# STUDIES OF BRAZILIAN METEORITES IV. ORIGIN OF A DARK-COLORED, UNEQUILIBRATED LITHIC FRAGMENT IN THE RIO NEGRO CHONDRITE

R. V. FODOR, K. KEIL and C. B. GOMES*

**ABSTRACT** A dark-colored lithic fragment, approximately 5 mm in diameter, in the Rio Negro, L 3-4 (gas-rich) chondrite, contains mineral fragments and a poikilitic chondrule, olivine ($Fa_{1-45}$), orthopyroxene ($Fs_{1-25}$), three high-Ca pyroxenes, an Fe-Mg silicate tentatively identified as a dehydrated layer-lattice silicate, glass, chromite, kamacite, taenite, and troilite. The fine-grained matrix of the fragment is responsible for its dark appearence. In the host chondrite, Fe-Mg silicates also vary in composition, but they cluster mainly in the L-group compositional range. Compared to the Rio Negro host, Fe/Mg ratios in olivine and low-Ca pyroxene of the fragment show less equilibration and indicate that the fragment is not simply shock-darkened or shock-melted host material, but a xenolith. Texture, bulk and mineral compositions of the fragment resemble those of unequilibrated ordinary chondrites and carbonaceous chondrites of type III, although some properties suggest a closer relationship to type III carbonaceous chondrites. It is concluded that the fragment was embedded into the Rio Negro host when the latter was part of a regolith on its parent body, and that the fragment originated from either coexisting rocks on the Rio Negro parent body or is the residue of infalling projectile material.

**RESUMO** Um fragmento lítico, de coloração escura e diâmetro aproximado de 5 mm, foi reconhecido no meteorito Rio Negro, Brasil, este um condrito rico em gás enquadrado dentro do tipo petrológico L 3-4. Esse material contém fragmentos minerais e um côndrulo poiquilítico, assim como olivina ($Fa_{1-45}$), ortopiroxênio ($Fs_{1-25}$), três tipos de piroxênio cálcico, um silicato ferromagnesiano tentativamente identificado como um filossilicato anidro, além de cromita, kamacita, taenita e troilita. A matriz, de granulação fina, do fragmento é responsável por sua coloração escura. No condrito hospedeiro, os silicatos de Fe-Mg mostram também composição química variável, conquanto esta esteja situada dentro do campo de variação estabelecido para o grupo L. Comparativamente ao hospedeiro, as razões Fe/Mg das olivinas e dos piroxênios pobres em cálcio do fragmento apresentam menor equilíbrio, a indicar que o fragmento não provém do material hospedeiro, escurecido ou fundido por um metamorfismo de choque, mas que corresponde em realidade a um xenólito. Feições texturais e composição química global e mineral do fragmento são semelhantes às exibidas pelos condritos comuns não-equilibrados e condritos carbonosos do tipo III, embora algumas propriedades sugiram uma associação mais estreita com os meteoritos carbonosos. Conclui-se que o fragmento foi incorporado ao material hospedeiro do Rio Negro quando este último fazia parte do regolito associado ao corpo parental; conclui-se, também, que o fragmento teria se originado a partir de rochas coexistentes no corpo parental do Rio Negro ou, como alternativa, que ele corresponderia ao produto residual de um projétil que se chocou contra o citado corpo.

**INTRODUCTION** True xenoliths in ordinary chondrites are relatively rare. Of hundreds of specimens examined (Fodor and Keil, 1973; Keil and Fodor, 1973), only a small number contain lithic fragments of compositions obviously unrelated to their host chondrites (*e.g.*, carbonaceous chondrite fragments in ordinary chondrite hosts). However, such fragments

Department of Geology and Institute of Meteoritics, University of New Mexico, Albuquerque, New Mexico 87131, USA

*Permanent address: Instituto de Geociências da Universidade de São Paulo, São Paulo, Brasil

are of considerable significance because they provide clues regarding the possible coexistence of meteorite types on their parent body and the complex processes which are responsible for the mixing of fragments of rocks of diverse origins.

The Rio Negro, Brazil, ordinary chondrite was noted in hand-specimen to contain a dark-colored lithic fragment, about 5 mm in size, clearly distinct on the basis of color from the host material. This paper presents a detailed microscopic and electron microprobe study of the lithic fragment and the Rio Negro host. The major objectives of this study are to classify the fragment and to decipher its origin, as well as to evaluate its significance regarding the origin and history of the Rio Negro, Brazil, chondrite and its parent body.

GENERAL DESCRIPTION The Rio Negro meteorite fell on September 22, 1934 at 20.30 hours in the State of Paraná, Brazil (49°48'W; 26°6'S) (Gatterer and Junkers, 1940). Attending the fall was a loud buzzing noise heard by local people. The mayor of Rio Negro, Mr. Ayres Rauen, visited the site of the fall at Voltagem (apparently a farm) and collected samples weighing slightly over 1 kilogram. The sample studied here was obtained on loan from the Museum of Natural History, Vienna, Austria.

The Rio Negro chondrite is composed of barred, radiating, and microporphyritic chondrules mainly consisting of olivine, low-Ca pyroxene (frequently twinned), and igneous glass. The chondrule margins are, in most cases, clearly discernible from a finer-grained matrix of mineral grains and fragments (Fig. 1a). Metal, troilite, and chromite are dispersed throughout the meteorite, and one grain each of high-Ca pyroxene and nepheline were located with the electron microprobe. Although the texture is highly chondritic, there is incipient integration (*i.e.* slight recrystallization) of matrix mineral grains and chondrules. The overall texture suggests that Rio Negro belongs to the petrographic class of type 3 transitional to type 4 of Van Schmus and Wood (1967); it was classified as such by those authors.

The lithic fragment contains an abundance of Fe-Mg silicate grains and fragments of olivine, orthopyroxene, and igneous glass that range in size from about 0.5 mm to dust size (Figs. 1b-d). The matrix of the fragment is opaque in transmitted light, due to its fine-grained and granular nature. Only one chondrule of substantial size (approximately 0.5 mm) is present and has a poikilitic texture of olivine in orthopyroxene (Fig. 1d).

MINERAL AND BULK COMPOSITIONS Mineral analyses were made with an ARL-EMX-SM electron microprobe using 15 keV accelerating voltage and about 0.02 $\mu$A sample current. Analyses were corrected according to the methods of Bence and Albee (1968). The bulk composition of the fragment was determined by using a broad electron beam (approximately 200 $\mu$m) following the techniques described by Prinz *et al.* (1971).

*Host* Olivine and low-Ca pyroxene in Rio Negro are variable in composition, but tend to cluster in the compositional range corresponding to the L-group on the basis of Fe/Fe + + Mg ratios (Fig. 2). Unfortunately, a bulk analysis of Rio Negro is not available and, thus, this classification is based on mineral composition only. As shown in Fig. 2, the variations in olivine and low-Ca pyroxene compositions are substantial, but are not as great as those observed in type 3 unequilibrated chondrites (Dodd *et al.*, 1967); this compositional range suggests that Rio Negro belongs to the petrographic class of type 4 of Van Schmus and Wood (1967) (compare with Dodd *et al.*, 1967). The CaO content of the low-Ca pyroxene ranges widely (Fig. 3), approaching values typical for pigeonite. The high-Ca pyroxene has a composition similar to that commonly found in ordinary chondrites (Tab. I; Fig. 3).

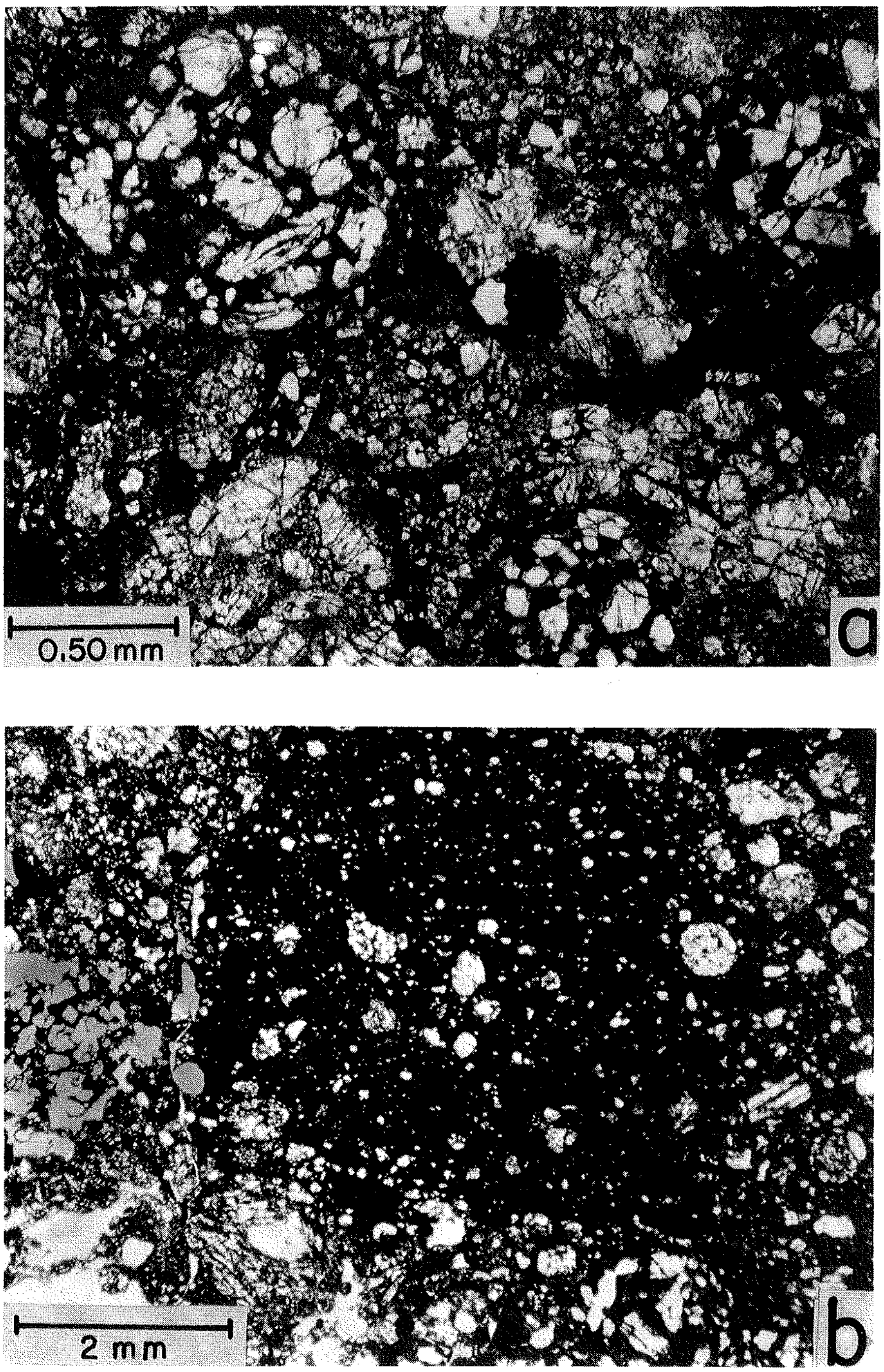
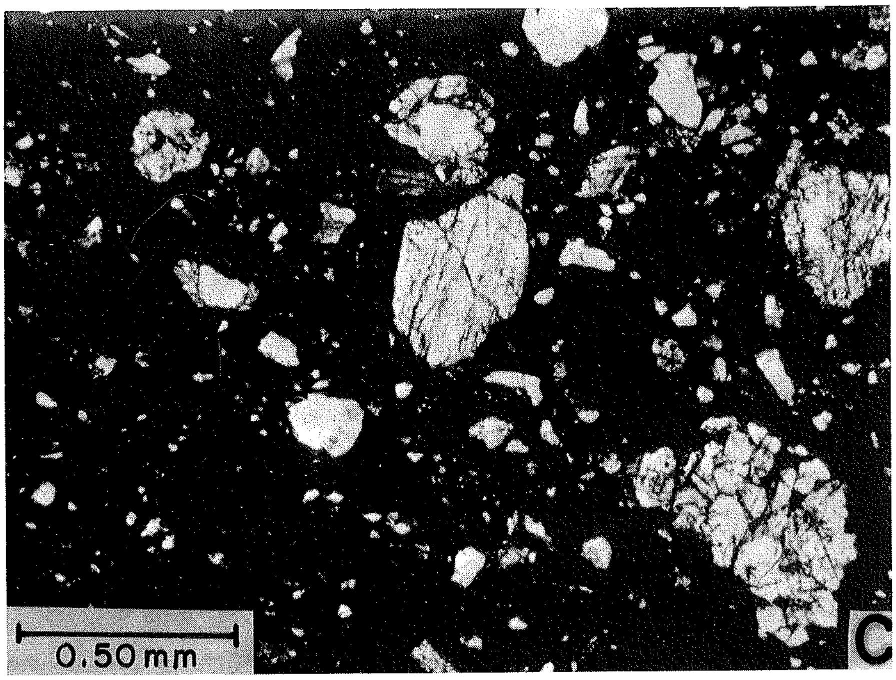
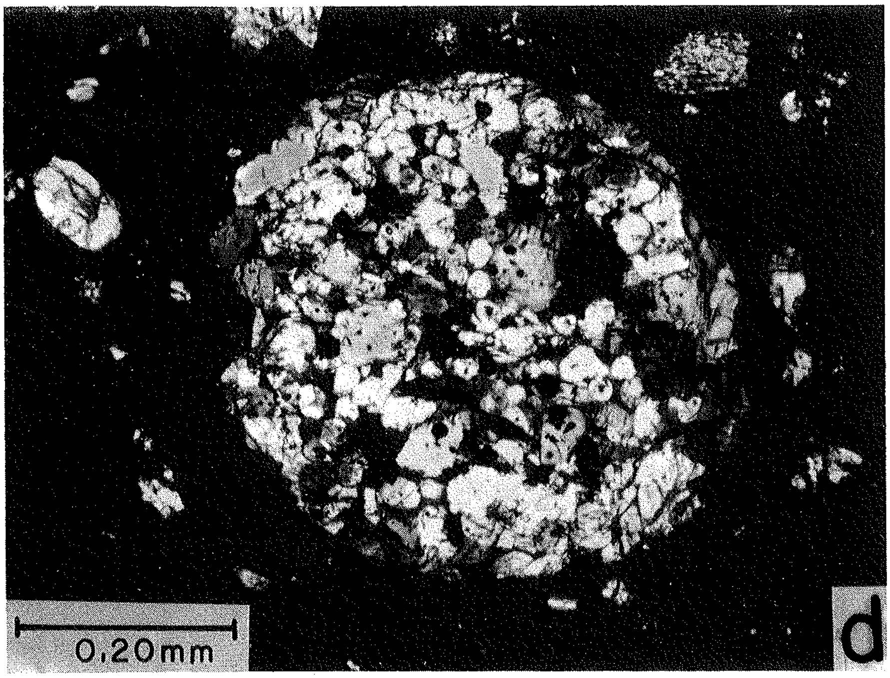



Figure 1 – a) Overview of the Rio Negro chondrite showing the pronounced chondritic texture and the surrounding matrix of Fe-Mg silicate grains; transmitted, plane polarized light. b) Subrounded, dark-colored lithic fragment in the Rio Negro, Brazil, L3-4 chondrite; transmitted, plane po-




larized light. c) Mineral grains and fragments in the opaque matrix of the lithic fragment shown in Fig. 1b; transmitted, plane polarized light. d) Poikilitic-textured chondrule consisting of olivine in orthopyroxene, in the lithic fragment shown in Fig. 1b; transmitted light, crossed nicols

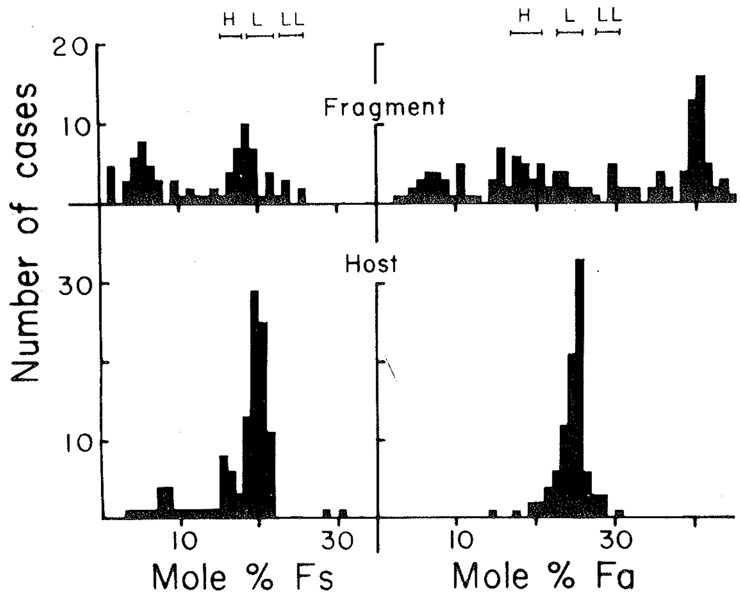



Figure 2 – Histogram illustrating the composition of low-Ca pyroxene and olivine in the Rio Negro host and lithic fragment, expressed as mole % end-members ferrosilite (Fs; $FeSiO_3$) and fayalite (Fa; $Fe_2SiO_4$). The compositional ranges are from Keil and Fredriksson (1964a), slightly modified according to Fodor *et al.* (1976; Fig. 2)

Glass in Rio Negro is dark-colored or dusty and is found mainly as interstitial and matrix material in olivine-and orthopyroxene-bearing chondrules. Glass compositions vary greatly in Ca/Na ratios and contain some FeO and MgO. Some glasses resemble feldspar in composition, although FeO and MgO are always too high for stoichiometric feldspar. The analysis of one nepheline grain, only a few microns in size, is also presented in Tab. II. Nepheline is virtually absent from ordinary chondrites, although glass of nepheline composition was previously reported from the Clovis, H3, chondrite (Noonan, 1975).

One type of spinel in Rio Negro is low in $Al_2O_3$ and is compositionally similar to the chromite typically found in L-group chondrites, although slightly lower in FeO and MgO (Tab. III) (Bunch *et al.*, 1967). Another type of spinel in Rio Negro is high in $Al_2O_3$ (Tab. III) and falls within the compositional range for spinels observed in the unequilibrated chondrites Gobabeb (Fudali and Noonan, 1975) and Mezo-Madaras (Hoinkes and Kurat, 1974). Small amounts of ZnO were observed in both types of spinel. For comparison, a check for ZnO in chromite was made in the equilibrated Plainview chondrite (Fodor and Keil, 1976a) and in a light-colored lithic fragment within Plainview (unpublished data) and was negative. Other opaque phases in Rio Negro are kamacite, taenite (Tab. IV), and troilite having less than 0.10 wt.% Ni.

*Lithic fragment* The bulk composition of the fragment, as determined by broad-beam electron microprobe techniques, has a low summation (Tab. V), mainly because of partial plucking of the surface during polishing, leaving a pitted surface, and possibly due to the presence of volatiles not detectable by electron microprobe techniques.

Olivine and pyroxene in the fragment are considerably more variable in composition than those phases in the host (Fig. 2). Whereas most individual low-Ca pyroxene grains

Table I — Representative compositions (in wt. %), as determined by electron microprobe techniques, for olivine (olv.), low-Ca pyroxene (opx), and high-Ca pyroxene (cpx), in the Rio Negro host chondrite and in the lithic fragment. Compositions are the averages of 10 to 25 spot analyses

| | HOST | | | | | | FRAGMENT | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | olv. | olv. | olv. | opx | opx | opx | olv. | olv. | olv. | opx | opx | cpx | cpx | cpx (range) | |
| $SiO_2$ | 39.1 | 38.1 | 38.8 | 57.0 | 56.0 | 56.0 | 39.1 | 38.7 | 36.5 | 58.2 | 55.6 | 52.0 | 47.6 | 48.0 | 44.3 |
| $TiO_2$ | .04 | .02 | .03 | .19 | .24 | .16 | .02 | .02 | .04 | .04 | .10 | .60 | 1.1 | .30 | 1.0 |
| $Al_2O_3$ | < .01 | < .01 | < .01 | .45 | .17 | .31 | < .01 | < .01 | .03 | .33 | .62 | 3.1 | 8.9 | 12.6 | 15.5 |
| $Cr_2O_3$ | .02 | .20 | .02 | .23 | .41 | .17 | .09 | .08 | .08 | .38 | .68 | .96 | .92 | .08 | .60 |
| FeO | 21.1 | 23.0 | 23.4 | 6.1 | 11.2 | 13.8 | 14.5 | 20.5 | 33.1 | 3.9 | 12.2 | 12.9 | 8.8 | 2.7 | 2.6 |
| MnO | .45 | .46 | .47 | .29 | .50 | .52 | .11 | .24 | .39 | .25 | .43 | .31 | .26 | .02 | .02 |
| MgO | 39.4 | 38.8 | 37.1 | 36.3 | 30.4 | 29.3 | 44.9 | 40.8 | 30.1 | 36.5 | 27.7 | 22.3 | 16.6 | 17.9 | 16.2 |
| CaO | .01 | .02 | .02 | .33 | 1.6 | .78 | .04 | .13 | .03 | .36 | 2.5 | 7.6 | 15.5 | 18.3 | 19.9 |
| $Na_2O$ | < .01 | < .01 | < .01 | .05 | .10 | .01 | < .01 | < .01 | < .01 | .06 | .04 | .01 | .01 | < .01 | .02 |
| Total | 100.12 | 100.60 | 99.84 | 100.94 | 100.62 | 101.05 | 98.76 | 100.47 | 100.27 | 100.02 | 99.87 | 99.78 | 99.69 | 99.90 | 100.14 |
| | Number of ions on the basis of 4 (O) for olivine; 6 (O) for pyroxene | | | | | | | | | | | | | | |
| Si | 1.009 | .990 | 1.015 | 1.952 | 1.976 | 1.982 | .993 | .993 | .999 | 1.986 | 1.988 | 1.903 | 1.756 | 1.721 | 1.602 |
| Al | --- | --- | --- | .018 | .007 | .013 | --- | --- | --- | .013 | .012 | .097 | .244 | .279 | .398 |
| Al | --- | --- | --- | --- | --- | --- | --- | --- | .001 | --- | .014 | .037 | .143 | .253 | .263 |
| Ti | .001 | --- | .001 | .005 | .006 | .004 | --- | --- | .001 | .001 | .003 | .017 | .031 | .008 | .027 |
| Cr | --- | .004 | --- | .006 | .011 | .005 | .002 | .002 | .002 | .010 | .019 | .028 | .027 | .002 | .017 |
| Fe | .455 | .500 | .512 | .175 | .330 | .409 | .308 | .440 | .758 | .111 | .365 | .395 | .272 | .081 | .079 |
| Mn | .010 | .010 | .010 | .008 | .015 | .016 | .002 | .005 | .009 | .007 | .013 | .010 | .008 | .001 | .001 |
| Mg | 1.515 | 1.503 | 1.446 | 1.853 | 1.599 | 1.546 | 1.699 | 1.561 | 1.228 | 1.857 | 1.476 | 1.216 | .913 | .956 | .873 |
| Ca | --- | .001 | .001 | .012 | .060 | .030 | .001 | .004 | .001 | .013 | .096 | .298 | .613 | .703 | .771 |
| Na | --- | --- | --- | .003 | .007 | .001 | --- | --- | --- | .004 | .003 | .001 | .001 | --- | .001 |
| Z | 1.009 | .900 | 1.015 | 1.970 | 1.983 | 1.995 | .993 | .093 | .999 | 1.999 | 2.000 | 2.000 | 2.000 | 2.000 | 2.000 |
| X | 1.981 | 2.018 | 1.970 | 2.062 | 2.028 | 2.011 | 2.012 | 2.912 | 2.000 | 2.003 | 1.989 | 2.002 | 2.008 | 2.004 | 2.032 |
| Sum | 2.990 | 3.008 | 2.985 | 4.032 | 4.011 | 4.006 | 3.005 | 3.005 | 2.999 | 4.002 | 3.989 | 4.002 | 4.008 | 4.004 | 4.032 |
| | Molecular End Members | | | | | | | | | | | | | | |
| Fs (Fa) | 23.1 | 25.0 | 26.1 | 8.6 | 16.6 | 20.6 | 15.3 | 22.0 | 38.2 | 5.6 | 18.8 | 20.1 | 15.1 | 4.7 | 4.6 |
| En (Fo) | 76.9 | 75.0 | 73.9 | 90.8 | 80.4 | 77.9 | 84.7 | 78.0 | 61.8 | 93.7 | 76.2 | 64.7 | 50.8 | 54.9 | 50.7 |
| Wo | -- | -- | -- | .6 | 3.0 | 1.5 | -- | -- | -- | .7 | 5.0 | 15.2 | 34.1 | 40.4 | 44.7 |

are rather homogeneous with respect to Fe/Mg, olivines show large within-grain variations. Typical compositions of low-, moderate-, and high-Fe olivine and orthopyroxene are presented in Tab. I and, as shown there and in Fig. 2, much of the olivine is far richer in Fe content ($Fa_{40}$) than olivine normally found in chondrites. It was noted that 80% of the small groundmass grains have fayalite contents greater than 30 mole percent. In contrast, 75% of the large olivine occurring in fragments of chondrules within the fragment have fayalite contents less than 30 mole percent.

Calcium is highly variable in the low-Ca pyroxene, ranging from 0.25 up to 2.5 wt. % CaO (Fig. 3). Three grains of high-Ca pyroxene were observed; all are high in $Al_2O_3$, but on the basis of FeO, CaO, and MgO contents they resemble diopside, augite, and pigeonite, respectively (Tab. I; Fig. 3).

Another type of Fe-Mg silicate was observed in the fragment as discrete, low-birefringent grains having somewhat platy texture. Microscopically, this phase resembles some of the low-birefringent, Fe-Mg serpentine-like phases described from Plainview (Fodor and Keil, 1976a) and Abbott (Fodor *et al.*, 1976). Its composition (Tab. VI) does not resemble any common stoichiometric meteoritic phases, and on the basis of the sum of FeO, MgO, and CaO, it falls between that for olivine (usually about 60 wt.%) and pyroxene (about 42 wt.%). Accordingly, the structural formula on the basis of 0 = 4 shows a deficiency of octahedral-site cations, $X_{1.5}\ Si_{1.2}\ O_4$, and when calculated on 0 = 6, it shows an abundance of octahedral-site cations, $X_{2.3}\ Si_{1.9}\ O_6$. Compositionally, it resembles most closely the Fe-rich dehydrated serpentine-like phases reported in carbonaceous chondrite type II lithic fragments from ordinary chondrites (*e.g.* Fodor *et al.*, 1976), although a marked difference is noted in the $SiO_2$ contents (Tab. VI).

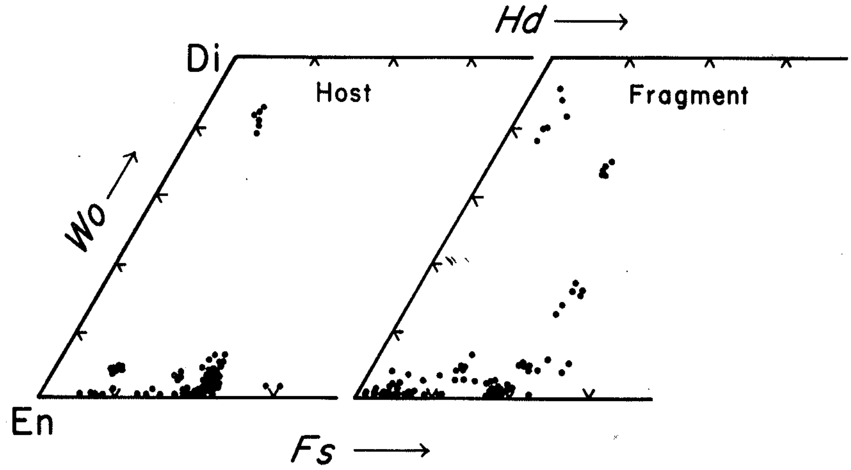



Figure 3 – Partial pyroxene quadrilaterals illustrating pyroxene compositions in the Rio Negro host and lithic fragment, expressed as mole % end-members enstatite (En; $MgSiO_3$), ferrosilite (Fs; $FeSiO_3$), and wollastonite (Wo; $CaSiO_3$), Di stands for diopside, (Ca, Mg) $SiO_3$, and Hd for hedenbergite, (Ca, Fe) $SiO_3$. Each point represents one electron microprobe spot analysis

The glass varies in composition, some grains being calcic, others sodic. Although some grains somewhat resemble feldspar in composition, the FeO and MgO contents are always too high for stoichiometric feldspar (Tab. II).

Table II – Representative compositions (in wt. %), obtained by electron microprobe techniques, and CIPW norms of glass in the Rio Negro host (cols. 1-4) and in the lithic fragment (cols. 6-8), and nepheline in the host (col. 5). For nepheline, a structural formula is presented (0 = 32)

| | HOST | | | | | | FRAGMENT | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | | 5 | 6* | 7 | 8 |
| $SiO_2$ | 57.7 | 57.6 | 64.0 | 67.2 | | 41.8 | 45.1 | 52.3 | 61.7 |
| $Al_2O_3$ | 7.5 | 21.3 | 20.7 | 19.5 | | 31.4 | 31.9 | 26.5 | 20.1 |
| FeO | 5.0 | 2.5 | 1.8 | 0.98 | | 0.81 | 1.6 | 2.5 | 2.0 |
| MgO | 10.2 | 5.2 | 3.0 | 1.8 | | 0.80 | 1.4 | 4.3 | 0.25 |
| CaO | 13.5 | 8.9 | 2.8 | 1.8 | | 2.0 | 15.7 | 8.3 | 2.9 |
| $Na_2O$ | 4.4 | 5.5 | 8.5 | 9.7 | | 16.8 | 3.3 | 4.5 | 9.4 |
| $K_2O$ | 0.55 | 0.86 | 0.94 | 0.90 | | 5.6 | 0.24 | 0.60 | 1.2 |
| Total | 98.65 | 101.86 | 101.74 | 101.88 | | 99.21 | 99.24 | 99.00 | 97.55 |
| q | — | — | — | 0.34 | Si | 8.207 | — | — | — |
| or | 3.21 | 4.82 | 5.21 | 4.97 | Al | 7.266 | 1.40 | 3.47 | 6.94 |
| ab | 35.07 | 46.31 | 71.62 | 81.36 | Fe | 0.133 | 7.11 | 39.51 | 73.03 |
| an | — | 29.30 | 13.04 | 6.55 | Mg | 0.234 | 70.43 | 40.27 | 8.92 |
| ne | 1.29 | 0.31 | — | — | Ca | 0.421 | 13.24 | — | 5.75 |
| di | 52.92 | 10.06 | — | 1.44 | Na | 6.395 | 5.01 | — | 4.13 |
| hy | — | — | 6.88 | 5.34 | K | 1.403 | — | 6.51 | — |
| ol | 6.61 | 9.19 | 2.63 | — | | | 2.80 | 6.66 | 1.23 |
| ac | .90 | — | — | — | Z | 15.473 | — | — | — |
| c | — | — | 0.62 | — | X | 8.586 | — | 3.58 | — |
| | | | | | Sum | 24.059 | | | |

*from a poikilitic fragment within the lithic fragment

Chromite in the lithic fragment is compositionally similar to chromite observed in the host (Tab. III), but slightly higher in FeO and lower in $Al_2O_3$. Other opaque phases in the fragment are kamacite, taenite, and troilite (less than 0.10 wt. % Ni). The Ni and Co contents in the metal are presented in Tab. IV. In taenite, the Co content clearly increases with increasing Fe content. In mixed taenite-kamacite grains, Ni is lower and Co higher than in similar mixed-grains of the host (Tab. IV).

A search in the fragment by microprobe failed to locate any Ca-Al-(Ti)-rich phases or Na-rich phases other than the glasses listed in Tab. II.

A detailed analysis was made of a chondrule and an irregular fragment within the lithic fragment, both of which have poikilitic textures of olivine within low-Ca pyroxene (Fig. 1d). Olivine in the chondrule ranges from $Fa_{4-29}$, whereas the pyroxene is enstatite and has a limited compositional range of $Fs_{1.5-3}$. The irregular fragment has olivine $Fa_{24-32}$ within pyroxene of $Fs_{17-22}$. In each, glass resembling bytownite is present (Tab. II).

**DISCUSSION** One major objective of this paper is to understand the origin of the lithic fragment, *i.e.* to show whether it is a xenolith (*e.g.*, a fragment of a known or heretofore unknown meteorite type unrelated to the Rio Negro host meteorite), or whether it is related to the host (or host-like material) and formed from it, for example, by shock darkening, shock melting, etc. (Fodor *et al.*, 1972, 1976; Keil and Fodor, 1973; Fodor and Keil, 1973, 1976a, b). That the fragment did not form by shock darkening of the host is evident from the mineral compositions of the fragment as compared to those of the host. Although both host and fragment are unequilibrated (*i.e.*, both have variable Fe/Fe + Mg within and between mafic silicate grains), the compositional variations are much greater in the lithic fragment than in the host. Also, the presence of poikilitic fragments and chondrules and apparently dehydrated layer-lattice silicates in the lithic fragment and not in the host supports this conclusion. Furthermore, shock-melting of Rio Negro host-type material cannot account for the texture of the lithic fragment. The fragment is a breccia in itself,

Table III – Average compositions (in wt. %), as obtained by electron microprobe techniques, of chromite in the Rio Negro host and lithic fragment. Each composition is the average of 5 to 10 spot analyses per grain

| | HOST | | FRAGMENT |
|---|---|---|---|
| $SiO_2$ | .49 | .44 | .77 |
| $TiO_2$ | 2.1 | .95 | 1.8 |
| $Al_2O_3$ | 4.7 | 22.4 | 1.7 |
| $Cr_2O_3$ | 56.7 | 40.3 | 58.5 |
| $V_2O_3$ | .74 | .26 | .83 |
| FeO | 30.6 | 25.6 | 31.4 |
| MnO | .93 | .56 | .57 |
| MgO | 2.8 | 7.9 | 2.2 |
| CaO | .07 | .09 | .37 |
| ZnO | .02 | .15 | .09 |
| Total | 99.15 | 98.65 | 98.23 |
| Number of ions on the basis of 32 (O) | | | |
| Si | .141 | .114 | .228 |
| Ti | .454 | .185 | .401 |
| Al | 1.594 | 6.819 | .593 |
| $Fe^{+2}$ | .743 | .597 | .890 |
| Cr | 12.898 | 8.231 | 13.691 |
| V | .170 | .054 | .197 |
| $Fe^{+2}$ | 6.619 | 4,933 | 6.882 |
| Mn | .227 | .123 | .143 |
| Mg | 1.201 | 3.042 | .971 |
| Ca | .022 | .025 | .117 |
| Zn | .004 | .028 | .020 |
| X | 16.000 | 16.000 | 16.000 |
| Z | 8.073 | 8.151 | 8.133 |
| Sum | 24.073 | 24.151 | 24.133 |

Table IV – Compositional ranges (in wt. %), as obtained by electron microprobe techniques, of Co and Ni in individual grains of kamacite ($\alpha$) and taenite ($\gamma$) and grains consisting of both kamacite and taenite in the Rio Negro fragment and host, and in C3 chondrites (Fuchs and Olsen, 1973). Numbers in parentheses indicate the number of grains analyzed

| | $\alpha$ | $\gamma$ | mixed $\alpha$ | mixed $\gamma$ |
|---|---|---|---|---|
| FRAGMENT | (1) | (9) | (3) | |
| Co | 1.2 -1.4 | .18- .78 | 1.0 -1.3 | .23-1.0 |
| Ni | 5-6 | 24-27 | 5-6 | 20-39 |
| HOST | (1) | (6) | (3) | |
| Co | .83- .91 | .22- .90 | .77- .91 | .11- .27 |
| Ni | 4.5 -6.5 | 14-47 | 4-5 | 46-49 |
| C3 | | | | |
| Co | .4 -1.5 | 1.6 -2.5 | .59-1.3 | .12- .98 |
| Ni | 4.5 -6.2 | 61-66 | 3.3 -6 | 37-50 |

consisting of chondrules and mineral fragments in a fine-grained, dark matrix. Thus, shock melting cannot account for this texture and it is concluded that the dark lithic fragment must be a xenolith. The problem of the parent rock of the fragment thus remains, and a comparison of textures, bulk and mineral compositions of the fragment to known stone meteorite types might assist in deciphering its source.

The fragment, which consists of silicate grains and chondrules in an opaque, fine-grained matrix, is compatible in texture with either a fragment of an unequilibrated ordinary chondrite or a type II or III carbonaceous chondrite. However, it lacks the light-colored inclusions with its Ca-Al-rich mineral assemblages common to many of the carbonaceous chondrites of type III, although the small size of the fragment may preclude a valid comparison. Furthermore, the poikilitic material of olivine enclosed by pyroxene is known from both type III carbonaceous chondrites (Isna; Methot *et al.*, 1975) and unequilibrated ordinary chondrites (Ngawi; Fodor and Keil, 1975) and, thus, its occurrence in the lithic fragment does not allow one to conclude as to the parentage of the lithic fragment. The bulk composition of the fragment, as determined by broad-beam electron microprobe techniques, is in general similar to the compositions of unequilibrated L3- and H3- group chondrites and carbonaceous chondrites of types II and III (Tab. V). However, in spite of these similarities, unambiguous assignment of the fragment to any one of these meteorite groups cannot be made, because there is considerable compositional overlap between these groups, particularly when analyses are calculated on an $H_2O$-, C-, and organic material-free basis, and because broad-beam electron microprobe analyses of porous lithic fragments are not sufficiently accurate. However, it is clear that bulk compositional similarities exist between the lithic fragment and these meteorite groups, although certain oxides and elements are consistently in disagreement (*e.g.* $Al_2O_3$ is appreciably higher and S is appreciably lower in the fragment than in these meteorite groups). Thus, the bulk composition of the fragment, although indicating relationships to L3, H3, and

Table V — Bulk compositions, as obtained by broad-beam electron microprobe techniques (recalculated with all Fe as FeO) of the Rio Negro lithic fragment (col. 1), recalculated to 100% (col. 2); L- and H- group unequilibrated ordinary chondrites (cols 3, 4, respectively; averages and ranges); the Isna type III carbonaceous chondrite (col. 5); a partial average analysis and ranges for type III carbonaceous chondrites (col. 6), and the average composition of carbonaceous chondrites of type III, with all Fe as FeO, and recalculated on an $H_2O$-, C-, and organic material-free basis (col. 7)

| | 1 | 2 | 3 | | 4 | | 5 | 6 | | 7 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 36.0 | 37.4 | 38.8 | (37.7-40.8) | 34.7 | (34.6-36.6) | 34.0 | 33.7 | (31.9-34.9) | 32.5 |
| $TiO_2$ | .12 | .13 | .15 | | .12 | | .13 | * | | .12 |
| $Al_2O_3$ | 3.8 | 4.0 | 2.25 | ( 1.6- 2.9) | 2.31 | ( 1.9- 2.5) | 2.75 | * | | 2.75 |
| $Cr_2O_3$ | .48 | .50 | .43 | | .34 | | .47 | * | | .47 |
| FeO | 29.1 | 30.5 | 27.3 | (24.2-27.7) | 33.7 | (30.5-33.5) | 32.3 | 31.6 | (28.7-34.4) | 32.2 |
| MnO | .28 | .29 | .26 | | .24 | | .23 | * | | .20 |
| MgO | 21.2 | 22.0 | 24.3 | (23.5-27.7) | 22.3 | (22.0-23.1) | 23.8 | 24.2 | (22.1-25.3) | 22.6 |
| CaO | 1.8 | 1.9 | 1.85 | ( 1.5- 3.1) | 1.70 | ( 1.4- 2.6) | 2.16 | * | | 2.42 |
| $Na_2O$ | .63 | .65 | .86 | ( .60- 1.4) | .81 | ( .6- .9) | .75 | * | | .64 |
| $K_2O$ | .16 | .17 | .14 | | .13 | | .06 | * | | .06 |
| $P_2O_5$ | .25 | .26 | .25 | | .22 | | .20 | * | | .32 |
| S | 1.2 | 1.3 | 2.19 | | 1.85 | | 1.66 | * | | 3.72 |
| Ni | .86 | .90 | 1.09 | | 1.58 | | 1.52 | * | | 1.86 |
| Co | - | - | .06 | | .09 | | .07 | * | | * |
| Total | 95.88 | 100.00 | 99.93 | | 100.09 | | 100.10 | | | 99.86 |

col. 1 broad beam electron microprobe analysis
cols. 3, 4 after Dodd et al. (1967)
col. 5 after Methot et al. (1975)
col. 6 after Mason (1971)
col. 7 after Keil (1969).
* not determined.

carbonaceous chondrites of types II and III, suggest that the fragment may be unique and may represent a heretofore unknown meteorite type or a modified (*e.g.*, devolatilized) known meteorite type.

Analogously, similarities exist in the compositions of minerals in the lithic fragment and unequilibrated L3- and H3- group ordinary chondrites and type III carbonaceous chondrites. However, type II carbonaceous chondrites can almost certainly be ruled out as the source of the lithic fragment on the basis of low ($< 0.10\%$) Ni in troilite and the relatively FeO-rich olivines and pyroxenes (note that troilite in type II carbonaceous chondrites ranges in Ni up to $\sim 19\%$ and that most olivines and pyroxenes are FeO-poor; Keil and Fredriksson, 1964b). However, distinction between a source from L3- and H3- group ordinary chondrites on the one hand, and carbonaceous chondrites of type III on the other, is more difficult. For example, Ca-rich glass resembling plagioclase (*e.g.* Hutchison and Graham, 1975; Kurat, 1970, Methot *et al*, 1975), metallic nickel-iron (Tab. IV), and Ca-rich pyroxene are found in unequilibrated ordinary chondrites as well as carbonaceous chondrites of type III and do not show characteristic differences. However, Fe/Fe + + Mg ratios in olivine and pyroxene vary widely in unequilibrated ordinary chondrites and carbonaceous chondrites of type III (*e.g.* Dodd *et al.*, 1967; Van Schmus, 1969; Kurat, 1975; Methot *et al.*, 1975), and these ratios show a preponderance of occurrences near $Fa_{40}$ for the Isna (Methot *et al.*, 1975) and Warrenton (Van Schmus, 1969) type III carbonaceous chondrites. A similar preponderance is observed for olivine compositions in the lithic fragment of Rio Negro (Fig. 2), but is not observed for unequilibrated ordinary chondrites. Thus, it appears that the lithic fragment more closely resembles type III carbonaceous chondrites than unequilibrated ordinary chondrites.

In summary, therefore, it may be said that the dark-colored lithic fragment in Rio Negro is a xenolith of either unequilibrated chondrite or carbonaceous chondrite type III

Table VI – Average compositions (in wt. %), as obtained by electron microprobe techniques, of two Fe-Mg silicate grains in the lithic fragment in the Rio Negro chondrite (cols. 1, 2), compared to the matrix composition of an anhydrous type II carbonaceous chondrite lithic fragment in the Plainview, Texas, chondrite (col. 3; Fodor and Keil, 1976a). Compositions of cols. 1, 2 are averages of 10 spot analyses

| | 1 | 2 | 3 |
|---|---|---|---|
| $SiO_2$ | 48.5 | 49.5 | 43.1 |
| $TiO_2$ | .04 | .01 | .14 |
| $Al_2O_3$ | .28 | .21 | 3.6 |
| $Cr_2O_3$ | .43 | .43 | .41 |
| FeO | 22.8 | 23.0 | 22.3 |
| MnO | .35 | .38 | .25 |
| MgO | 24.8 | 25.4 | 25.7 |
| CaO | 3.1 | 1.5 | .68 |
| $Na_2O$ | .22 | .19 | .71 |
| $K_2O$ | .05 | .03 | .36 |
| $P_2O_5$ | .07 | .03 | .10 |
| Ni | n.d. | n.d. | 1.3 |
| S | n.d. | n.d. | .85 |
| Total | 100.64 | 100.68 | 99.50 |

n.d. = not determined

parentage. There are some indications suggesting a closer relationship to carbonaceous chondrites of type III than to unequilibrated ordinary chondrites, but these are not unambiguous. The source area of the fragment, *i.e.* whether it represents a rock type that coexisted on the same parent body with the Rio Negro host material, or whether it is the residue of a projectile impacting the Rio Negro parent body, is difficult to ascertain. It is clear, however, that the fragment was implanted into the Rio Negro host by impact processes (either from the same parent body or as a projectile from a different source), and that it once was part of the regolith that covered the Rio Negro parent body, as is indicated by the presence of solar-type rare gases in the Rio Negro host (Wasson, 1974, p. 104).

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