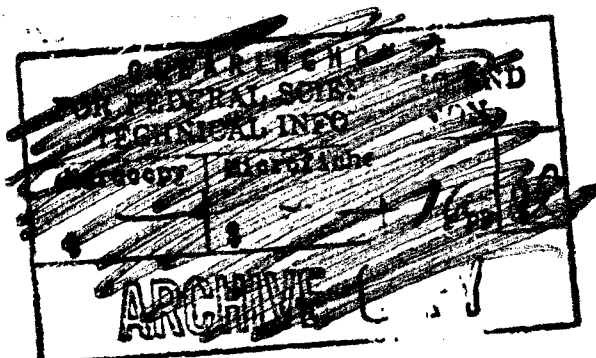


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By Fred B Phleger

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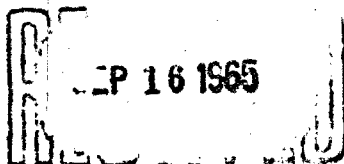
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DEPTH PATTERNS OF BENTHONIC FORAMINIFERA IN THE EASTERN PACIFIC*

FRED B PHLEGER

Abstract. Depth zonations of benthonic Foraminifera off the western United States are summarized. Generalized depth biofacies in 55 new samples from coastal Mexico are at 25 m, 35 m, 55 m, 75–85 m, 120 m, 180 m, 340 m and 550 m.

Criteria for determining depth biofacies are examined. Distributions based on living specimens are the most reliable. Shallow limits of species are the best boundary indicators; deep limits of species vary in value as indicators due to possible movement of specimens downslope. Each species seems to have a distinctive depth range and there are almost as many depth boundaries as there are species. Analysis of species depth ranges in new samples from coastal Mexico shows at least 24 depth boundaries. Analysis of data from the San Diego, California, area suggests 72 boundaries which can be recognized on the basis of shallow and deep limits of species.

INTRODUCTION

The use of planktonic Foraminifera in analyzing certain oceanographic processes such as the distribution and movement of water masses and their applications to history of the ocean basins is now well-established. Benthonic Foraminifera are equally valuable tools for the study of benthonic water masses, changes in sea level, displacement of sediment and rates of sediment deposition. Knowledge of the distribution and ecology of Foraminifera is essential for their application to any of these marine problems.

One of the major features of benthonic foraminiferal distributions is the occurrence of different assemblages at different water depths. The purposes of this paper are (1) to summarize information on depth zonation of benthonic Foraminifera in the northeast Pacific, (2) to present some new data on shallow-water depth ranges off the west coast of Mexico and (3) to evaluate the criteria for determining depth zonation of these populations.

The writer is grateful to J. R. Curray for collecting the samples studied from coastal Mexico and to J. P. Hosmer for assistance in identifying the

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faunas and in preparing the manuscript. This work was supported by a contract of the Office of Naval Research with the University of California and by the National Science Foundation.

REPORTED DEPTH ZONATIONS

Depth biofacies of benthonic Foraminifera in the eastern Pacific region have been described principally from off California, Baja California and the Gulf of California. There is one study of faunas from off Central America and another which extends from northern Washington to the end of the Baja California Peninsula. The following is a summary of the significant

| | LANKFORD 1962 | NATLAND 1933 | BANDY 1953 | UCHIO 1960 | WALTON 1965 | BANDY 1961 | PHLEGER 1964 | BANDY & ARNAL 1957 |
|------|------------------|-----------------|---------------|---------------|----------------|---------------|-----------------|-----------------------|
| | PACIFIC COAST | CALIFORNIA | CALIFORNIA | SAN DIEGO | BAJA CALIF | GULF CALIF | GULF CALIF | CEN AMER |
| | ---13--- | ---4--- | | ---24--- | | ---18--- | ---27-35--- | |
| | ---34--- | ---40--- | ---46--- | | ---55--- | ---37--- | ---58-65--- | ---46--- |
| 100 | //// | | | ---80--- | ---90--- | ---73--- | ---75-90--- | |
| | | | | | | | ---125--- | ---122--- |
| 200 | | | | ---180--- | ---180--- | ---152--- | ---165--- | |
| 300 | | ---275--- | ---244--- | | | ---244--- | | |
| 400 | | | | ---450--- | | ---366--- | ---365--- | |
| 500 | | | | | | | | |
| 600 | | | | ---640--- | | ---610--- | | ---610--- |
| 700 | | | | | ---640-730--- | | | |
| 800 | | | | ---820--- | | | ---730-910--- | |
| 900 | | | | | | ---914--- | | |
| 1000 | | | | //// | | ---1219--- | ---1100-1450--- | ---1219--- |
| 2000 | | ---2000--- | ---1829--- | | | ---1524--- | ---1800--- | |
| | | //// | ---2438--- | | | ---1829--- | ---2400--- | |
| 3000 | | | | | | ---2134--- | ---2750--- | |
| | | | | | | ---2438--- | //// | |
| 4000 | | | //// | | | | //// | |

FIG. 1. Depth biofacies of benthonic Foraminifera reported from the northeast Pacific.

published papers on depth zonation in this region. Figure 1 summarizes depth zones based on Foraminifera which have been proposed by the various authors.

The earliest study of depth distributions of Foraminifera was by NATLAND (1933) from the area between Los Angeles and Catalina Island. Techniques were not available to Natland for differentiating living specimens although he recognized the problem of contamination of faunas from both Recent and fossil specimens. He established depth zones based on about 150 samples at 4-40 m, 40-275 m, 275-2000 m and 2000-2500 m. The faunas were correlated generally with temperatures as well as depths.

BANDY (1953) studied the dead faunas in 63 samples from off San Francisco, off Pt. Conception and off San Diego. On the basis of these materials he recognized a "middle neritic zone" at 0-46 m, a "lower neritic zone" at 46-244 m, a "bathyal zone" at 244-1829 m, an "upper abyssal zone" at 1829-2438 m and a "lower abyssal zone" extending from 2438 to about 3658 m. These occurrences were correlated with temperature, salinity and oxygen distributions as well as with depth. Differences in faunal compositions and distributions from north to south were noted.

LANKFORD (1962) studied living faunas in 150 carefully collected turbulent zone samples between northern Washington and southern Baja California. He reports turbulent zone depth zonation on sand bottoms with boundaries at about 13 and 34 m. These nearshore depth boundaries were attributed to turbulence which varies with depth.

WALTON (1955) charted depth distributions of living benthonic Foraminifera in about 200 samples from Todos Santos Bay in Baja California. He suggested depth boundaries at 55 m, 90 m, 180 m and 640-730 m, and explained these distributions by variations in depth and temperature.

UCHIO (1960) has analyzed faunas in 157 samples off San Diego and reports major faunal depth boundaries at 24 m, 80 m, 180 m, 450 m, 640 m and 820 m.

Two studies have been made of depth distributions of faunas in the Gulf of California. BANDY (1961) studied non-living faunas from about 160 sediment samples. His results indicate clearly recognized depth biofacies having boundaries at 18 m, 37 m, 73 m, 152 m, 244 m, 366 m, 610 m, 914 m, 1219 m, 1524 m, 1829 m, 2134 m and 2438 m. PHLEGER (1964) reports distributions of living benthonic Foraminifera in 76 samples from the Gulf of California. Recognizable depth assemblages are suggested which have boundaries at approximately 25-35 m, 55-65 m, 75-90 m, 125 m, 165 m, 365 m, 730-910 m, 1100-1450 m, 1800 m, 2400 m and 2750 m.

BANDY and ARNAL (1957) studied non-living faunas in 36 samples from off the west coast of three areas of Central America and indicated depth biofacies of Foraminifera at approximately 46 m, 122 m, 610 m and 1219 m.

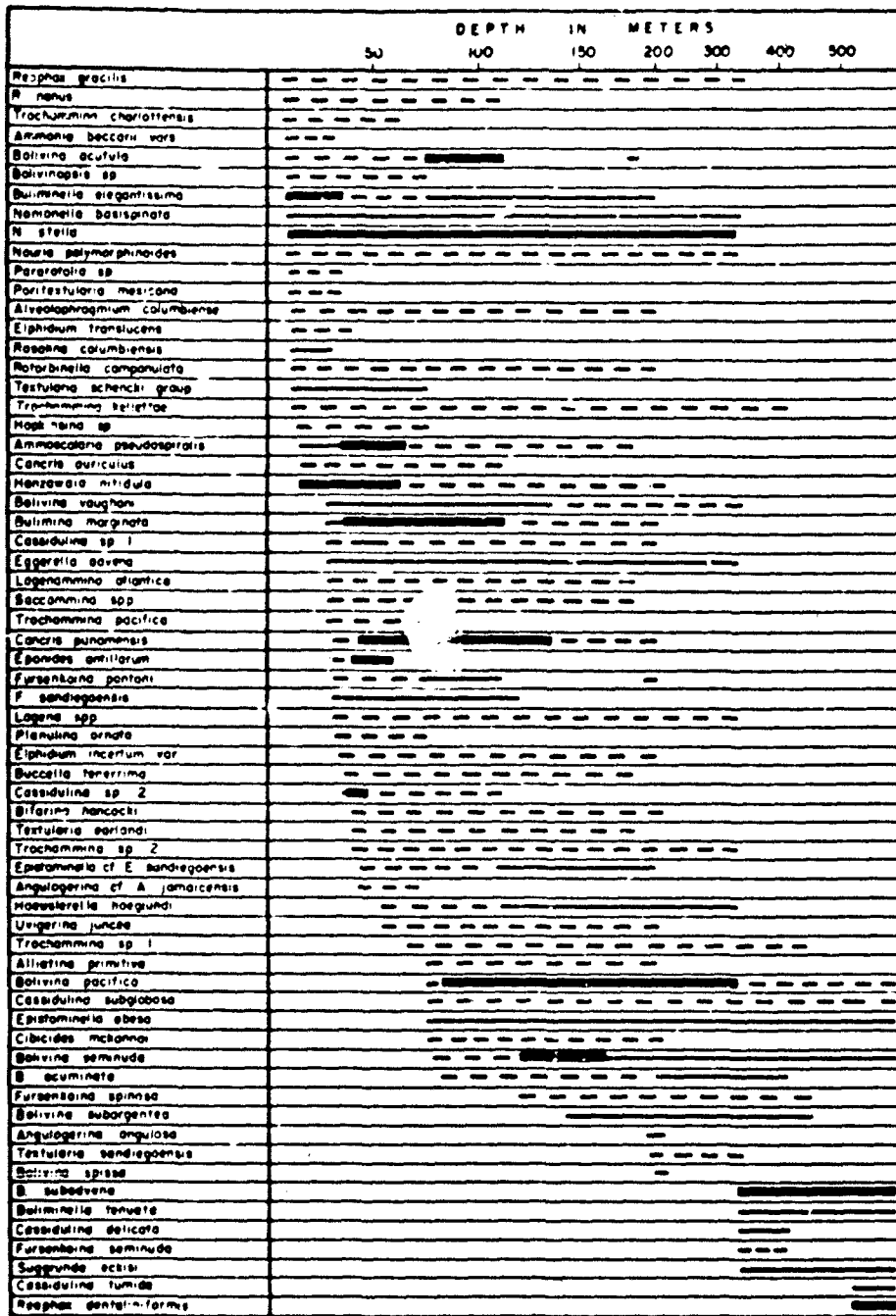


FIG. 3. Depth ranges of species. Width of line indicates relative abundance.

on Fig. 3. The species on Fig. 3 are arranged according to shallow limit of occurrence. It is apparent that several faunal depth zone boundaries are indicated by these distributions.

25 m boundary. A boundary at this depth is recognized by the shallow limits of:

Bolivina vaughani Natland
Bulimina marginata d'Orbigny
Cancris panamensis Natland
Cassidulina sp. 1
Eggerella advena (Cushman)
Eponides antillarum (d'Orbigny)
Fursenkoina pontoni (Cushman)
F. sandiegoensis (Uchio)
Lagena spp.
Lagenamina atlantica (Cushman)
Planulina ornata (d'Orbigny)
Saccamina spp.
Trochammina pacifica Cushman

The deep limits of *Ammonia beccarii* (Linné) vars. and *Rosalina columbiense* (Cushman) also occur in the present samples at about 25 m.

35 m boundary. A boundary at approximately 34-45 m is indicated by the shallow limits of:

Angulogerina cf. *A. jamaicensis* Cushman and Todd
Bifarina hancocki Cushman and McCulloch
Buccella tenerrima (Bandy)
Cassidulina sp. 2
Elphidium incertum (Williamson) var.
Epistominella cf. *E. sandiegoensis* Uchio
Textularia earlandi Parker
Trochammina sp. 2

The deep limits of the following also occur at about this depth:

Elphidium translucens Natland
Pararotalia sp.
Poritextularia mexicana Loeblich and Tappan

55 m boundary. This is marked by the shallow limits of:

Haeuslerella heoglundii (Uchio)
Uvigerina juncea Cushman and Todd

75-85 m boundary. This is marked by the shallow limits of the following species at approximately this depth:

Alliatina primitiva (Cushman and McCulloch)

Bolivina acuminata Natland
B. pacifica Cushman and McCulloch
B. seminuda Cushman
Cassidulina subglobosa Brady
Cibicides mckannai Galloway and Wissler
Epistominella obesa Bandy and Arnal
Trochammina sp. 1

The deep limits of the following species also mark this depth:

Angulogerina cf. *A. jamaicensis* Cushman and Todd
Bolivinopsis sp.
Hopkinsina sp.
Planulina ornata (d'Orbigny)
Textularia schencki Cushman and Valentine group
Trochammina charlottensis Cushman
T. pacifica Cushman

A boundary at about 120 m is indicated by the shallow limit of *Fursenkoina spinosa* (Heron-Allen and Earland) and the deep limit of *Bolivinopsis* sp., *Canceris auriculus* (Fichtel and Moll), *Cassidulina* sp. 2, *Fursenkoina pontoni* (Cushman), *F. sandiegoensis* (Uchio) and *Reophax nanus* Rumbler.

180 m boundary. This appears to be moderately well-marked and is characterized by the shallow limits of *Angulogerina angulosa* (Williamson), *Bolivina spissa* Cushman and *Textularia sandiegoensis* Uchio. The deep limits of the following species occur at about this position:

Alliatina primitiva (Cushman and McCulloch)
Alveolophragmium columbiense (Cushman)
Ammoscalaria pseudospiralis (Williamson)
Bifarina hancocki Cushman and McCulloch
Buccella tenerrima (Bandy)
Bulimina marginata d'Orbigny
Buliminella elegantissima (d'Orbigny)
Canceris panamensis Natland
Cassidulina sp. 1
Cibicides mckannai Galloway and Wissler
Epistominella cf. *E. sandiegoensis* Uchio
Hanzawaia nitidula (Bandy)
Lagenammina atlantica (Cushman)
Rotorbinella campanulata (Galloway and Wissler)
Saccammina spp.
Textularia earlandi Parker
Uvigerina juncea Cushman and Todd

340 m boundary. This appears to be indicated by the shallow limits of:

Bolivina subadriana Cushman
Bulimirella tenuata Cushman
Cassidulina delicata Cushman
Fursenkoina seminuda (Natland)
Suggrunda eckisi Natland

The deep limits of the following occur at about 340 m:

Bolivina raugnani Natland
Eggerella adriana (Cushman)
Haustrerella hoeglundi (Uchio)
Lagena spp.
Nonionella basispinata (Cushman and Moyer)
N. stella Cushman and Moyer
Nouria polymorphinoides Heron-Allen and Earland
Reophax gracilis (Kiaer)
Textularia sandiegoensis Uchio
Trochammina sp. 2

A faunal boundary at about 550 m seems to be suggested by the shallow range limits of *Cassidulina tumida* Natland and *Reophax dentaliniformis* Brady.

The depth biofacies indicated in the present materials correspond generally with those suggested in the same region by BANDY (1961) and PHLEGER (1964). A comparison of the ranges of the same species also shows general agreement. Differences which do occur in faunal and species ranges can be attributed to differences in sample frequency and distribution.

DISCUSSION

Meaningful boundaries between foraminiferal depth assemblages are difficult to determine and often are based largely on the opinion of the person who defines them. A "depth biofacies" should be a natural and distinctive association of Foraminifera. Natural distributions of organisms are very complex and each sample collected differs somewhat from every other sample. There are no positive criteria for determining the degree of difference which qualifies a population of Foraminifera to be classified as a "biofacies". One of the criteria which has been used is whether such an assemblage can be differentiated easily from other assemblages. This is probably as useful a method as any that can at present be devised.

In general there are three bases for determining depth assemblages: (1) shallow limits of occurrences of species, (2) deep limits of occurrences of species and (3) frequencies of species. The shallow and deep limits are the

most widely used in practice, although high and low frequencies also are of considerable importance. It is generally believed that the shallow limits are more reliable than deep limits because of the possibility of transport of specimens downslope. Transportation of sand-size particles, such as Foraminifera, from shallow into deep water does not appear to be as common as many seem to believe. It is suggested, therefore, that deep limits of ranges of species in many or most instances may be as reliable as shallow limits.

It is obvious that distribution of living specimens is much more reliable for ecological interpretations than distribution of non-living specimens. This may be illustrated by the published distribution of a species of Foraminifera from the continental shelf of the northwest Gulf of Mexico. In 1951 (PHLEGER, 1951) the depth range of a common species, *Elphidium gunteri* Cole, was listed as occurring to a depth of about 100 m; this was the range for the total population and living specimens were not listed. In 1956 (PHLEGER, 1956) living specimens from the same area were differentiated by a new technique. It was shown that the living population of *Elphidium gunteri* occurs only as deep as about 50 m, although the dead population does extend to more than 100 m. This shows that the true depth range of *E. gunteri* is on the inner part of the continental shelf. Specimens occurring at outer continental shelf depths were deposited there when the sea level was lower and are a part of the relict sediment deposited during an earlier cycle. Earlier cycle sediments are a common source of "natural contamination" of faunal assemblages, and are especially common on outer continental shelves.

In some instances living specimens have been found transported beyond their normal depth range with displaced sediment. These are not common and usually can be recognized by a striking discontinuity in depth distribution. A common source of contamination is from submarine or coastal exposures of older marine rocks containing Foraminifera. Contamination by post-Miocene specimens may not be easily recognized if the living assemblage is not studied.

Each species of Foraminifera seems to have a distribution which differs somewhat from the distribution of all other species. It is possible, therefore, to determine the depth of occurrence of a fauna from any area which has been studied adequately much more closely than indicated by most reports of depth biofacies. The biofacies listed are generalizations but are useful for descriptive purposes. There may be almost as many boundaries as there are species.

Decisions concerning locations of depth boundaries are partly a matter of opinion. Boundaries listed above for the new faunas described off coastal Mexico, for example, were mostly based on shallow and deep limits of species. The following is the number of shallow and deep limits actually observed and the depths of the samples in which they occurred:

| Sample depth in m | No. of shallow limits of species | No. of deep limits of species | Sample depth in m | No. of shallow limits of species | No. of deep limits of species |
|-------------------|----------------------------------|-------------------------------|-------------------|----------------------------------|-------------------------------|
| 15 | 3 | | 73 | | 1 |
| 27 | 7 | | 77 | 5 | 5 |
| 31 | 8 | 1 | 113 | | 3 |
| 33 | | 1 | 122 | 1 | 1 |
| 35 | 1 | | 144 | 1 | |
| 37 | 2 | 1 | 177 | | 6 |
| 40 | 4 | | 186 | 2 | |
| 44 | 2 | | 201 | 1 | |
| 55 | 2 | | 338 | 5 | 10 |
| 58 | | 1 | 417 | | 2 |
| 64 | | 1 | 456 | | 2 |
| 68 | 1 | | 525 | 2 | |

The depths chosen to describe the boundaries of these assemblages are at approximately 25 m, 35 m, 75-85 m, 120 m, 180 m, 340 m and 550 m. These depths are generalized because there are relatively few samples in a large area and the depth distribution of the samples is uneven. It is possible that some other interpretation is more nearly the correct one. A more valid interpretation, for example, may be that a significant faunal boundary occurs at each depth where a shallow or deep limit of a species occurs. This interpretation gives 24 depth biofacies boundaries instead of eight, and if frequencies also are considered the number of boundaries is further increased.

The data on depth distribution of Foraminifera in the San Diego, California, area given by UCHIO (1960) have been analyzed in this manner, and we have listed the numbers of species having shallow and deep limits of occurrences at various depths.

Uchio listed generalized boundaries at 24 m, 80 m, 180 m, 450 m, 640 m and 820 m. He could have chosen other depths which could have been a more realistic general description. He could also have argued for as many as 72 faunal depth boundaries based on all depths of upper and lower limits of species. Uchio's report was based on three times as many samples and there were three times as many species considered as in the present material from coastal Mexico, and in addition the samples extended somewhat deeper. This explains the larger number of boundaries.

The significance of these numerous depth boundaries of species cannot be assessed at the present time. It is possible to determine depth of occurrence of an assemblage within very narrow limits if it is from an adequately studied area, such as off San Diego. The usefulness of this ability in ecologic problems

in the modern ocean or in paleoecologic problems in ancient rocks is uncertain. It is possible that the number of different associations or communities of Foraminifera is very large, and is a function of the large number of species.

| Sample depth in m | No. of shallow limits of species | No. of deep limits of species | Sample depth in m | No. of shallow limits of species | No. of deep limits of species |
|-------------------|----------------------------------|-------------------------------|-------------------|----------------------------------|-------------------------------|
| 16 | 5 | 1 | 251 | | 1 |
| 20 | 4 | | 256 | 1 | 1 |
| 27 | 1 | 1 | 274 | 1 | |
| 31 | 3 | | 287 | 2 | |
| 35 | 7 | | 293 | 1 | |
| 37 | 11 | | 305 | | 2 |
| 38 | 4 | | 329 | 2 | 3 |
| 53 | 1 | | 331 | 1 | 1 |
| 55 | 2 | | 366 | | 3 |
| 60 | 6 | | 391 | 1 | |
| 69 | 7 | | 452 | 1 | |
| 71 | 2 | | 454 | | 3 |
| 73 | 11 | | 457 | 1 | 1 |
| 75 | 2 | | 521 | 1 | |
| 82 | 3 | | 567 | 1 | 2 |
| 84 | 1 | | 631 | 2 | |
| 86 | 4 | | 640 | 1 | |
| 91 | 3 | | 649 | | 1 |
| 97 | | 1 | 722 | | 2 |
| 112 | 1 | | 768 | 1 | 1 |
| 117 | | 1 | 786 | | 2 |
| 122 | | 1 | 805 | 1 | |
| 134 | | 2 | 823 | 1 | 1 |
| 135 | 1 | | 832 | 1 | |
| 137 | 1 | 2 | 841 | | 1 |
| 146 | 1 | 3 | 850 | 1 | 1 |
| 159 | 1 | | 866 | | 1 |
| 168 | | 1 | 896 | | 2 |
| 179 | 1 | | 924 | 2 | 1 |
| 181 | 1 | | 966 | | 1 |
| 190 | 2 | | 1006 | 1 | |
| 219 | 1 | 2 | 1033 | | 2 |
| 221 | | 1 | 1106 | | 2 |
| 229 | 1 | | 1113 | 1 | |
| 234 | 1 | 1 | 1125 | | 3 |
| 245 | | 1 | | | |

Foraminiferal associations of different ranks may be a useful concept, with "biofacies", "super-biofacies" and "sub-biofacies", etc. A more sophisticated statistical analysis than any yet applied to this problem will be required for clarification.

LOCATIONS OF STATIONS

| Station | N. Lat. | W. Long. | Depth (meters) | Station | N. Lat. | W. Long. | Depth (meters) |
|---------|-----------|------------|----------------|---------|-----------|------------|----------------|
| 276 | 21° 51-8' | 105° 45-5' | 33 | 394 | 23° 30-0' | 106° 56-0' | 80 |
| 277 | 21° 51-2' | 105° 46-5' | 38 | 395 | 23° 36-0' | 107° 00-0' | 64 |
| 286 | 21° 45-6' | 105° 55-4' | 55 | 396 | 23° 41-0' | 107° 06-0' | 66 |
| 300 | 21° 43-7' | 105° 40-3' | 31 | 397 | 23° 45-0' | 107° 13-0' | 73 |
| 303 | 21° 46-8' | 105° 35-5' | 13 | 398 | 23° 49-0' | 107° 20-0' | 73 |
| 304 | 21° 47-8' | 105° 34-3' | 9 | 399 | 23° 58-0' | 107° 21-0' | 46 |
| 306 | 21° 48-6' | 105° 33-9' | 7 | 400 | 24° 06-0' | 107° 24-0' | 27 |
| 312 | 22° 03-3' | 105° 48-5' | 35 | 403 | 24° 13-0' | 107° 42-0' | 40 |
| 315 | 22° 12-0' | 105° 44-2' | 22 | 404 | 24° 18-0' | 107° 50-0' | 44 |
| 320 | 22° 15-8' | 105° 50-0' | 33 | 405 | 24° 22-0' | 107° 58-0' | 46 |
| 327 | 22° 10-1' | 106° 07-8' | 58 | 407 | 24° 33-0' | 108° 03-0' | 37 |
| 333 | 22° 11-9' | 106° 22-4' | 594 | 408 | 24° 50-0' | 108° 28-0' | 144 |
| 337 | 22° 16-6' | 106° 11-7' | 77 | 410 | 25° 00-0' | 108° 41-0' | 40 |
| 342 | 22° 22-4' | 105° 58-0' | 48 | 413 | 25° 12-0' | 109° 02-0' | 55 |
| 361 | 22° 33-2' | 106° 09-5' | 68 | 425 | 28° 14-7' | 111° 33-0' | 58 |
| 364 | 22° 29-2' | 106° 18-2' | 163 | 430 | 28° 02-3' | 111° 41-8' | 417 |
| 367 | 22° 32-3' | 106° 26-4' | 525 | 431 | 27° 59-9' | 111° 43-7' | 456 |
| 370 | 22° 37-1' | 106° 17-0' | 137 | 432 | 28° 04-2' | 111° 50-1' | 338 |
| 372 | 22° 40-3' | 106° 10-9' | 73 | 434 | 28° 08-9' | 111° 46-7' | 201 |
| 376 | 22° 45-7' | 105° 59-1' | 15 | 452 | 28° 33-5' | 111° 52-2' | 11 |
| 379 | 22° 49-4' | 106° 09-4' | 42 | 479 | 28° 28-3' | 112° 14-5' | 186 |
| 384 | 23° 06-5' | 106° 23-5' | 35 | 481 | 28° 31-7' | 112° 07-8' | 77 |
| 385 | 23° 05-9' | 106° 24-4' | 44 | 490 | 29° 34-3' | 112° 55-3' | 214 |
| 390 | 23° 05-3' | 106° 34-6' | 122 | 494 | 29° 49-2' | 112° 44-6' | 77 |
| 391 | 23° 13-0' | 106° 36-0' | 84 | 495 | 29° 50-6' | 112° 40-1' | 35 |
| 392 | 23° 19-0' | 106° 44-0' | 84 | 499 | 29° 50-3' | 112° 47-6' | 113 |
| 393 | 23° 25-0' | 106° 51-0' | 84 | 501 | 29° 44-7' | 112° 59-1' | 177 |

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