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Ingersoll, R.V., et al., 2014, Paleotectonics of a complex Miocene half graben formed above a detachment fault: The Diligencia basin, Orocopia Mountains, southern California: Lithopshere, doi:10.1130/L334.1.

## PREVIOUS WORK

The nearly simultaneous publication of evidence for large lateral displacement along faults of the San Andreas system by Crowell (1952), and Hill and Dibblee (1953) initiated a decades-long search for constraints on timing and magnitude of past fault displacements. Subsequent studies included matching similar terranes across faults (e.g., Crowell, 1960, 1962, 1975a; Matthews, 1976; Tennyson, 1989; Frizzell and Weigand, 1993; Matti and Morton, 1993; Powell, 1993), matching source terranes to sedimentary deposits across faults (e.g., Bohannon, 1975, 1976; Ehlig et al., 1975; Ehlert, 1982, 2003; Dillon and Ehlig, 1993; Matti and Morton, 1993; Sadler, 1993; Sadler et al., 1993; Weldon et al., 1993; Crowell, 2003), reconstruction of faunal provinces and paleogeography across faults (e.g., Hall, 1960, 2002; Stanley, 1987; Graham et al., 1989), reconstruction of volcanic centers across faults (e.g., Matthews, 1976; Cole and Basu, 1992, 1995; Frizzell and Weigand, 1993; Dickinson, 1997), constraining vertical-axis rotations across faults (e.g., Terres and Luyendyk, 1985; Hornafius et al., 1986; Carter et al., 1987; Luyendyk and Hornafius, 1987; Luyendyk, 1991; Dickinson, 1996) and constraining regional reconstructions through plate-tectonic marine records (e.g., Atwater, 1970, 1989; Legg, 1991; Legg et al., 1991; Lonsdale, 1991; Nicholson et al., 1994; Bohannon and Parsons, 1995; Atwater and Stock, 1998; Bohannon and Geist, 1998). Integration of these diverse data sets into well constrained paleogeographic and paleotectonic reconstructions has steadily advanced during the last 50 years (e.g., Hamilton, 1961; Yeats, 1968a, 1968b; Crowell, 1981, 1982, 1987; Weldon and Humphreys, 1986; Tennyson, 1989; Sedlock and Hamilton, 1991; Wright, 1991; Powell and Weldon, 1992; Crouch and Suppe, 1993; Richard, 1993; Nicholson et al., 1994; Bohannon and Parsons, 1995; Ingersoll and Rumelhart, 1999; Ingersoll, 2008a).

Miller (1944) produced the first map of the northern part of the Orocopia Mountains and named the Orocopia Schist, which he presumed to be Precambrian; he commented that the Orocopia Schist resembled the Pelona Schist of Hershey (1902). Hill and Dibblee (1953) speculated that the northeast end of the Pelona Schist of Sierra Pelona might be offset by the San Andreas fault from the west end of the Orocopia Schist in the Orocopia Mountains (Figs. 1 and 2). Dibblee (1954) suggested the presence of Eocene strata somewhere in the Orocopia Mountains, based on the occurrence of Eocene fossils in clasts of the Pliocene Mecca Formation. Williams (1956) and Gillies (1958) produced the first geologic maps, cross sections and stratigraphic sections of the Diligencia basin area, utilizing informal stratigraphic nomenclature. Kirkpatrick (1958) studied the Eocene paleontology, which Crowell and Susuki (1959) incorporated into their definition of the Eocene Maniobra Formation. Crowell (1960, 1962, 1975a) and Ehlig (1968, 1981) suggested specific correlations between the Orocopia and Soledad areas across the San Andreas fault, and the Tejon (Plush Ranch) area across the San Gabriel fault. Johnston (1961) provided additional micropaleontologic support for the Eocene age of the Maniobra Formation. Crowell and Walker (1962) described the anorthosite and related rocks in the Orocopia Mountains and suggested strong similarities with rocks in the San Gabriel Mountains. Woodburne and Whistler (1973) described an Early Miocene oreodont from the middle of the Diligencia Formation. Spittler and Arthur (1973) suggested that contrasts between the Orocopia and Soledad areas did not support direct correlations across the San Andreas fault. Arthur (1974) and Spittler (1974) (summarized by Spittler and Arthur, 1982) provided new data on volcanic petrology and geochemistry, sedimentology and stratigraphy of the Miocene strata.

Howell (1974, 1975) discussed the paleogeographic and paleotectonic significance of the Maniobra Formation. Bohannon (1975, 1976) suggested correlations of mid-Tertiary nonmarine strata across strands of the San Andreas fault, including the Miocene Diligencia Formation (Crowell, 1975b) of the Orocopia Mountains; Tennyson (1989) modified Bohannon's (1975, 1976) paleogeographic reconstruction of these basins. Haxel and Dillon (1978) described and interpreted the Orocopia Schist and the Chocolate Mountain "thrust" system. Powell (1981, 1993) and Powell and Weldon (1992) described the crystalline rocks of the Orocopia Mountains and proposed possible palinspastic reconstructions. Spittler and Arthur (1982) and Squires and Advocate (1982) provided new sedimentologic, stratigraphic, petrologic and structural data and interpretations for the Diligencia basin.

Terres (1984) and Carter et al. (1987) determined the extent of clockwise vertical-axis rotations of the Diligencia basin and surrounding areas. Jacobson et al. (1988, 1996, 2000, 2002, 2007, 2011), Jacobson and Dawson (1995), and Grove et al. (2003) summarized the depositional, metamorphic, structural and tectonic evolution of the Orocopia and related schists. Advocate et al. (1988) interpreted the Maniobra Formation as a fault-controlled submarine-canyon deposit, which Grove (1993) correlated with submarine-fan deposits of Salinia (across the San Andreas fault). Crowell (1993) summarized the structure, stratigraphy, sedimentology and age of the Diligencia Formation, and noted that dextral NW-SE faults and sinistral NE-SW faults that cut the Diligencia Formation resulted from north-south compression that was younger than Middle Miocene and older than Quaternary. Frizzell and Weigand (1993) provided new radiometric ages for the Diligencia Formation. Dillon and Ehlig (1993), Matti and Morton (1993), Powell (1993) and Richard (1993) included the Orocopia Mountains in their palinspastic reconstructions of southeastern California.

Robinson and Frost (1996) suggested that faults along the northeast side of the Orocopia Schist antiform represent normal detachment faults, with down-to-the-northeast movement, which resulted in half-graben development of the Diligencia basin. Law et al. (2001) summarized the stratigraphy, sedimentology, petrology, structure and tectonic setting of the Diligencia basin area, and discussed a model for half-graben sedimentation (e.g., Leeder and Gawthorpe, 1987; Gawthorpe and Leeder, 2000) resulting from a theoretical fault bounding the north side of the basin. Vucic (2002) and Ebert (2004) provided additional thermochronologic, geochronologic and structural analyses for the Orocopia Mountains in order to test models for origin and evolution of the Orocopia Schist, detachment faults and the Diligencia basin. Yin (2002) proposed a passive-roof-thrust model for the emplacement of the Pelona-Orocopia Schist. Preliminary results from the present investigation were presented by Ingersoll (2009, 2010), and Caracciolo et al. (2013) discussed the diagenetic history of the Maniobra and Diligencia formations.

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TABLE 1. DILIGENCIA FORMATION CONGLOMERATE CLAST SIZE
(MEAN DIAMETER OF 10 COARSEST CLASTS (CM))

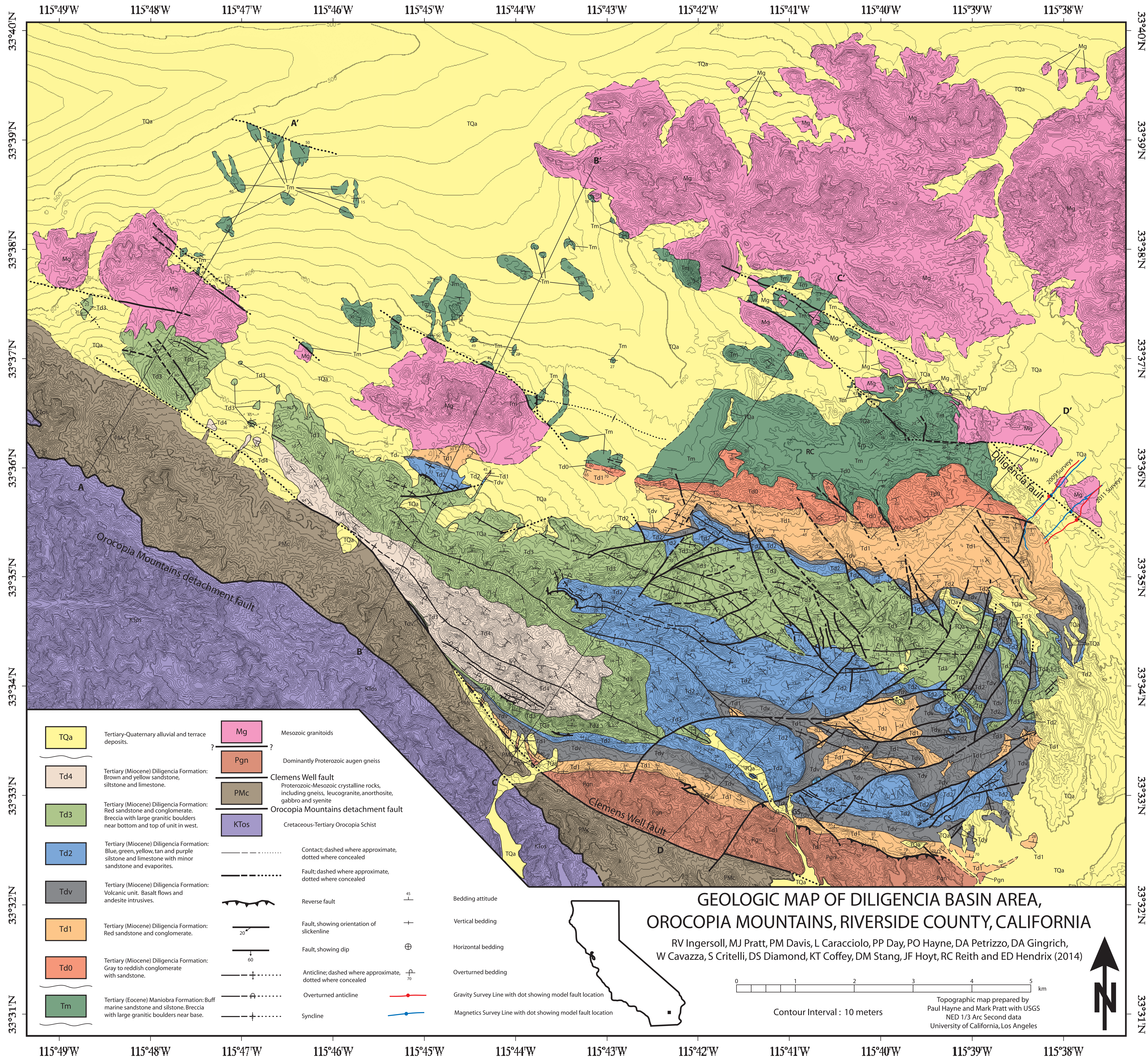
| SAMPLE | | | | | | | | | | | MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DL-1 | 135 | 70 | 80 | 80 | 65 | 70 | 85 | 70 | 85 | 110 | 85 |
| DL-2 | 270 | 160 | 165 | 130 | 180 | 150 | 125 | 140 | 120 | 120 | 156 |
| DL-3 | 110 | 110 | 130 | 120 | 115 | 105 | 100 | 150 | 140 | 150 | 123 |
| DL-4 | 160 | 110 | 90 | 110 | 195 | 95 | 105 | 100 | 150 | 100 | 121.5 |
| DL-5 | 90 | 75 | 80 | 110 | 80 | 90 | 80 | 90 | 70 | 105 | 87 |
| DL-6 | 80 | 65 | 50 | 55 | 70 | 45 | 70 | 45 | 55 | 45 | 58 |
| DL-7 | 75 | 95 | 65 | 55 | 60 | 80 | 90 | 95 | 80 | 60 | 75.5 |
| DL-8 | 80 | 80 | 65 | 70 | 60 | 60 | 60 | 75 | 65 | 90 | 70.5 |
| DL-9 | 85 | 60 | 70 | 100 | 60 | 65 | 70 | 60 | 80 | 55 | 70.5 |
| DL-10 | 65 | 45 | 50 | 50 | 55 | 75 | 40 | 40 | 70 | 45 | 53.5 |
| DL-11 | 60 | 80 | 65 | 85 | 55 | 60 | 60 | 65 | 65 | 60 | 65.5 |
| DL-17 | 50 | 60 | 80 | 65 | 55 | 60 | 55 | 50 | 60 | 45 | 58 |
| DL-18 | 65 | 50 | 55 | 90 | 50 | 55 | 65 | 55 | 50 | 60 | 59.5 |
| DL-19 | 100 | 130 | 70 | 110 | 75 | 80 | 90 | 70 | 75 | 80 | 88 |
| DL-20 | 140 | 135 | 120 | 125 | 115 | 145 | 215 | 175 | 133 | 113 | 141.6 |
| DL-21 | 110 | 102 | 105 | 150 | 132 | 140 | 170 | 205 | 145 | 150 | 140.9 |
| DL-22 | 135 | 95 | 110 | 110 | 85 | 105 | 120 | 88 | 110 | 75 | 103.3 |
| DL-23 | 170 | 125 | 105 | 106 | 120 | 130 | 135 | 100 | 110 | 85 | 118.6 |
| DL-24 | 95 | 165 | 130 | 93 | 135 | 105 | 160 | 97 | 200 | 140 | 132 |
| DL-25 | 88 | 130 | 100 | 120 | 90 | 170 | 86 | 110 | 100 | 160 | 115.4 |
| DL-26 | 75 | 80 | 90 | 120 | 100 | 95 | 150 | 100 | 90 | 130 | 103 |
| DL-27 | 75 | 80 | 80 | 115 | 75 | 95 | 110 | 90 | 70 | 105 | 89.5 |
| DL-28A | 110 | 130 | 90 | 205 | 85 | 85 | 95 | 100 | 85 | 150 | 113.5 |
| DL-28B | 135 | 150 | 165 | 120 | 125 | 115 | 115 | 205 | 175 | 175 | 148 |
| DL-29 | 170 | 115 | 135 | 115 | 125 | 155 | 190 | 140 | 120 | 125 | 139 |
| DL-30 | 170 | 175 | 130 | 205 | 190 | 145 | 180 | 135 | 145 | 160 | 163.5 |
| DL-31 | 125 | 110 | 105 | 115 | 100 | 95 | 90 | 95 | 105 | 100 | 104 |
| DL-32 | 115 | 105 | 85 | 90 | 145 | 110 | 95 | 160 | 120 | 105 | 113 |
| DL-33 | 85 | 75 | 115 | 120 | 85 | 95 | 110 | 90 | 95 | 85 | 95.5 |
| DL-34 | 65 | 75 | 90 | 60 | 75 | 70 | 60 | 65 | 85 | 90 | 73.5 |
| DL-35 | 75 | 83 | 105 | 122 | 85 | 110 | 130 | 120 | 82 | 75 | 98.7 |
| DL-36 | 58 | 84 | 59 | 77 | 72 | 108 | 66 | 63 | 59 | 59 | 70.5 |
| DL-37 | 76 | 49 | 53 | 55 | 51 | 64 | 57 | 55 | 64 | 70 | 59.4 |
| PDL-3 | 150 | 80 | 100 | 110 | 90 | 80 | 120 | 100 | 150 | 120 | 110 |
| PDL-4 | 180 | 140 | 150 | 180 | 150 | 140 | 150 | 180 | 140 | 200 | 161 |
| PDL-6 | 150 | 200 | 150 | 140 | 130 | 140 | 140 | 140 | 190 | 140 | 152 |
| PDL-8 | 150 | 130 | 120 | 130 | 150 | 140 | 140 | 130 | 120 | 150 | 136 |
| TD-M9 | 85 | 90 | 75 | 85 | 80 | 120 | 95 | 125 | 70 | 110 | 93.5 |
| TD-M10 | 80 | 110 | 100 | 70 | 60 | 60 | 80 | 85 | 65 | 65 | 77.5 |
| TD-M11 | 85 | 95 | 115 | 130 | 90 | 140 | 100 | 80 | 75 | 85 | 99.5 |
| TD-M12 | 110 | 85 | 95 | 70 | 65 | 60 | 62 | 65 | 60 | 55 | 72.7 |
| TD-M13 | 85 | 85 | 80 | 70 | 65 | 55 | 55 | 55 | 65 | 60 | 67.5 |
| TDRB-1-2 | 27 | 28 | 25 | 58 | 30 | 35 | 22 | 33 | 35 | 22 | 31.5 |
| TDRB-5 | 35 | 57 | 30 | 33 | 90 | 30 | 24 | 30 | 27 | 26 | 38.2 |

TABLE 2. PALEOCURRENT MEASUREMENTS
(VECTOR MEANS OF 10 ORIENTATION MEASUREMENTS
OF THE MAXIMUM CROSS-SECTIONAL AREAS
OF IMBRICATED CONGLOMERATE CLASTS)

| Samples | Vector Mean Direction (Azimuth) |
|---|---|
| DL-1 | 137$^o$ |
| DL-3 | 171$^o$ |
| DL-4 | 135$^o$ |
| DL-5 | 144$^o$ |
| DL-7 | 158$^o$ |
| DL-8 | 139$^o$ |
| DL-9 | 114$^o$ |
| DL-10 | 080$^o$ |
| DL-11 | 120$^o$ |
| DL-36-37(1) | 153$^o$ |
| DL-36-37(2) | 170$^o$ |
| DL-36-37(3) | 244$^o$ |
| DL-36-37(4) | 254$^o$ |
| TD-M10 | 198$^o$ |
| TD-M11 | 144$^o$ |
| TD-M12 | 180$^o$ |
| TD-M13 | 190$^o$ |
| TDRB-2 | 096$^o$ |
| TDRB -5 | 144$^o$ |
| PDL-3 | 250$^o$ |
| PDL-5 | 273$^o$ |
| PDL-8 | 255$^o$ |

TABLE 3. DILIGENCIA FORMATION CONGLOMERATE CLAST COMPOSITIONS
(100 COUNTS/SAMPLE)

| SAMPLE | Granite | Gneiss | Amphibolite Metavolcanic | Other Plutonic | Other | TOTAL |
|---|---|---|---|---|---|---|
| DL-1 | 63 | 23 | 8 | 6 | 0 | 100 |
| DL-2 | 81 | 14 | 2 | 1 | 2 | 100 |
| DL-3 | 72 | 19 | 6 | 3 | 0 | 100 |
| DL-4 | 76 | 13 | 6 | 4 | 1 | 100 |
| DL-5 | 69 | 20 | 8 | 3 | 0 | 100 |
| DL-6 | 85 | 11 | 4 | 0 | 0 | 100 |
| DL-7 | 80 | 16 | 4 | 0 | 0 | 100 |
| DL-8 | 75 | 18 | 6 | 0 | 1 | 100 |
| DL-9 | 73 | 25 | 2 | 0 | 0 | 100 |
| DL-10 | 85 | 10 | 5 | 0 | 0 | 100 |
| DL-11 | 73 | 22 | 5 | 0 | 0 | 100 |
| DL-17 | 77 | 18 | 3 | 2 | 0 | 100 |
| DL-18 | 77 | 20 | 3 | 0 | 0 | 100 |
| DL-19 | 80 | 18 | 2 | 0 | 0 | 100 |
| DL-20 | 77 | 18 | 3 | 2 | 0 | 100 |
| DL-21 | 76 | 19 | 5 | 0 | 0 | 100 |
| DL-22 | 90 | 7 | 3 | 0 | 0 | 100 |
| DL-23 | 89 | 8 | 3 | 0 | 0 | 100 |
| DL-24 | 73 | 21 | 3 | 3 | 0 | 100 |
| DL-25 | 83 | 16 | 1 | 0 | 0 | 100 |
| DL-26 | 84 | 14 | 1 | 1 | 0 | 100 |
| DL-27 | 79 | 19 | 2 | 0 | 0 | 100 |
| DL-28A | 78 | 16 | 5 | 0 | 1 | 100 |
| DL-28B | 76 | 22 | 2 | 0 | 0 | 100 |
| DL-29 | 56 | 42 | 2 | 0 | 0 | 100 |
| DL-30 | 70 | 28 | 2 | 0 | 0 | 100 |
| DL-31 | 38 | 60 | 2 | 0 | 0 | 100 |
| DL-32 | 34 | 65 | 1 | 0 | 0 | 100 |
| DL-33 | 48 | 48 | 2 | 0 | 2 | 100 |
| DL-34 | 38 | 60 | 1 | 0 | 1 | 100 |
| DL-35 | 46 | 52 | 2 | 0 | 0 | 100 |
| DL-36 | 22 | 77 | 1 | 0 | 0 | 100 |
| DL-37 | 21 | 73 | 1 | 0 | 5 | 100 |
| PDL-3 | 86 | 4 | 1 | 8 | 1 | 100 |
| PDL-4 | 70 | 21 | 0 | 4 | 5 | 100 |
| PDL-6 | 47 | 12 | 0 | 41 | 0 | 100 |
| PDL-8 | 68 | 23 | 9 | 0 | 0 | 100 |
| TD-M9 | 73 | 22 | 5 | 0 | 0 | 100 |
| TD-M10 | 75 | 20 | 4 | 1 | 0 | 100 |
| TD-M11 | 73 | 20 | 4 | 2 | 1 | 100 |
| TD-M12 | 71 | 24 | 3 | 2 | 0 | 100 |
| TD-M13 | 73 | 21 | 2 | 4 | 0 | 100 |
| TDRB-1-2 | 68 | 27 | 5 | 0 | 0 | 100 |
| TDRB-5 | 68 | 28 | 4 | 0 | 0 | 100 |

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