. 750. 751. 752. 753. 754. 755. 756. 757. 758. 759. 760. 761. 762. 763. 764. 765. 766. 767. 768. 769. 770. 771. 772. 773. 774. 775. 776. 777. 778. 779. 780. 781. 782. 783. 784. 785. 786. 787. 788. 789. 790. 791. 792. 793. 794. 795. 796. 797. 798. 799. 800. 801. 802. 803. 804. 805. 806. 807. 808. 809. 810. 811. 812. 813. 814. 815. 816. 817. 818. 819. 820. 821. 822. 823. 824. 825. 826. 827. 828. 829. 830. 831. 832. 833. 834. 835. 836. 837. 838. 839. 840. 84

3.5

1. 2

CONCENTRATIONS IN PHI INTERVALS

island was considered small enough to facilitate sample analysis around the entire land body in the limited amount of time allotted for research completion. More importantly, this area was selected because it offered the carbonate sediments needed for the carbonate settling velocity studies. Buck Island is surrounded by coral reef formations, and hence, high production rates of carbonate sediments.

Preliminary observations indicated that an abundance of Halimeda is produced near shores of Buck Island, and probably in the reefs as well. Halimeda flakes are platy in nature and were found to act hydraulically similar to silt size particles of terrigenous material. This example illustrates the importance of standardizing the physical grain sizes with hydraulic correlations,

Methods and Materials:

Collection and analysis of data was completed in four separate phases of operation. Phase one of the experimental procedure determined the areas in which coring was to be done. Through charts and aerial photograph survey, and subsequent observations of morphologic features of the study area, sample areas were chosen that were predicted to exemplify best the sediment transport energies, currents, of the lagoonal areas around Buck Island. Lagoonal is defined in this study as the area of Buck Island National Park, within the reef system. (fig.4)

The cores were taken with the help of SCUBA, using an 8" inch long, by 2" inch diameter plastic core tube which was inserted into the sediments of the sample area, and withdrawn. The subsequent step was to place the sample into a labeled plastic bag. The ¹⁵ samples were then brought back to lab for analysis. Upon return to lab, the samples were flushed carefully with fresh water so as

to not lose fine sediment that might be disturbed into suspension. Flushing the samples with fresh water prevents the samples from cementing while dessicating in an oven set at 110° C. The drying process took approximately 15 hours.

Next, each sample was seived in its entirety into groupings of .5 phi intervals from -1.00 to 1.50, after which .25 phi intervals were used up to 4.0+ 0. Each sample of each seive size was then weighed and archived per sample number per seive size. The samples, 1-15, were then interpreted in reference to physical grain size. Histograms, Cumulative frequencies, and accompanying statistics were used for these analysis. (app.1)

The next task of the data collection phase of the experiment entailed examination of each archived sample. Each sample was microscopically examined (sample in this case designates each sample, per seive size.) to determine its ratio of round grains to platy grains (R:P). Round grains were assigned to particles of generally spherical nature, platy assigned to flattened, flaky particles. (fig.2)

The final procedure involved determination of settling velocities to be used to correlate the relationships between carbonate sediment types and terrigenous types. The velocity determinations were conducted in a 2 meter settling tube filled with fresh water. Samples to be subjected to the settling velocity trials were soaked in fresh water prior to actual experimentation. This step eliminated trapped air acquired through dessication in the drying oven, and also questions of the drying process in dealing with the significance of the final results.

For each settling velocity determination, multiple runs were run to strengthen the statistical averages. Each individual "run" consisted of approximately 10 grains. The average settling velocity of which was determined by summing the velocity of each individual grain of that run, and dividing that number by the number of grains in the run. A tape recorder facilitated the timing of each indi-

vidual grain per run. It is important to note that each run was conducted using grains of equal physical size.⁽¹⁾

In order to determine the pure carbonate round and platy settling velocities as accurately as possible, those grains that best fit their respective definitions were carefully selected. The selection process was determined microscopically, and the velocities determined as aforementioned.

Finally, the produced model of correlation relating platy carbonate sediment grains to round carbonate grains, to terrigenous grains, in reference to hydraulic properties, was used to adjust the Buck Island samples from physical values to their terrigenous hydraulic equivalent. This standardized the values for each sample for more accurate determination of the study area's energy distribution.

Results:

Initial experimental procedures determined the settling velocities of different grain types of similar sizes. The three grain types used were terrigenous round, carbonate round, and carbonate platy. The average settling velocities of terrigenous and carbonate round grains were found to decrease with size decrease. Platy carbonate grains greater than .50 were found to decrease settling velocities, rather than increase due to size increase. Grains of platy type smaller than .50 decreased settling velocities as did the round grains. Grains finer than 2.00 settled at equal velocities regardless of terrigenous round, carbonate round, or carbonate platy. Table 1 compares the average settling velocities of each of the three types per sieve size. Figure 1 illustrates the working relationship between the three grain types.

(7)

¹ Timings per grain were started as the grain passed "0", the starting mark. This mark was 12cm. lower than the point at which the grains were introduced to the settling tube.

Table 1: average settling velocities cm/sec. T=terrigenous C_r= carbonate round C_p=platy

| φ | -1.0 | -0.5 | 0.0 | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 |
|----------------|------|------|------|------|------|-----|-----|-----|-----|-----|-----|
| T | 31.9 | 26.0 | 22.0 | 17.0 | 14.5 | 9.5 | 4.7 | 3.0 | 2.3 | 1.7 | 1.2 |
| C _r | 22.0 | 19.0 | 16.0 | 11.0 | 9.0 | 6.5 | 4.7 | 3.0 | 2.3 | 1.7 | 1.2 |
| C _p | 9.0 | 9.6 | 9.0 | 7.0 | 5.0 | 4.8 | 4.7 | 3.0 | 2.3 | 1.7 | 1.2 |

Figure 3 illustrates the theory that each R:P ratio in between the pure round and pure platy samples, will have average settling velocities that are mathematically predictable, i.e. a 6:4, R:P ratio assigned to a sediment of a particular phi size, will have a settling velocity equal to the 6 round grains multiplied by the settling velocity of the round grains for that phi size, added to, the platy grains (4) multiplied by their respective settling velocity, and then divided by 10, the total number of grains considered. (fig. 5) If the sample contained a percentage of terrigenous the sample could be adjusted accordingly by using the equation stated in figure 5.

To test the validity of this hypothesis, for use with direct correlation with field work, each sieved sample of each sieve size was microscopically analyzed to determine its R:P ratio. (table 2) The ratios were assigned on a ten grain ratio basis, i.e. 9:1, 8:2, 7:3, 6:4, 5:5, 4:6, 3:7, 2:8, and 1:8. 10:0 was assigned to samples considered to have pure round grains, and 0:10 was assigned to those samples containing only platy grains. Variances within the ten grain limit were expected, but were not considered significant in determining the accuracy of the hypothesis. In general, it was found that the physically coarser grain sizes had the lowest R:P ratio, less than 5:5, and phi sizes of higher values (finer) of 1.5 or more were observed to have a dominant R:P ratio of between 9:1 and 10:0.

After the R:P ratios were assigned, 25 carbonate samples were selected for settling velocity determinations. Each sample was greater ^{in size} than 2.0φ. These coar-

- a. Given an R:P ratio for sample of $x\theta$ size
 R_v = Co_3 round settling velocity @ $x\theta$
 R = #round grains of R:P @ $x\theta$ size
 P_v = Co_3 platy settling velocity
 $R:P_v$ = avg. settling velocity for R:P @ $x\theta$

equation:

$$\frac{R * R_v + P * P_v}{10} = R:P_v @ x\theta$$

- b. w/terrigenous percentage:

$T\%$ = terrigenous percentage of sample
 P = unadjusted physical size of sample
 T_e = adjusted terrigenous hydraulic equivalent
 $C\%$ = carbonate percentage of sample

equation:

$$\frac{T\% * P + C\% * T_e}{100} = \text{actual } T_e \text{ of that sample}$$

Figure 5a. mathematical equation for prediction of settling velocities in relationship to R:P ratios. b. corrective factor with % terrigenous.

se fractions were selected because the grains within the fraction vary hydraulically in their settling properties, i.e. grains smaller than 2.00 settle with equal velocity regardless of grain type. Out of each fraction, sample, thirty grains were randomly selected for three trial runs of ten grains each. The runs were conducted and the average velocities determined as stated in methods and materials and figure 5 respectively. The ensuing results comparing the expected predicted velocities to the observed velocities are listed in table 2 and graphically plotted in figure 6. This subsequently proved that the theory of predictable settling velocities with knowledge of round grain settling velocities and platy grain settling velocities, and the equation of figure 5, was significantly accurate. The R/P/T (equivalence) graph was then applied to the Buck Island samples for comparison of hydraulic to physical grain sizes of each sample of each sieve size.

| #
θ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|--------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| -1.0 | 5:5 | 4:6 | 3:7 | 3:7 | 9:1 | 4:6 | 0:10 | 0:10 | 2:8 | 5:5 | 6:4 | 4:6 | 3:7 | 2:8 | 5:5 |
| -0.5 | 6:4 | 5:5 | 5:5 | 5:5 | 5:5 | 3:7 | 0:10 | 0:10 | 2:8 | 4:6 | 6:4 | 3:7 | 2:8 | 2:8 | 4:6 |
| 0.0 | 7:3 | 7:3 | 5:5 | 6:4 | 8:2 | 3:7 | 1:9 | 1:9 | 2:8 | 5:5 | 5:5 | 4:6 | 6:4 | 4:6 | 4:6 |
| 0.5 | 9:1 | 6:4 | 7:3 | 9:1 | 8:2 | 5:5 | 3:7 | 4:6 | 3:7 | 7:3 | 6:4 | 6:4 | 5:5 | 5:5 | 5:5 |
| 1.0 | 6:4 | 7:3 | 8:2 | 9:1 | 8:2 | 6:4 | 5:5 | 6:4 | 5:5 | 7:3 | 7:3 | 7:3 | 7:3 | 6:4 | 4:6 |
| 1.5 | 8:2 | 8:2 | 9:1 | 9:1 | 9:1 | 7:3 | 9:1 | 8:2 | 6:4 | 6:4 | 7:3 | 9:1 | 8:2 | 10:0 | 6:4 |
| 1.75 | 8:2 | 8:2 | 9:1 | 10:0 | 9:1 | 9:1 | 9:1 | 8:2 | 6:4 | 7:3 | 9:1 | 9:1 | 9:1 | 10:0 | 7:3 |
| 2.00 | 7:3 | 8:2 | 9:1 | 10:0 | 9:1 | 10:0 | 9:1 | 7:3 | 8:2 | 6:4 | 10:0 | 10:0 | 9:1 | 10:0 | 7:3 |
| 2.25 | 9:1 | 7:3 | 9:1 | 8:2 | 9:1 | 10:0 | 9:1 | 6:4 | 9:1 | 7:3 | 10:0 | 10:0 | 9:1 | 10:0 | 7:3 |
| 2.50 | 9:1 | 7:3 | 10:0 | 10:0 | 9:1 | 10:0 | 10:0 | 8:2 | 9:1 | 8:2 | 10:0 | 10:0 | 9:1 | 10:0 | 10:0 |
| 2.75 | 9:1 | 8:2 | 10:0 | 10:0 | 10:0 | 9:1 | 9:1 | 9:1 | 9:1 | 9:1 | 10:0 | 10:0 | 9:1 | 10:0 | 10:0 |
| 3.00 | 10:0 | 9:1 | 10:0 | 9:1 | 10:0 | 8:2 | 9:1 | 8:2 | 10:0 | 10:0 | 10:0 | 10:0 | 9:1 | 10:0 | 10:0 |
| 3.25 | 10:0 | 10:0 | 10:0 | 9:1 | 9:1 | 9:1 | 10:0 | 9:1 | 9:1 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 |
| 3.50 | 10:0 | 9:1 | 10:0 | 8:2 | 9:1 | 9:1 | 10:0 | 9:1 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 |
| 3.75 | 9:1 | 10:0 | 10:0 | 8:2 | 9:1 | 8:2 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 |
| 4.00 | 9:1 | 8:2 | 10:0 | 8:2 | 10:0 | 8:2 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 |
| 4.0+ | 10:0 | 9:1 | 10:0 | 8:2 | 10:0 | 9:1 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 | 10:0 |

TABLE 2 R:P ratios for each sample size of each sample #1-15

Physical grain sizes were determined by seive analysis, and histograms, cumulative frequencies and related statistics, i.e. standard deviation, mean, and median, were calculated. Examples of these analysis are found in Appendix 1. Table #4 lists the calculated standard deviation, mean, and median of the physical values. The map below the table places the values in proper perspective in relation to the respective sample sites. This table also depicts the terrigenous

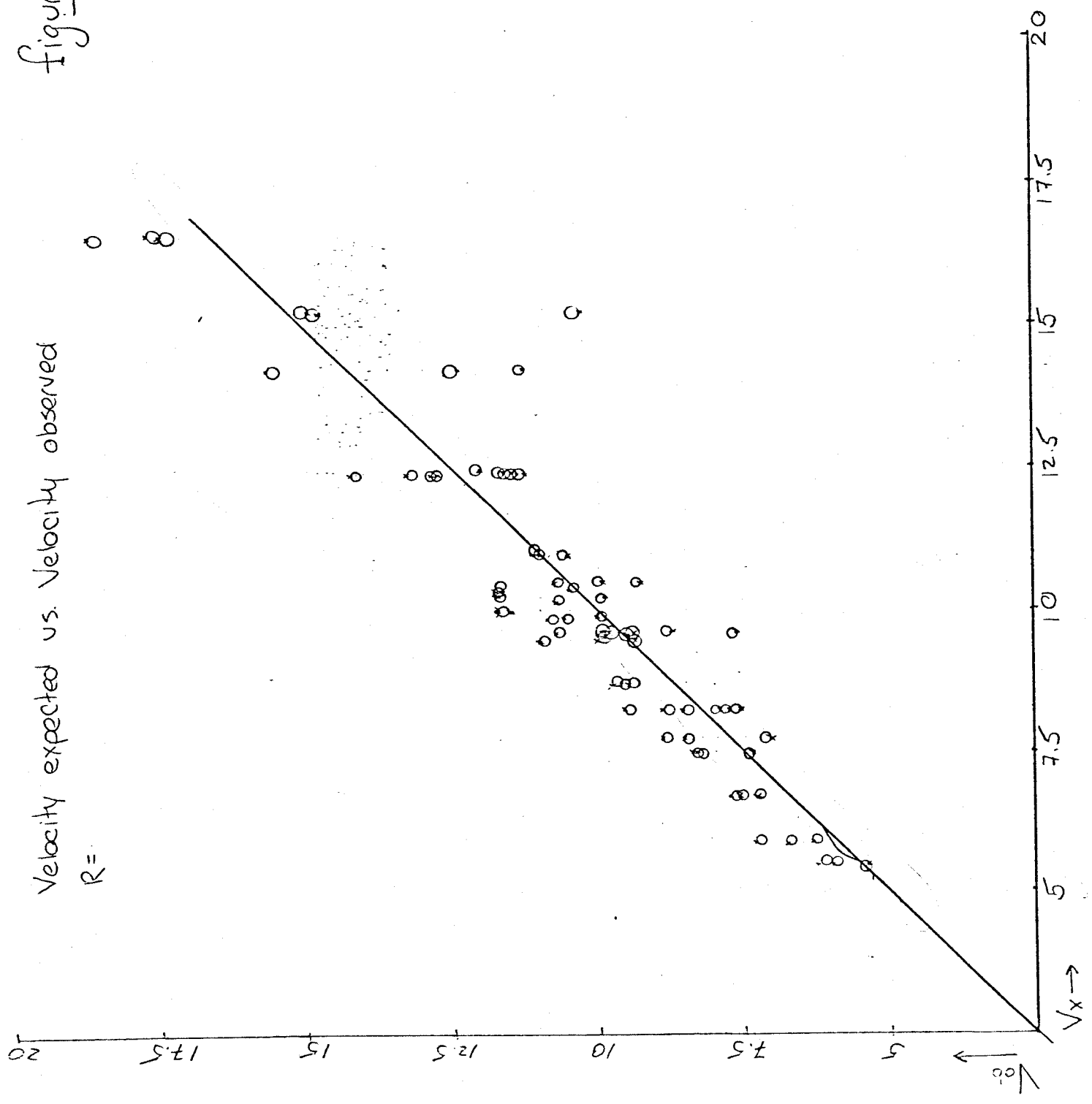
hydraulic equivalents in relation to physical determinations. The T_e were determined by the R·P·T graph of fig.3. The lower figures on the Buck Island chart, fig. 4, place these values in their respective locale for visual comparison with the physical values.

| sample # | Phi size | R:P | V_x | V_o | %error |
|------------------|----------|------|-------|-------|--------|
| 11 | -1.0 | 6:4 | 16.63 | 18.24 | 8.00 |
| 8 | -1.0 | 1:9 | 10.18 | 11.16 | 8.70 |
| 7 | -1.0 | 1:9 | 10.18 | 10.83 | 6.00 |
| 6 | -0.5 | 3:7 | 12.39 | 12.40 | 0.08 |
| 8 | -0.5 | 0:10 | 9.60 | 9.61 | 0.10 |
| 12 | -0.5 | 3:7 | 12.39 | 12.41 | 0.16 |
| 5 | -0.5 | 5:5 | 14.25 | 13.10 | 8.00 |
| 7 | -0.5 | 0:10 | 9.60 | 10.16 | 5.50 |
| 11 | -0.5 | 6:4 | 15.18 | 13.3 | 12.30 |
| 4 | 0.0 | 6:4 | 12.45 | 12.07 | 3.00 |
| 1 | 0.0 | 3:7 | 11.07 | 10.76 | 2.80 |
| 2 | 0.0 | 1:9 | 9.69 | 10.46 | 7.40 |
| 7 | +0.5 | 3:7 | 8.26 | 8.41 | 1.80 |
| 8 | +0.5 | 4:6 | 8.68 | 9.63 | 9.80 |
| 12 | +0.5 | 6:4 | 9.52 | 10.21 | 6.70 |
| 4 | +0.5 | 9:1 | 10.78 | 10.22 | 5.20 |
| 5 | +0.5 | 8:2 | 10.36 | 11.29 | 8.20 |
| 2 | +0.5 | 6:4 | 9.52 | 8.62 | 9.50 |
| 4 | +1.0 | 9:1 | 8.24 | 8.32 | 0.96 |
| 7 | +1.0 | 5:5 | 6.80 | 7.52 | 9.60 |
| 11 | +1.0 | 7:3 | 7.52 | 8.00 | 6.00 |
| 5 | +1.0 | 8:2 | 7.88 | 8.21 | 4.00 |
| 5 | +1.5 | 9:1 | 5.88 | 6.74 | 13.3 |
| 10 | +1.5 | 6:4 | 5.52 | 5.89 | 6.28 |
| Average % error: | | | | | 5.73 |

Table 3: Velocities expected (V_x) and velocities observed (V_o) and % error, of randomly tested carbonate sediment samples.

figure 6

Velocity expected vs. Velocity observed
R =



Graph:

| sample# | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Sd.-P | 1.38 | 1.33 | 1.23 | 0.97 | 1.30 | .78 | 0.88 | 1.15 | 1.04 | 1.07 | 1.01 | 0.95 | 1.45 | 0.86 | 0.92 |
| H | 1.16 | 0.60 | 0.80 | 0.35 | 0.96 | .38 | 0.33 | 0.31 | 0.50 | 0.58 | 0.44 | 0.46 | 0.76 | 0.42 | 0.60 |
| D | 0.22 | 0.73 | 0.43 | 0.62 | 0.34 | .40 | 0.55 | 0.84 | 0.54 | 0.49 | 0.57 | 0.49 | 0.69 | 0.44 | 0.32 |
| Mz-P | 0.90 | 1.40 | 1.13 | 0.56 | 0.85 | 1.58 | 0.75 | 0.50 | 1.70 | 1.45 | 0.67 | 1.19 | 1.61 | 1.48 | 2.16 |
| H | 1.36 | 2.21 | 1.50 | 1.50 | 1.41 | 1.97 | 1.74 | 1.59 | 2.03 | 1.93 | 1.53 | 1.78 | 2.07 | 1.93 | 2.35 |
| D | 0.46 | 0.81 | 0.37 | 0.94 | 0.56 | 0.39 | 0.99 | 1.09 | 0.33 | 0.48 | 0.86 | 0.59 | 0.46 | 0.45 | 0.19 |
| Md-P | 1.05 | 1.35 | 1.10 | 0.70 | 0.90 | 1.60 | 0.95 | 0.60 | 2.00 | 1.50 | 0.70 | 1.15 | 1.55 | 1.55 | 2.25 |
| H | 1.75 | 1.87 | 1.45 | 1.50 | 1.65 | 1.95 | 1.80 | 1.65 | 2.00 | 1.95 | 1.64 | 1.78 | 1.90 | 1.90 | 2.25 |
| D | 0.70 | 0.52 | 0.35 | 0.80 | 0.75 | 0.35 | 0.85 | 1.05 | 0.00 | 0.45 | 0.94 | 0.63 | 0.35 | 0.35 | 0.00 |

table 4: statistics determined from physical analysis of the Buck Island samples (P) and adjusted hydraulic values (H). Sd=standard deviation Mz=Mean Md=median the difference in θ measurements is denoted by D.

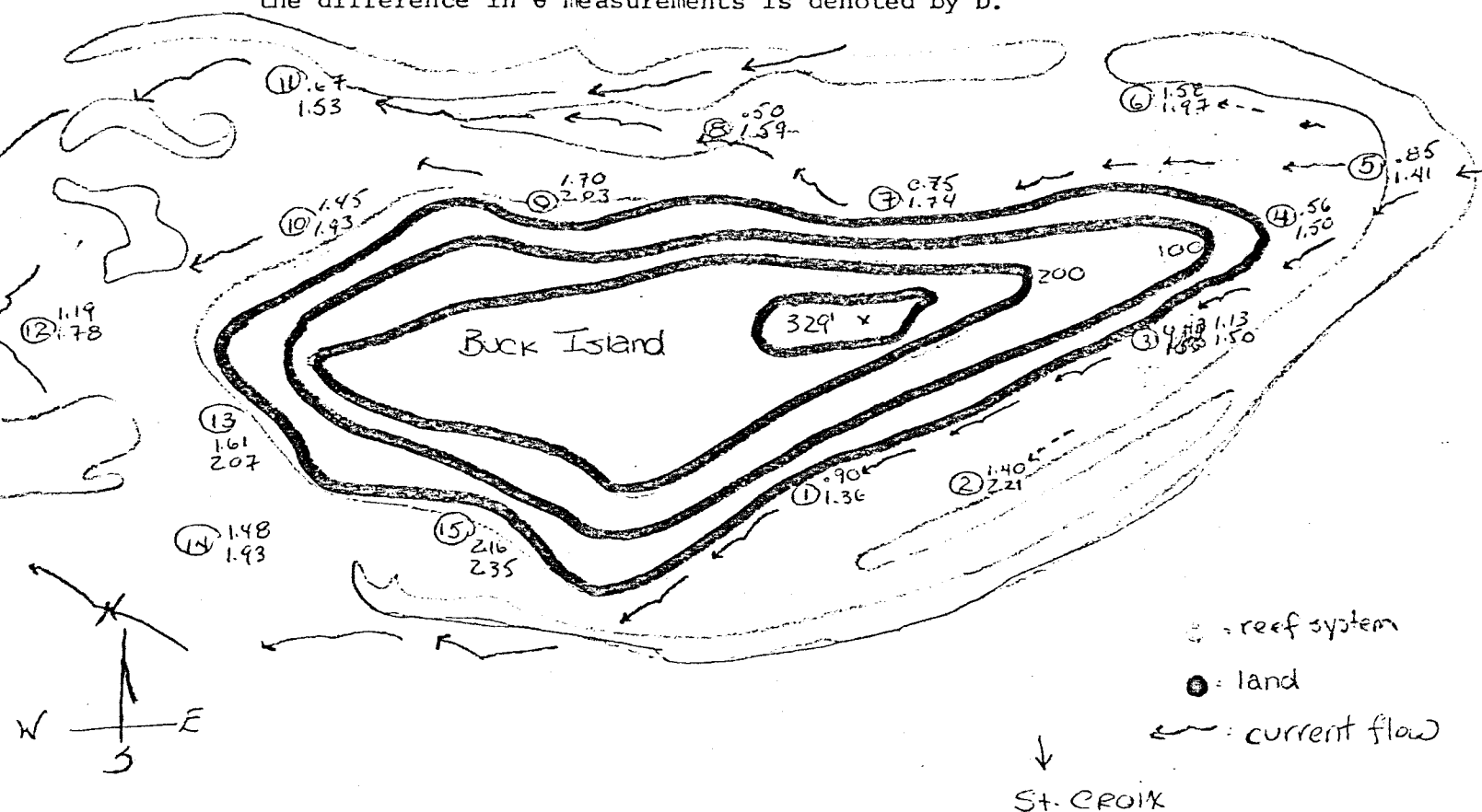


Figure 4: Key to sample sites and numbers. b. topographical map of the study area. top number designates physical mean of sample, lower number designates the hydraulic mean after adjustment using the R.P.T. equivalence curve.

Discussion:

Conclusively, it has been determined that analyzation of physical grain sizes extracted from a marine carbonate environment in reference to interpretation of the areas relative energy relationship is inaccurate. To accurately determine the relationship of current energy in a carbonate system, in respect to *THE STUDY AREA*, it is necessary to apply terrigenous hydraulic equivalents to the grains. The T_e may then be quantitatively compared to existing models which classically exemplify terrigenous values. The Hjølstrom diagram of figure #7 illustrates such a model. With this in mind, the equivalence curve comparing the hydraulics of round carbonate and platy carbonate grains to terrigenous grains of spherical nature (R·P·T curve) was prepared.

Application of the R·P·T curve is necessary to correctly evaluate carbonate sediment distribution in a marine environment. As shown by the R/P/T curve, fig.3, a sediment grain of carbonate platy nature of the -0.50 size is equal hydraulically to a carbonate round grain of 0.80, which in turn is hydraulically equal to a terrigenous grain of 1.60. Hence, the importance of determining such equivalence should not be underestimated. Illustrating the point with an actual sample, sample number 14 was determined to be poorly sorted in respect to physical grain size. The mean grain size was physically determined to be 0.560 with a standard deviation away from the mean of 0.97. After the sample was hydraulically adjusted, the mean dropped to 1.500 and had a standard deviation from that mean of only 0.35. This is quite a difference in considering phi sizes decrease in size logarithmically. Further, after adjusting the physically poorly sorted sample, the 2.00 fraction of the sample was de-

terminated to contain 61.6% of the entire sample, an obviously well sorted sample. Using such adjustments, each sample obtained from Buck Island was reevaluated hydraulically.

As determined through standard analysis, the mean physical grain size of the samples obtained, and subsequent analysis of this value in reference to the sample site, produced trends which indicate the general relationships of current energies moving around Buck Island. However, applying the R/P/T equivalence curve to the Buck Island samples, the physical grain sizes were adjusted to their terrigenous hydraulic equivalence, for better correlation to current energy flow of the study area. Before adjusting the samples to the T_e , the mean physical grain size of the fifteen samples was calculated to be 1.17 (0.44mm) with an average standard deviation of 1.100 (± 0.67 mm). After the samples were hydraulically adjusted, the mean size decreased to 1.790 (0.28mm) and the standard deviation also decreased to .570 (± 0.130 mm). The lower Sd indicates that the samples were better sorted than physical analysis indicated. After the adjustments were made, the hydraulic values of the fifteen samples were diagrammatically plotted (fig.4) and trends were noted.

Starting at the eastern most sample, #5, and moving to within 20m from the eastern most shoreline of Buck Island at sample site #4, the hydraulic mean was found to decrease in size from 1.410 to 1.500, denoting sample #5 to be the higher energy area of the two. This indicates that the current, flowing in a Westerly direction, encounters the effects of the island further out than site #4. The current is hypothesized then to split to move around the island mass at some point further than sample #5 which would then explain the resultant decrease in current energy depositing finer sediments at points near the eastern exposure of the island.

Further, as one moves along the Southeast coastline of Buck Island, intersecting sample sites #3 and #1 respectively, it is observed that the mean hydraulic size of the samples of sample #3 stabilizes in respect to #4, then increases in size at sample site #1. The mean sizes of samples #4, #3, and #1, are 1.50, 1.50, and 1.360, respectively. This is interpreted as an energy flow of mid-strength, which is steady until past sample #3, after which it becomes accelerated, shown by the increased coarseness in sample #1. Apparently, the current is accelerated by the effects of the morphologic protrusion of the Southern most portion of the island, which would account for the decrease of mean phi size, and the coarser sedimentary covering. Further from the shoreline, mean grain size was found to be extremely fine in comparison to 1, 3, 4, and 5. Sample #2 had an average hydraulic size of 2.21, medium-fine by terrigenous standards. This size grain reflects a lower energy environment. In fact, this was determined to be the second lowest energy area of the samples examined.

The Southwest portion of the island exhibited decreased grain sizes in the mean. Mean grain size decreased to 2.360 and 1.930 at sample sites #15 and #14 respectively. This indicates that the current effecting the Southeast portion of the island, i.e. samples 4, 3, and 1, is effectively deflected by the aforementioned land feature protruding Southward. (fig 4) Sample #15 is seemingly sheltered best from the current as indicated by its fine hydraulic size. And, though sample #14 was taken at a point almost parallel, latitudinally, to the land mass supposedly responsible for the current deflection, the mean grain size of #14 still exemplifies a low energy environment.

The Northern portion of Buck Island reflects similar trends in relating hydraulic mean sizes of the samples taken to the current energies. In an East to West direction, again starting at #5, moving through #4, and Northward along the coastline samples #7 and then #9, it was found that a steady decrease in

hydraulic means indicate a decreasing amount of current energy, and thus an increase in the amounts of fine sediment covering along this coast. The values of the means of samples number 5, 4, 7, and 9 are 1.41, 1.50, 1.74, and 2.03 phi respectively.

Sample site 9, determined to have a mean hydraulic grain size of 2.030, sits on the Westward side of a land protrusion jutting Northward, similar to the protruding land feature existing on the South shore, but of a much smaller scale. The difference in hydraulic values of sample #7, on the East side of the point, and sample #9, on the West side, is explained as a similar situation to the deflected current discussed in consideration of the Southeast shore sediment trends. Further, as the deflected Northern shore current joins the current already seemingly accelerated on the "offshore" sector of the area due to the effects of the massive reefs paralleling the island, on the passing ocean current, an increase in sediment sizes in samples 8 and then 11 indicate an added acceleration as well. The resulting effects show a trend from sample #7 at 1.740 to increase in size at the proposed meetings of the currents, sample #8, which has a mean hydraulic size of 1.590. Sample #11, in turn, exemplifies a higher energy environment with an average hydraulic grain size of 1.530. These increases in sediment size increase the strength of the current energy hypothesis.

The Western side of the island seems to be "starved" of current energy of any relative strength in comparison with the East side. The two land protrusions which seem to direct current flow away from the islands effectively reduce the energies of the West side of the island, at the points the samples were taken. The hydraulic mean sizes of the samples taken on this side, samples #10, #13 and #12, all exhibit grain sizes of the finest values of those taken around the island, except ^{ing} sample #2. The mean sizes of sample #10, #13, and #12, are 1.930, 2.070, and

1.78 respectively. Sample #10, although a fine sediment, is coarser in relation to sample #13 because of their relative exposures. Sample #10, as illustrated in figure #8, is less sheltered from the Westerly flowing current than the even more "secluded" sample site #13. Noting the increase in coarseness of the most Westerly sample taken, i.e. #12, it seems to indicate an increase in current strength. This might be ^{due to} the two deflected currents rejoining, having passed the effects of the land mass. The completed profile of current energies as related to the hydraulic grain size determinations is found in Figure #3. Further studies should be initiated to determine the accuracy of these current determinations. The direction of current flow, and its relationship to energy flow, as constructed from the hydraulic values of the samples extracted from Buck Island National Park, displays the significance of using the R/P/T curve in carbonate sediment studies.

Further application of this hydraulic equivalency curve should be considered in the field of Paleontology, dealing with carbonate sediments. By hydraulically examining stratified, undisturbed core samples, fluctuations of current energies throughout the past may be accurately determined. If one layer is dominated by hydraulically coarse sediments, and the successive layers become hydraulically finer, it could be safely hypothesized that the system has undergone a general decrease in energies. Conclusions can be drawn from there for contribution to the actual environmental model of the past.

In contrast to the prior example, if the same core were to be examined through visual observations considering only physical size of the particles, errors are inevitable. Perhaps one physically coarse layer of the undisturbed core sample is dominated by large platy granules. Classifying this particular

layer as coming from a high energy environment would be grossly misinterpretive. In fact, the large platy granules will represent an extremely low energy environment. Conclusively, in analyzing carbonate sedimentary environments, for relative energy intensities, it is imperative to consider hydraulics of the dissimilar grain types.

Conclusion:

In examining the standard seive analysis of the samples taken around Buck Island National Park, St. Croix, U.S. Virgin Islands, it becomes evident that there are dominant physical grain sizes. However, by determining the hydraulic differences between carbonate grains of the same size, but of different shapes, and comparing them to terrigenous hydraulic equivalent, it is determined necessary to further adjust the samples to standardized hydraulic values. Only after the hydraulic adjustments are made can an accurate evaluation of the energy restraints of a carbonate system be confidently defined.

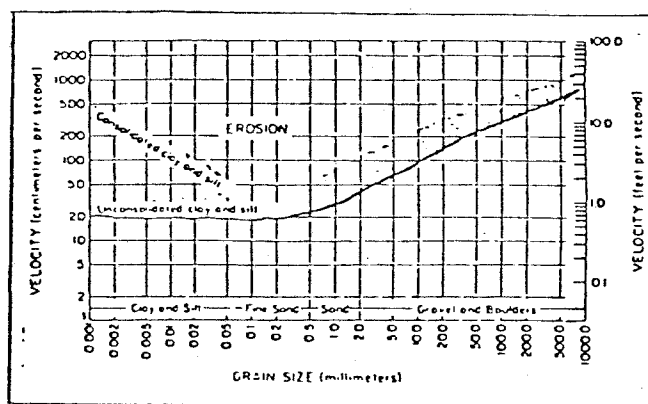


figure 7: Hjulstrom diagram

REFERENCES CITED

- Ginsburg, Robert, ed. 1973. Evolving Concepts in Sedimentology. Johns Hopkins University Press, Baltimore.
- Krumbein, W.C. and Sloss, L.L., 1963. Stratigraphy and Sedimentation. W.H. Freeman & Co., San Francisco.
- Milliman, J.D., 1974. Marine Carbonates. Springer, New York, Berlin, Heidelberg.
- Pettijohn, F.J., 1957. Sedimentary Rocks. Harper and Row, New York.

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