UNIVERSIDADE DE SÃO PAULO
FACULDADE DE FILOSOFIA, CIÊNCIAS E LETRAS

Boletim 146 | Geologia n. 9

JOHN LYON RICH

University of Cincinnati; visiting Professor of the Department of Geology and Paleontology of the Faculdade de Filosofia, Ciências e Letras, University of São Paulo

PROBLEMS IN BRAZILIAN GEOLOGY AND GEOMORPHOLOGY SUGGESTED BY RECONNAISSANCE IN SUMMER OF 1951

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SÃO PAULO — BRASIL
1953

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All correspondence should be addressed to the Department concerned. Caixa Postal 8.105, São Paulo, Brasil.

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A) RESUMO

Numa excursão à parte central do estado de São Paulo, chamaram-nos a atenção diversos problemas interessantes que suscitam estudos ulteriores.

Entre Itú e Salto de Itú, um patamar de granito pouco alterado, com forma de terraço, sugere que uma antiga superfície dessa rocha, de relêvo suave, houvesse sido recoberta por rochas sedimentares pouco resistentes de idade permo-carbonífera. Removidas, recentemente, pela erosão, puseram à mostra o granito mais resistente.

Varvitos expostos nas pedreiras a oeste de Itú revelam caracteres esclarecedores não só do problema da origem dêsses sedimentos, como da direção de sua proveniência. A sua estratificação fina indica deposição em águas paradas. Estratificação cruzada de corrente, em pequena escala, e a singular superposição de "ripples" cujas cristas migraram lentamente no decorrer da deposição, sugerem movimento lento da água para oeste-noroeste. Os caracteres em conjunto indicam que a deposição teve lugar num fundo de declividade muito suave, provàvelmente próximo à frente de uma "foreset" de tipo deltaico, sujeita aos efeitos de corrente de densidades que se esvanecem nas águas paradas ao atingirem o pé da rampa da "foreset" Tais condições evocam, ainda que não necessàriamente, a sua associação à glaciação.

Uma visita aos afloramentos da formação Iratí nas proximidades de Assistência, ao sul de Rio Claro, trouxe à consideração os seguintes problemas: (1) o ambiente de sua deposição que parece corresponder ao de uma bacia fechada, cuja água ter-se-ia tornado tóxica pela falta de aeração; (2) a origem e extensão do seu conglomerato basal, quer corresponda êste a um depósito fluvial ou a um conglomerato de transgressão; (3) as possibilidades da formação Iratí como rocha mater de petróleo. O fato do óleo encontrado nos afloramentos ser pesado não implica em que o óleo no fundo da bacia também o seja, pois processos químicos associados a águas portadoras de oxigênio ou sulfatos, geralmente alteram o óleo originalmente leve em óleo pesado nos afloramentos. As possibilidades da formação Iratí como camada geradora de petróleo parecem excelentes.

Consideram-se sumàriamente certos aspectos da geomorfologia do centro de São Paulo. O nível geral do planalto entre 700 e 800 m indica um peneplano relativamente recente a êsse nível. Outras possíveis superfícies de erosão são mencionadas: uma no tôpo das mesas de lava, e outra abaixo dos sedimentos permo-carboníferos nas proximidades de Itú e Sorocaba. O fato dos maiores rios não terem ainda regularizado o seu perfil onde atravessam sills de rochas resistentes, sugere um levantamento inclinado da região. Ao longo da rodovia entre Indaiatuba e Campinas, a topografia observada indica falhamento em bloco; o problema é se o falhamento ocorreu antes ou depois da deposição dos sedimentos permo-carboníferos.

A oeste de Sorocaba, pedreiras recentemente abertas em arenito, cujo aspecto assemelha-se ao do arenito Furnas (Faxina) merecem investigação, com o fito de verificar a possibilidade da extensão da área conhecida recoberta por arenito devoniano.

Uma excursão à região de Juquiá-Iguape-Xiririca revelou um "rock terrace" extenso e maturamente dissecado, ocupando uma área considerável adjacente ao baixo curso do Ribeira de Iguape (bem vizível ao longo da rodovia de Registro a Pariquera-Açú) e ao longo do rio Juquiá, de Registro até acima de Juquiá.

Nas partes elevadas dos cortes da rodovia entre Registro e Pariquera-Açú, onde êstes atingem os divisores locais, verificam-se numerosos tratos remanescentes de seixos trabalhados pela água. Indicam que toda a área do terraço, agora maturamente dissecado, com um relêvo de 50m ou mais, foi incrustada com cascalho depositado seja por rios de largos meandros ou, menos provàvelmente, no mar — em qualquer dos casos numa época em que o mar se achava mais elevado.

Aluvionamento recente nas cabeceiras dos rios, verificado tanto ao longo da rodovia de Pariquera-Açú a Xiririca, como em muitos outros pontos do planalto em São Paulo, etc., constitui um problema para o qual ainda não se obteve solução satisfatória. Teria sido causado por mudança climática, por erosão consequente ao desflorestamento ou por outro processo não precisado?

Os problemas surgidos na excursão ao Paraná referem-se, principalmente, à possível existência de tilito sob o arenito Furnas; de erráticos glaciais neste último arenito; ao arenito Barreiro; a origem do arenito de Vila Velha; ao elevado teor de silte verificado no sedimento glacial mais recente e no post-glacial do Paraná; e a vários aspectos da fisiografia.

Na rodovia entre Castro e Tibagi, observou-se um sedimento (prèviamente descrito por Maack), tendo toda a aparência de tilito, sob um arenito que parece corresponder ao arenito Furnas. De acordo com o que verifiquei, a rocha só pode corresponder a um tilito. Tudo parece indicar que o arenito sobrejacente seja Furnas, mas não se deve menosprezar a sugestão de que se trate do arenito Itararé, tendo-se em vista a brevidade da nossa visita. O problema só será cabalmente resolvido com a observação cuidadosa da sua continuidade até os locais em que se sabe ocorrer o arenito Furnas.

Nas proximidades de Tibagí, tanto na barranca do rio a este da cidade, como nos cortes frescos da rodovia para Castro, ocorrem no arenito Furnas grandes seixos e blocos erráticos esparsos, como se tivessem sido desprendidos de gelos flutuantes e não sido transportados por correntes ordinárias de fundo. Sua presença sugere que o gelo flutuava no mar durante a deposição do arenito Furnas.

O arenito Barreiro, exposto no alto das elevações, a oeste de Tibagí, contém, igualmente, numerosos blocos erráticos, alguns deles medindo mais de meio metro, distribuidos também, como se tivessem caido de gelos flutuantes.

A estratificação e certas estruturas do tipo de barra no arenito Barreiro sugerem deposição em águas que se abriam para oeste, sob a influência de fortes vagas. Se tais águas eram marinhas ou lacustres foge à determinação. Semelhanças gerais entre os arenitos Barreiro e Furnas e a presença em ambos de prováveis erráticos transportados por gelo, indicam que ambos poderiam ser devonianos e depositados em águas sujeitas a gelos flutuantes.

A origem do famoso arenito de Vila Velha representa um problema interessante. Sugere-se aquí que o mesmo corresponde a uma forma particular de tilito, resultante de areias intemperisadas e, em parte, retrabalhadas pelo vento, as quais jaziam sobre a superfície do afloramento do arenito Furnas quando do avanço do gelo, tendo sido colhidas e incorporadas por êste. Tal explicação parece a mais aceitável para conciliar a ocorrência de singulares juntas de contração e a ausência generalizada de estratificação caracteristica de Vila Velha.

Outro aspecto notado na excursão ao Paraná foi o alto teor de silte dos sedimentos glaciais e post-glaciais aquosos. Alguns deles, que apresentam fósseis marinhos, têm o aspecto de loess depositados na água. Aventamos a possibilidade de que sejam de origem loessica, em parte depositados diretamente na água e em parte depositados primeiramente em terra, em seguida retrabalhados por correntes, e finalmente transportados para o mar ou outra massa de água.

Entre os caracteres fisiográficos importantes discutidos neste trabalho, estão o arredondamento dos topos das elevações; a inversão da topografia, graças ao que, antigos depósitos de correntes passaram a ocupar os topos das elevações atuais; a abundância de afundamentos (sink holes) no arenito Furnas; e a presença de topografia semicárstica nas lavas da região de Guarapuava, provàvelmente resultante de drenagem subterrânea originada da alta permeabilidade das corridas de lava.

Os problemas surgidos durante uma excursão de São Paulo até Itatiaia, Petrópolis, Nova Friburgo e Rio de Janeiro, referem-se à possível glaciação no Itatiaia; aos sedimentos nas bacias de São Paulo e do Paraiba; a um vale desajustado a este de Mogí das Cruzes; à origem das montanhas-domo "graníticas" e à possível origem de alguns dos xistos no Complexo Cristalino do planalto.

Ao observador familiarizado com os efeitos das geleiras em terrenos graníticos, todos os caracteres da região elevada circunvizinha ao Itatiaia sugere fortemente glaciação. Vales com as encostas sulcadas, bacias rochosas com pequenos lagos, vales em forma de U, a condição de "limpeza" do vale a noroeste do monte Itatiaia, e a ausência de um manto de intemperismo sôbre a rocha intrusiva de granulação grosseira, tudo corresponde ao que se poderia esperar se uma glaciação intensa houvesse afetado o topo da montanha e nada evocando uma erosão normal.

O exame dos sedimentos das bacias de São Paulo e do Paraiba dá-nos a impressão de que tais bacias na época da deposição, não eram marginados por montanhas como presentemente. Sedimentos do tipo de depósitos originados em uma larga planície aluvionar por meandros vagarosos drenando uma região de relêvo suave, podem ser hoje encontrados próximos às bases das montanhas limítrofes. As condições sugerem que os sedimentos em questão foram depositados ou em uma larga planície aluvionar que cobria uma extensão maior que as bacias atuais, ou em depressões rasas, que mais tarde, em virtude de afundamento por falhas, tomaram a posição atual.

Na rodovia Rio de Janeiro-São Paulo, alguns quilómetros a oeste de Campo Belo, pouco antes de atingir o rio Paraiba, ocorrem sedimentos com a aparência de tilito. Tendo-se em vista as secções de De Martonne interessando as vizinhanças, nas quais se vêm tratos abatidos por falhas, lembra-se aqui a conveniência de um estudo sôbre êsses sedimentos com o fito de averiguar a possibilidade de representarem um bloco de tilito permo-carbonífero abatido na fossa do Paraíba e aí protegido da erosão até hoje.

Num voo do Rio de Janeiro a São Paulo, seguimos um vale extenso e antigo, de fundo plano, entre Paraibuna e Mogi das Cruzes. O vale apresenta tão só um pequeno rio com um sistema de meandros muito complexo e que parece ser desajustado (underfit), isto é, pequeno demais para o vale que ocupa. Corresponderia esta região à cabeceira do sistema do Tietê antes da captura pela drenagem que conduz ao Paraíba?

A origem das montanhas-domo na região de Petrópolis, Nova Friburgo e Rio de Janeiro tem sido muito discutida. A hipótese aqui aventada é de que apesar de tais domos não serem exclusivos de climas tropicais, podem ter resultado da erosão num tipo especial de rocha. Quero crer que tais domos se desenvolvessem, sem exceção, em rochas de granulação grosseira, de textura granítica (mas não necessàriamente granito magmático), essencialmente desprovidos de juntas, que pudessem permitir a entrada de águas causadoras de intemperismo. A investigação das montanhas-domos brasileiras tendo em vista essa idéia talvez possa conduzir a resultados interessantes.

No tocante aos xistos metamórficos do planalto, atraiu-me a atenção a aparente falta de evidências de antigas estruturas ou composições sedimentares em muitas localidades. Xistos biotíticos relativamente uniformes, sem feições sedimentares características reconhecíveis parecem cobrir grandes áreas. Não encontrei na literatura brasileira a sugestão de que tais xistos possam ser o produto de metamorfismo de rochas vulcânicas tais como lavas andesíticas. Se uma tal explicação não tivesse sido ainda considerada, talvez mereça investigação.

A questão da serra do Mar, um dos maiores problemas ainda não resolvidos da geologia brasileira, chamou-me a atenção durante as excursões a Santos, Itanhaen, Iguape, Paranaguá e Rio de Janeiro. Examinei fotografias aéreas com a esperança de que pudessem esclarecer a respeito. Cumpre resolver se o escarpamento da serra do Mar é principalmente o resultado de falhamento relativamente recente ou de arqueamento, acompanhado de falhas subordinadas, combinado com os efeitos de uma erosão mais rápida realizada por rios de curso curto e de forte inclinação para o mar, em contraposição aos rios do planalto de curso muito mais longo.

Em conexão íntima com o mesmo problema, temos o fato de "monadnocks" e massas montanhosas de igual conformação serem muito mais numerosas e conspícuas na baixada, entre a escarpa da serra do Mar e o mar (e até mesmo sôbre a plataforma continental, onde aparecem como ilhas), que no planalto. Uma das explicações possíveis é a das massas de rochas resistentes originadoras dos monadnocks terem sido mais numerosas na região costeira. Outra seria a de que durante a peneplanização do planalto tanto as rochas duras como as mais fracas foram reduzidas a um relêvo baixo e a dissecação post-peneplânica não foi bastante grande para trazer as rochas resistentes em evidência na forma de conspícuos relêvos, enquanto que, ao contrário, nas baixadas costeiras a erosão ativa e a forte "energia do relêvo" (available relief) reuniram-se para acentuar os efeitos da diferença da resistência das rochas, tanto que numerosos conspícuos monadnocks foram produzidos, muito embora mesmo massas de rochas resistentes não fossem tão abundantes como no planalto.

Se for correta esta última explicação, contrapõe-se à idéia de um recente afundamento por falha da planície costeira, e corrobora a suposição da serra do Mar ser em grande parte resultante de um arqueamento combinado com uma erosão rápida efetuada por rios curtos e fortemente inclinados, drenando diretamente para o oceano, em comparação à erosão lenta provocada pelos rios de curso longo até o mar, via rio Paraguai e rio Paraiba.

O exame da topografia da escarpa, tanto em excursão como em fotografias aéreas, não trouxe nenhuma evidência decisiva de falhamento, embora em muitos pontos, mudanças bruscas de declive evoquem a ocorrencia de falhas. De um modo geral a evidência geomórfica fala a favor de uma elevação por arqueamento para grande parte da escarpa. As evidências parecem conduzir à conclusão de ser a escarpa da serra do Mar não o produto tão só de uma grande falha, mas, antes, da combinação de uma elevação por arqueamento do lado continental, com abatimento do lado oceânico, acompanhados de falhamentos locais em certos trechos. O arqueamento combinou-se aos efeitos diferenciais da erosão mais rápida no flanco voltado para o oceano, produzindo a escarpa atual. Nos pontos em que o eixo de encurvamento coincidiu aproximadamente com o primitivo divisor de drenagem, verificamos agora uma escarpa íngreme, elevando-se junto à planície costal. Nestas circunstâncias a erosão fluvial estende-se sòmente a pequena distância para o interior, com referência ao antigo divisor, ao passo que em áreas como as antes drenadas pelo Ribeira de Iguape, onde o divisor se localizava longe da costa, encontramos uma região maturamente dissecada abrangendo uma superfície que se estende mais amplamente para o interior. O dobramento que originou a serra do Mar deve ter ocorrido em época suficientemente remota para que rios como Ribeira de Iguape pudessem desenvolver uma topografia matura sôbre toda sua área de drenagem.

Ao discutir os problemas que se nos apresentaram quando das excursões ao Brasil, não o fazemos com a pretensão de que em poucas semanas seja dado a um geólogo estrangeiro atingir soluções cabais. Animou-nos apenas a esperança de que a visão dos mesmos por um estrangeiro e as possíveis soluções por êle aventadas pudessem estimular estudos futuros, contribuindo, ainda que em pequena parcela, para a sua elucidação.

B) INTRODUCTION

In the course of a three-months stay in southern Brazil, a visitor from outside obviously cannot do much toward solving the many geological problems presented on every side in that fascinating country but, having a fresh point of view, he may perhaps render a service by pointing out some of the outstanding problems which came to his attention, and adding what little he can of observations bearing on them.

In the course of field excursions to several regions within five hundred miles of São Paulo under the capable guidance of Dr. Josué Camargo Mendes, Dr. Ruy Ozorio de Freitas, Dr. João Dias da Silveira, and Reinhard Maack, as well as on the excursions of the Fifth Congresso Brasileiro de Geologia, in Paraná, many of these problems came up for discussion.

On following pages, some of the most interesting of them are presented and commented upon briefly. It will be most convenient to relate these comments to the various field excursions and to the various regions visited on them, more or less in the order in which the excursions were taken.

C) EXCURSION TO CENTRAL ESTADO DE SÃO PAULO

a) Stripped Pre-Carboniferous Surface Near Itú.

Between Itú and Salto de Itú on the Itú-Indaiatuba road, granite is widely exposed east of the road on either side of the Tieté River. The granite area forms a relatively flat-topped terrace or bench between the plains on the west underlain by

Fig. 1 — «Varvite» from quarry near Itú. Siltstone beds separated by thin partings of shale.

Fig. 2 — Details of bedding in varvite quarry near Itú. At «B» and «C» are thin beds of siltstone showing rolling, or balling-up such as that pictured in Fig. 5. Small-scale current cross-bedding visible to the right of «A» indicates water movement from right to left, or, roughly, N. 75° W. Length of knife is 87 mm.

the Permo-Carboniferous rocks and the hills of pre-Paleozoic crystalline rocks on the east. This rock terrace is youthfully trenched by the Tieté River and somewhat dissected by its small tributary streams.

The most striking thing about this "granitic" area, aside from its forming an even-topped bench bordering the hilly region to the east, is the comparatively fresh condition of the granite. The deep residual soil which covers most of the crystalline area of southern Brazil has not been developed here. Why?

The suggestion here made is that the area under discussion is a pre-Permian surface stripped of its former cover of relatively weak glacial sediments so recently that the granite beneath the former cover has not yet had time to weather deeply.

In driving east towards São Paulo from Sorocaba, I thought I could recognize a similar bench skirting the higher hills east of Sorocaba. It would be interesting to check the extent of this phenomenon and to verify or disprove the above suggested explanation for it. Since writing the above, I discovered that De Martonne, 1940, p. 5, Fig. 2, and p. 8, and in the map opposite p. 80, discusses and maps this stripped bench and gives essentially the same explanation for it as that suggested above.

b) "Varvites" West of Itú.

A flagstone quarry a few kilometers southwest of Itú is developed in a type of rock called "varvite" because of its similarity to glacial varves. This quarry presents many interesting sedimentary features which, when properly understood, should throw light on the conditions under which the varvites were deposited. In the first place, their remarkably even stratification (Fig. 1) indicates deposition in a body of quiet water undisturbed by waves. The rock is almost entirely siltstone, indicating that the sediment which formed it was carried mainly in suspension. Most of the siltstone beds carry fine laminations (Fig. 6) marked by slight changes in texture or color, which, by their evenness, indicate deposition by settling from above; but in some places the silt shows small-scale current bedding such as that at "A" of Fig. 2, indicating that at some time a gentle current was flowing along the bottom, in this case from a southeasterly direction (the quarry face photographed trends approximately N. 75º W).

In another part of the quarry (Figs. 3 and 4, both of the same quarry face extending from left to right N. 80º W)

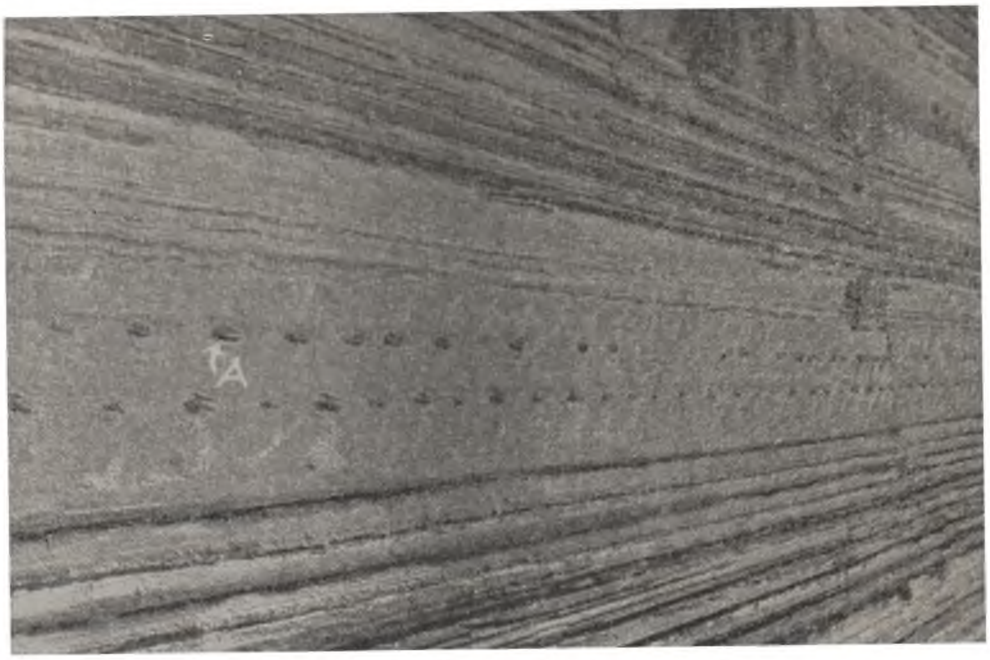

Fig. 3 — Face of varvite quarry showing marks of standing ripples indicating current movement from left to right (approximately N. 80° W.). The dark spots such as that at «A» are sand deposited in the lee of ripples. Note that the position of the ripple has moved slightly down-current with each successive bed deposited, thus causing distinct marks rising diagonally upward on the quarry face.

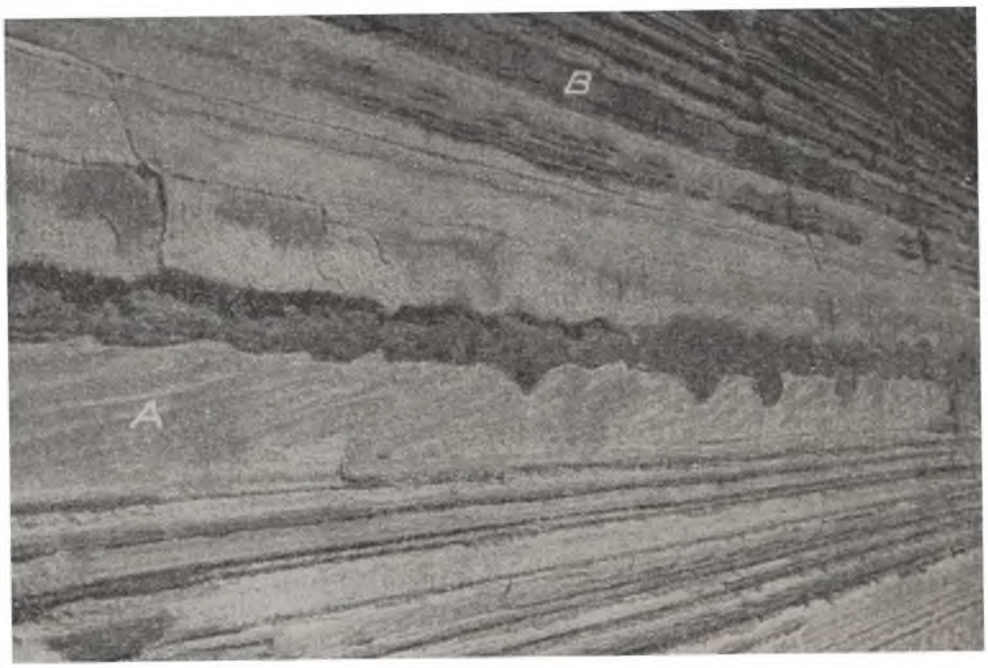

Fig. 4 — Another view of same quarry face as that of Fig. 3, taken about 2 m. higher. At «A» are marks believed to have been made by standing ripples moving down-current more rapidly than those of Fig. 3, hence rising upward at a smaller angle. The ripples shown in middle of Fig. 3 appear at lower right. At «B» is another rippled layer showing same direction of movement as in all the other rippled beds noted in this quarry.

a similar direction of water movement during deposition is shown by an interesting type of current ripples, each of which seems to have migrated very slightly down-current (to the right) as successive beds were deposited. This condition continued during the deposition of about 1 m. of beds and then gave place to quiet-water deposition without ripples or evidences of current bedding. A second period of steady water current from approximately the same east-southeasterly direction is indicated about 1 1/2 to 2 m. higher on the same quarry face (Fig. 4), especially by beds "A" and "B"

Another interesting feature observed in the same quarry is a peculiar surface on some of the siltstone slabs, shown on Fig. 5. The slab surface photographed is composed of black shale, but the shale layer is only about one millimeter thick between siltstones that lay above and below.

As seen from the edge, the beds showing this peculiar surface appear to have been crumpled or rolled slightly. Two such appear on Fig. 2 at "B" and "C" A vertical say-cut through a specimen from the slab of Fig. 5 taken to Cincinnati shows clearly how a thin layer of siltstone was rolled between the two very thin beds of black shale (Fig. 6). This condition seems to indicate slight flowage movement and adjustment promoted by the thin, slippery black shale beds. Such flowage suggests at least a slight inclination of the bedding at the time of deposition, but no consistent directional component appears on Fig. 5.

Putting all of these features together, we find the following: (a) Deposition in quiet water, probably on a slightly inclined surface; (b) intermittent periods when a weak current flowed along the bottom with sufficient velocity to produce current bedding and current ripples in the silts, but always flowing in essentially the same direction and with so little velocity that current ripples downstream only about as fast as the deposit increased in thickness, with the result that the ripplemarks extend diagonally up across the bedding at an angle of about 45º, as suggested in the accompanying sketch (Fig. 7); (c) suggestion of slight down-hill sliding of the sediments after deposition, along planes lubricated by the thin black shale laminae.

The combination of these features suggests to me that the sediments composing the rocks in this quarry were deposited either (1) in the lower part of the "clino" environment (Rich,

Fig. 5 — Lower surface of a varvite slab showing pattern of flow rolls such as those seen in cross section at «A» of Fig. 2. This surface is composed of a layer of black shale about 1 to 2 mm. thick. For cross-section, see Fig. 6. Length of knife 87 mm.

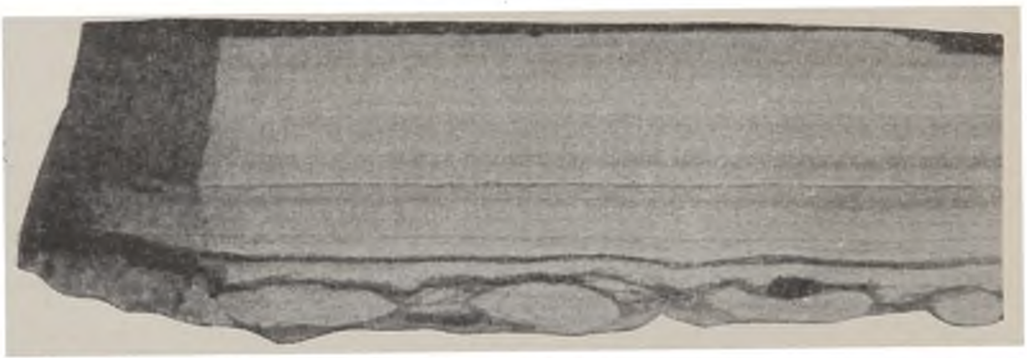

Fig. 6 — Detailed edge view of slab shown in Fig. 5. Note evidence of movement in the rolled siltstone bed. Note also how siltstone bed has been rolled into flattened balls. Total thickness of specimen is 20 mm.

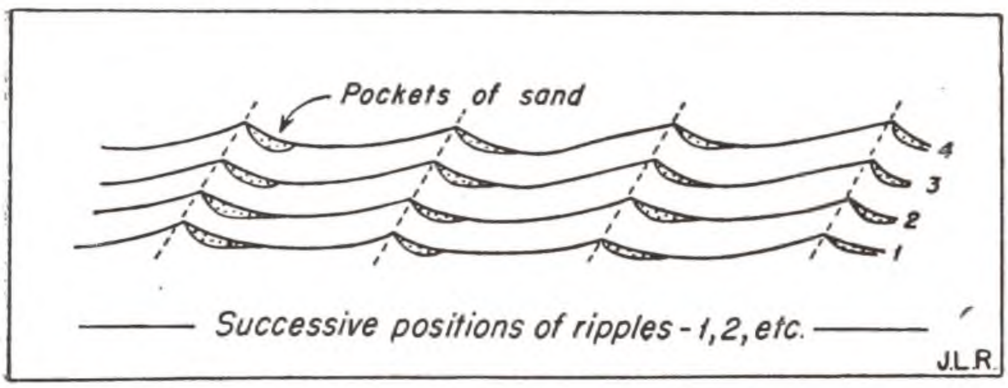

Fig. 7 — Sketch of effect of ripples migrating down current as deposition proceeds.

1951 *), where the angle of slope was so very small that the velocity of the density current was never at any time enough to scour down into the muds previously deposited and thus make flow-markings; or (2) on the "fondoform" close to the clinoform, where the density currents carrying silt in suspension were still present but the rate of flow was very small.

Environments such as those described above might occur on the lower foreset slopes of a delta or in the bottomset area adjacent to the base of the foreset slope.

The preponderance of silt and the almost complete absence of clay in the rocks of the quarry suggest that the finest material in the water delivered to the depositional basin traveled farther before settling, while the coarser sand constituents, not being able to travel in suspension, were deposited on the undaform or at its edge before reaching the site of the Itú quarry.

The layers of siltstone, such as found in this quarry, might be the product of density currents generated by muddy water stirred up on the adjacent undaform (shelf) by storms, while the black shale represents the material deposited during the quiet periods between storms. Or, the variations from silt to clay may represent a difference of material supplied in summer from that in winter because of glacial melting in summer. If the former, the "varvites" would not be true glacial varves and least only indirect.

(*) The terminology for the three critical environments of deposition any connection with glaciation would be non-existent or at here referred to is as follows:

The *unda* environment is that lying above wave base and therefore subject to agitation by wave action.

The *clino* environment is that extending from wave base down to the floor of the water body concerned. It corresponds in a general way with the foreset environment of a delta or with the continental slope.

The *fondo* environment is that constituting the generally relatively flat floor of the water body concerned.

The rock units formed in each of these environments are the *undathem*, *clinothem*, and *fondothem*, formed respectively in the unda, clino, and fondo environments.

The physiographic units corresponding with each of them are the *undaform*, the *clinoform*, and the *fondoform*. The undaform corresponds in general with the sub-aqueous top surface of a delta or with the continental shelf; the clinoform with the foreset slope of a delta or with the continental slope; and the fondoform with the principal floor of the water body.

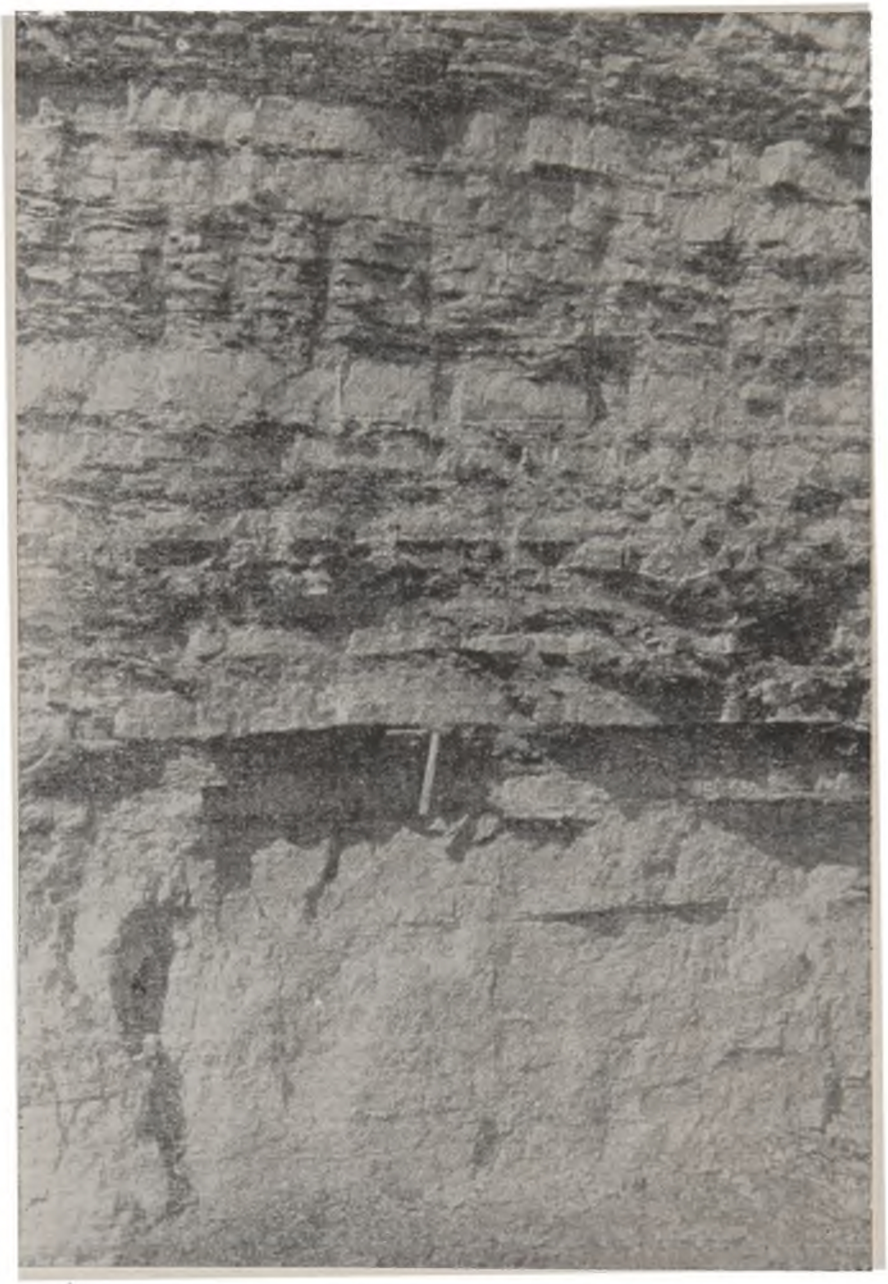

Fig. 8. Lower part of Irati formation in quarry near Assistencia, taken from 6 m. Lower 1¾ meters is massive, banded, cherty limestone. Above it is alternating cherty limestone and dark, bituminous shale. Length of hammer handle about 30 cm.

c) The Iratí Formation and Its Possibilities for the Generation of Petroleum.

The Iratí formation where seen at Assistencia south of Rio Claro consists of interbedded dark limestone and black shale (Figs. 8 and 9). Chert concretions and chert replacements of the limestone are common. Cavities commonly occur in or around the concretions and most of these are lined with heavy petroleum oil.

The considerable thickness and obvious bituminous nature of this formation make it seem to me a competent source bed for petroleum deeper in the Paraná basin. The fact that the oil at the outcrop is heavy is not an unfavorable indication, because all oils at the outcrop tend to have been made heavy by an oxidation process.

The Iratí formation seems to me to present all the criteria for a "fondo" deposit made in an enclosed, unaerated basin deep enough so that waves did not stir the bottom. Whether it was a marine basin or a lake seems to me still an open question.

The conglomerate at the base of the Iratí formation is exposed in the stream bed at Assistencia a short distance east of the road (Fig. 10). It poses an interesting problem as to whether it is a basal conglomerate of an advancing lake or sea, or was deposited in a stream bed. The conglomerate contains numerous pebbles of various sizes, mostly consisting of chert of several varieties, embedded in a matrix of alluvial type containing sand-and silt-sized grains of great variety, as well as considerable kaolin that may have come from the decomposition of sand-sized grains of feldspar. The conglomerate, about one meter thick, is overlain by about 46 cm. of well-stratified sand that appears to have been wave-worked. This sand in turn is overlain by gray clay shale of which only the lower 46 cm. was exposed. I did not see the section between this clay shale and the base of the calcareous part of the Iratí formation.

As to environment of deposition, the succession exposed in the stream bed suggests the basal deposits made by an advancing sea or lake which deepened rather rapidly so that only the 46 centimeters of stratified sand above the conglomerate represents the time during which the depth was little enough so that the bottom was worked over by waves. The clay shale

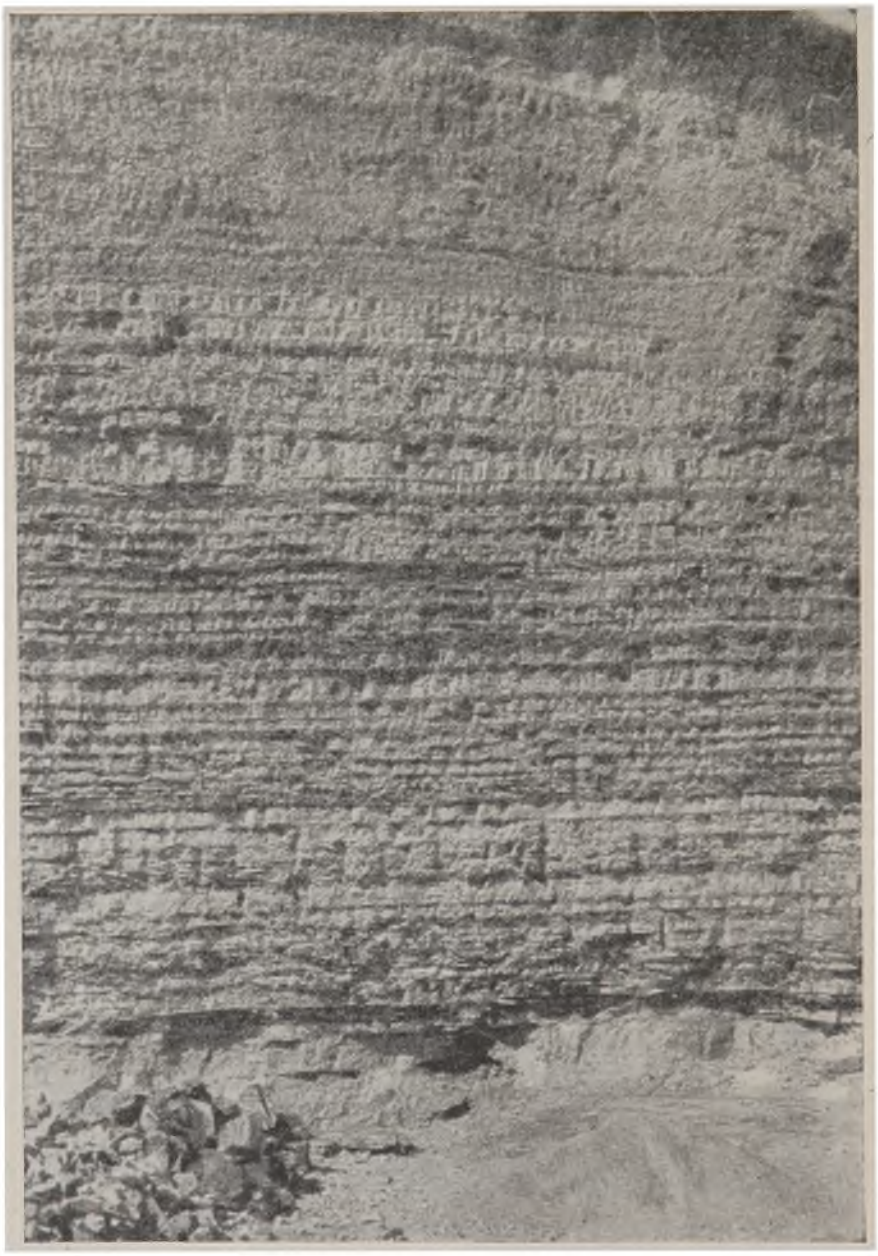

Fig. 9 — Same exposure as Fig. 8 from 15.2 m. Shows about 13 m. of alternating even beds of bituminous shale and of limestone.

at the top of the exposure is interpreted as of fondo type, made before the water became toxic as a result either of increase in depth so that it was no longer aerated by wave action, or of an enclosed basin condition.

The section suggests submergence so quickly that there was no time for clino deposits to be built out to this locality before the fondo conditions supervened.

Whether the conglomerate at the base of the Irati formation is a widespread basal deposit recording the encroachment of a large water body, or is a local river deposit, could probably be determined definitely by study of that basal contact at other places in the vicinity. If made by a river, it should be decidedly local in its occurrence; if by a large body of water it should be widespread.

d) Suggestion of Block Faulting between Indaiatuba and Campinas.

Along the road between Indaiatuba and Campinas, and nearer to the latter town, we noted interesting geomorphologic features which seemed to have a significant bearing on the problem of the geologic history of the area. Conspicuous were long, abrupt, relatively straight topographic breaks with a relief of about three hundred feet (100 m.) between lower ground on the Permo-Carboniferous glacial deposits and an even-topped upland of pre-Paleozoic crystalline rocks. The straightness and angular pattern of these topographic breaks seem to preclude the possibility of their representing normal erosional topography on uniform rocks.

Several possible alternative explanations have come to mind and are briefly commented upon below: Normal stream-eroded rough topography on granite may have been buried under glacial deposits and later exhumed. But the straightness and angularity of the lines of break in the topography oppose this explanation. The area may have been block-faulted, buried by glacial deposits, peneplaned, and then differentially eroded, leaving the crystalline areas standing high; or the area may have been mantled by glacial deposits, then block-faulted, then peneplaned, and finally differentially eroded to produce the present topography.

The third explanation seems to me to best agree with the facts as observed. It calls for post-glacial faulting and later peneplanation. It seems probable that careful analysis of the

Fig. 10 — Conglomerate at base of Iratí formation. About 200 m. upstream from road at Assistencia. At «A» is conglomerate; «B» is stratified, wave-worked sand; and at «C» is clay shale.

Fig. 11 — Rapids of Rio Piracicaba at Piracicaba, where the river flows over a sill of diabase.

geomorphology of the region bordering the eastern margin of the Paleozoic rocks would shed much light on the geological history of the eastern border of the Paraná basin.

A considerable group of lava-capped mesas in the lowland drained by Rio Piracicaba west of the little village of Porto J. Alfredo seems to indicate either a down-dropped block in that area or a down-fold. If it is the latter, there may be a structural closure to the west of these mesas that could be of interest in relation to exploration for oil. The mesas are much lower than the mesa north of São Pedro and seem to be too low to represent a continuation of the eastward rise on the normal regional dip from the outcrop along Tieté River many miles to the west.

e) Notes on Geomorphology. of the East-central Part of the State of São Paulo.

These notes are based on an auto traverse along the routes: Itú — Campinas — Limeira — Rio Claro — São Pedro — Piracicaba — Campinas. The rivers of this region are not yet graded, for they flow on bedrock in many places in valleys that are relatively narrow at the bottom. Both the smaller and the larger streams show this feature. The rapids in the river at Piracicaba are typical for one of the larger streams (Fig. 11). There, and in many other places, the falls are caused by the river flowing over a sill of diabase, but even rocks as hard as diabase would be brought to grade rather quickly by the larger streams. Hence this condition indicates a stage of late youth for the region.

A general level of the upland between 700 and 800 meters above the sea suggests that a more or less complete peneplain was once formed at that level. This is well shown by the flat tops of the outliers of crystalline rock southwest and south of Campinas. It is illustrated by Fig. 12, taken from the Botucatú scarp north of Rio Claro. In Fig. 12, the upland surface and the skyline to the right belong to what I think represents the peneplain, and the mesa at the left is part of the lava-capped Botucatú scarp which rises as a cuesta above the peneplain level. The same features appear on Fig. 13, which was taken from the Botucatú lava scarp northwest of Rio Claro. The mesas in the distance stand on the "peneplain" and are capped by Triassic lavas. The locally more or less flat tops of the lava mesas do not seem to me to have any significance in connection with the peneplain mentioned above, but they may be related to an earlier erosion cycle.

Below the peneplain level, distinct benches appear on the valley sides wherever more resistant rocks crop out.

f) Possible Furnas (Faxina) Sandstone West of Sorocaba.

On our return from the Iguape trip, on the road from Itapetininga to Sorocaba (I think much nearer the latter city) we passed new roadcuts and several new quarries along the road opened in a very pure, cross-bedded sandstone, weathered to a state of semi-incoherence. Our guides on that trip, Doctors Freitas and da Silveira, seemed to feel that the sandstone had de more of the physical characteristics (grain size, roundness, and character of bedding) of the Devonian sandstones than of the Permo-Carboniferous.

It seems to me that a very desirable project while the road-cuts and quarries are fresh would be a careful sedimentary study of that sandstone to determine whether it is a much disintegrated phase of the Furnas sandstone or is Permo-Carboniferous. The mineral composition of the sand should surely make it possible to settle the point.

The general geomorphic setting of the outcrop of such a sand stratum might well determine whether the sand would become disintegrated by weathering or would remain as a scarp-maker as is the Furnas in Paraná.

D) NOTES ON THE GEOMORPHOLOGY OF THE JUQUIÁ-IGUAPE-XIRIRICA LOWLAND AND ADJACENT PARTS OF THE SERRA do MAR

Under the guidance of Doctors João Dias da Silveira and Ruy Ozorio de Freitas, we visited the Juquiá-Registro-Iguape lowland, coming in on the road from Piedade and returning by way of Sete Barras and São Miguel Arcanjo, with a side trip from Pariquera-Açu to Xiririca on Ribeira de Iguape.

Fig. 12 — Looking about N. 82° E. from highway on lava-capped Botucatú sandstone scarp north of Rio Claro, State of São Paulo. The scarp is the face of a lava-capped cuesta rising above the general level of the «peneplain» visible in the right background.

Fig. 13 — Looking S. 43° W. at lava-capped mesas of Botucatú scarp from highway about 25 km. northwest of Rio Claro. The mesas stand on the «peneplain» mentioned in the text.

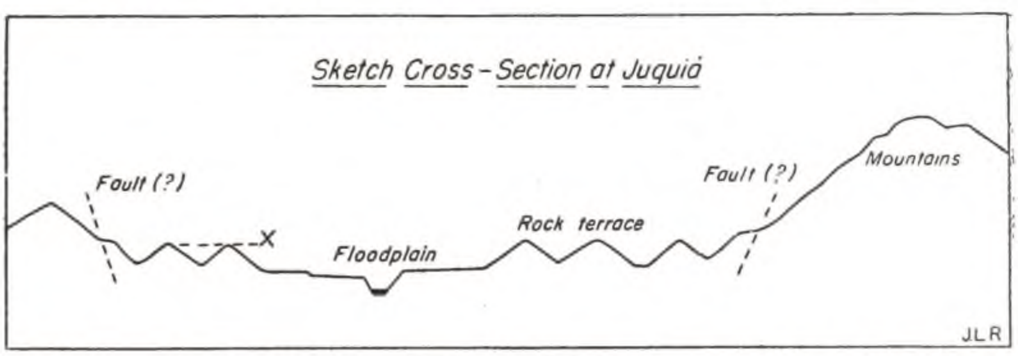

Fig. 14 — Diagrammatic sketch profile of Juquiá valley showing geomorphic features described and illustrated by preceding panoramas.

In coming down the face of the Serra do Mar from the divide south of Piedade to Juquiá, I had hoped to see some geomorphic indication of the faulting which is supposed to be responsible for the great Serra do Mar escarpment, but, to my surprise, I could find no definite indications of it. Somewhere in the neighborhood of Tapirai, we passed the parting of the waters between the drainage to the Rio Paraná and that to the coast in a maturely dissected region of moderate relief in which the actual position of the parting of the waters could not be determined as one drove along the highway. But finally, where the road began to descend steeply following a valley, the inter-stream areas also began to descend at about the same rate as the highway. At some point about halfway between Tapirai and Capela de Porto, the gradient of the stream which we were following flattened and became very small in a fairly wide, open valley. At the lower end of this open stretch the stream begins to cut deeply, forming a gorge, while the whole mountain front becomes more deeply dissected. But the interfluves still continue their descent southward at approximately the same rate as the road.

A view southeastward from the mountain spur on this section of the road shows a mature topography with summits sloping rather gradually to the southeast in the foreground, and higher moutain masses, possibly including the Serra dos Itatins, in the far background. Finally, the road comes out into a maturely dissected lowland of only 75 to 100 meters relief, which it follows, not far from Rio Juquiá, to the city of Juquiá. Nowhere in this section was it possible to recognize any geomorphic indication of a recent fault scarp or even of an older fault-line scarp.

What is the reason for the low-gradient open stretch in the valley which the road follows down the scarp, and for the "hanging" condition of that valley with respect to the very steep gradient of the stream after it enters the gorge? This change in grade, at first thought, might be assumed to have been caused by faulting, but it would seem that such faulting should also have broken the generally fairly even descent of the upland (interfluves) on either side of that valley. Of course, being in the valley bottom, we were not well situated to observe such a break in the topography, but if it is present, it escaped notice, though I was consciously on the lookout for it.

Another possibility which would explain the observed "hanging valley" condition without the necessity of faulting is that the stream in the low-gradient part of its course, where it flows

Fig. 15 — Panorama looking southeasterly from steps leading to church on hill at Juquiá. Modern floodplain bordens river. Behind it is dissected rock terrace, widespread in this region, and standing an estimated 50 to 75 m. above the floodplain. In background is a range of what appear to be residual mountains.

Fig. 16 — Panorama from church on hill at Juquiá. In middle distance is profile of the 50-75-meter rock terrace. At left is straight-fronted scarp rising some 120 m. higher. This may be a fault scarp or fault-line scarp. Looking easterly.

Fig. 17 — Panorama looking southwest up valley of Ribeira de Iguape from church on hill at Sete Barras. Above the floodplain, and visible in the right foreground and right and left middle distance is the rock terrace, or local peneplain, corresponding to that at Juquiá and that between Registro and Paraquera-Açú. Dimly visible in the far background are monadnock mountains at the left, and a considerable mountain range at the right.

in an open valley, may have been held up by a mass of very resistant rock through which it has not been able to cut rapidly enough to keep a graded condition.

I have noted such "hanging valleys" in several places in the Southern Appalachian Mountains where there is no possibility of glaciation or recent faulting to explain the hanging condition. In each instance, there, it can be shown clearly that a mass of extremely resistant rock in the course of the stream is responsible for the hanging condition. At Chimney Rock, a few miles southeast of Asheville, North Carolina, a stream of about the same size as that under discussion, and having an open valley above, drops over the edge of a resistant granitic intrusive into a valley about 250 meters lower and has not cut even a notch in the resistant intrusive at the top of the waterfall.

I have a feeling that such differences in rock resistance have been very important in connection with topographic development at many places in the crystalline-rock areas of southeastern Brazil. Streams are surprisingly ineffective in cutting a channel through a resistant intrusive rock which is not broken by joints.

A brief stop at Juquiá gave opportunity to make a photographic record of the interesting and significant geomorphic features of the region. These are clearly brought out in the two panoramas (Fig. 15 and Fig. 16), the latter taken from near the church on the hill, and the former from the steps part way up the hill.

The significant features revealed by these panoramas are: The floodplain and associated low alluvial terraces of Rio Juquiá, occupying the lowest ground; next above, a maturely or submaturely dissected rock terrace several miles wide whose summit remnants lie at roughly fifty to sixty meters above the floodplain; and, along the relatively straight southern border of the terrace, a range of mountains of old-age type rising in places to peaks 800 or more meters above the terrace.

The relatively straight line of contact between the dissected terrace and the old-age mountains raises the question as to whether that line is a product of faulting or merely of the contact of rocks of differing resistance to erosion. If the former, the question arises as to whether the faulting was recent, in which case the line of contact would be a *fault scarp*, or ancient, in which case it would be a *fault-line scarp*. The evidence, in so far as it can be deduced from the photographs, suggests either differences in rock resistance without faulting or a fault-line scarp, because, if the line in question were a product of relatively recent faulting, the fault scarp should appear as a more or less continuous wall bordering the dissected lowland terrace, but no suggestion of such a "wall" appears on the photos. This question could probably be solved by careful field work, giving special attention to the nature of the rock on the two sides of the line of contact.

At the extreme left of the panorama (Fig. 16) is a relatively straight escarpment rising some 100 meters more or less, above the general level of the summits of the dissected lowland rock terrace mentioned above. This has the appearance of being a fault scarp, but not enough of it was seen to give basis for sure conclusions. Interpreting the physiographic history of this region as revealed on the panoramas, we find in the present floodplain and low alluvial terraces a suggestion of a slight recent relative lowering of sealevel amounting, perhaps, to four or five meters; then, at the elevation of about 50 to 75 meters above the recent alluvial terraces, the broad, relatively even-topped dissected rock terrace discussed above indicates local peneplanation or beveling at the general level of the top of that terrace at a higher relative stand of sea level which endured long enough to develop the wide valley, presumably on relatively weak rocks. This dissected rock terrace is believed to be continuous with that to be described for the region around Registro, between Registro and Pariquera-Açu, and along the valley of Ribeira de Iguape to and beyond Sete Barras.

The accompanying sketch (Fig. 14) expresses graphically the essential features shown on the photographs and described briefly above.

From Juquiá to Registro we were traveling at night, but seemed to be following the dissected lowland already described ("X" of Fig. 14) for the entire distance. This dissected rock terrace or local peneplain is widespread in the region. It extends continuously from Registro to Pariquera-Açu and southward from there for much of the way to Iguape; it is well developed along Ribeira de Iguape in the vicinity of Sete Barras; and, in modified form, it appears in the topography at least as far up that river as Xiririca.

From Registro to Pariquera-Açu the highway crosses this terrace, which is here maturely dissected and continuous except for the more recent trench of Rio Jacupiranga. The skyline of the dissected surface is remarkably uniform in summit elevation, but to the south of Pariquera-Açu, residual granitic mountains rise above the "peneplain" level. Road-cuts show that the underlying rock is very deeply weathered schist, all apparently of fairly uniform resistance to decomposition and erosion.

A striking feature along the road between Registro and Pariquera-Açu is that in the cuts where the road crosses the local divides of this maturely dissected area, numerous exposures at the highest levels show ancient resistant-rock gravels occupying shallow channels on the divides. The wide distribution of such gravels and their occurrence on the divides indicate that formerly this entire lowland, whose summits are now some 50 meters above present drainage, was once covered by a sheet of gravel. This gravel is similar to that which da Silveira has described (1950) and which we saw in a terrace in the village of Registro, but I think that on the "peneplain" it lies generally at a somewhat higher level than that terrace.

By way of interpretation: The presence of this broad area apparently once covered by gravel and extending up Ribeira de Iguape and up the valley of Rio Juquiá certainly indicates a long-continued still-stand of the land at the level of the now-dissected terrace surface.

The problem arises as to the origin of this beveled, once gravel-covered surface. Is it a product of wave planation at a stand of the sea higher than the present, or was it produced by lateral planation by Ribeira de Iguape and possibly also by Rio Juquiá? In the stretch between Registro and Pariquera-Açu, the lowland is extensive enough so that it might conceivably be a product of wave planation. But such an explanation would scarcely suffice for the rock terrace at and above Juquiá, for any bay there would necessarily have been too narrow and too much protected for extensive wave planation. On the whole, I am inclined to favor the interpretation that this erosion surface is a product mainly of lateral planation by the larger streams during a time when the sea stood for a long period at a level about 50 meters higher than now. (I have no exact figures as to elevations in the region under discussion).

At Sete Barras, the church stands on the gravel-veneered rock terrace under discussion at an elevation, according to da Silveira, of 60 m. A panorama (Fig. 17) representing the view up the river from that church brings out clearly this terrace, or local peneplain, lying above the present floodplain of the stream and much below the residual mountains dimly visible in the distance.

At Xiririca the erosion level under discussion seems not to exist as a flat-topped surface. What is believed to be a product of this same period of still-stand with respect to erosion is indicated by large ingrown meanders of the stream and by a rather broad lowland of slip-off slopes related to those meanders. The river at Xiririca is now flowing in a trench, apparently with very little true floodplain.

On the south border of the slip-off-slope lowland mentioned above, a few kilometers south of Xiririca on the road to Pariquera-Açu, old gravels (Fig. 18), apparently related to an earlier meandering course of Ribeira de Iguape, are well exposed filling a shallow channel now situated on a local divide and exposed in section by the road cut. The gravels in this cut probably were not deposited directly by Ribeira de Iguape but, rather, re-worked from old terraces of that river by smaller streams long enough ago so that the local relief has been reversed, leaving the relatively resistant gravels on the local divides. Their occurrence in a shallow channel clearly cut into decomposed crystalline rock is evident from the picture. It is interesting to note that a soil cover about one-half meter thick has developed over the gravels since their deposition.

These gravels, occurring on a local divide cut through by the highway are of the same type as those previously mentioned as occurring on the divides along the road from Registro to Pariquera-Açu.

An intriguing problem, well illustrated in the Iguape region as well as on the Planalto around São Paulo and between São Paulo and Piedade, is alluviation of the present valley bottoms. This phenomenon is especially conspicuous on the road from Pariquera-Açu to Xiririca and also between Pariquera-Açu and Registro. This alluviation commonly extends all the way up to the amphitheatre like heads of the small valleys. On the Iguape lowland the alluviated valley bottoms are commonly swampy and covered with grass or rushes. The streams in them seem totally inadequate to have widened the valleys to their present width during the current cycle of erosion.

If such alluviation were confined to the Iguape lowland, it might be believed that it was caused by recent sinking of the land with respect to sealevel, but since it occurs also conspicuously on the Planalto, it would seem that some climatic or cultural change is probably responsible. The streams appear to have cut and widened their valleys and then to have lost their power to cut, and to have begun filling up the valley bottoms.

One possible explanation which suggests itself is that the valleys were cut and widened during a period of drier climate, when the present dense forest cover was not in existence, and

Fig. 18 — Stream gravels filling channel on crest of low divide a few kilometers southeast of Xiririca. These are a product of drainage inversion of a type commonly seen in road cuts between Registro and Pariquera-Açú.

Fig. 19 — Exposure of pre-Furnas (?) tililte (?) about 16 km. northwest of Castro on Castro-Tibagí road. The lower 6.1 m. (A) is massive till; the next higher 4.9 m. (B) is till showing vague layering, and the upper 4.9 m. (C) is massive till like (A). Base of Furnas sandstone is at top of white band in upper right, and area circled in white is that included in Fig. 24.

that, with the growth of the forest and modification of the run-off, the streams lost their effectiveness and are permitting the valleys to be alluviated gradually by fine material brought in from the sides and by the growth of vegetation in the swampy valley bottoms. Another possibility, almost diametrically opposite, is that the alluviation may be a result of overloading of the streams because of soil erosion following clearing of the forests. In this connection, I noted that the stream valleys seemed normal, without alluviation, in a section of the highway between Guapiara and Ribeira (on the road to Curitiba), where the land had never yet been cleared.

Our opportunity to study this problem was not sufficient to make possible any decision as to the cause of the alluviation.

In climbing out of the Iguape lowland on the road from Sete Barras to São Miguel. I had hoped to see definite geomorphic evidence of faulting along the Serra do Mar, but again failed to find such evidence in the geomorphology. The general impression gained on this trip was that the Serra do Mar escarpment, in the region visited, is not a product of recent faulting. It seems to have been produced either by up-arching of the Planalto, with possible local faulting here and there, or to be merely a product, like the Blue Ridge of southeastern United States, of the difference in erosional effect between a long course to the sea, like that followed by the Rio Paraná drainage, and a short, steep course such as that of the southern slope of the Serra do Mar. This problem will be discussed more fully on a following page.

E) PROBLEMS ENCOUNTERED ON THE EXCURSION TO PARANÁ

a) Pre-Furnas (?) Tillite (?)

Completely exposed in a roadcut (Fig. 19) about 16 kilometers northwest of Castro, on the road to Tibagi, is a very interesting and important outcrop of what appears to be tillite (hereafter called till) lying immediately beneath the Furnas (?) sandstone. This material overlies Castro volcanics, which there seem to be either lavas or volcanic agglomerates. The total thickness of the till section is 15.8 m. comprising 6.1 m. of unstratified rather stony till at the base (Fig. 20 and "A" of

Fig. 20 — Detail view of till near base of section. Looking straight down from .91 m. (3 feet). Knife is 87 mm. long.

Fig. 21 — Middle, layered part of till section («B» of Fig. 19). Vague layering, but material shows no indication of water stratification.

Fig. 19) followed by 4.9 m. of till showing vague stratification Fig. 21 and "B" of Fig. 19) and that, in turn, by 4.9 m. of unstratified till ("C" of Fig. 19), beveled sharply at the top by the basal contact of the Furnas (?) sandstone (Fig. 22).

On noting the stratified till in the middle of the section, the first thought was that it must be water-laid material, but a more careful examination showed that such was not the case. Instead, the stratification was of a type often noted in Pleistocene tills of the United States which seems to have been produced by a plastering-on process during deposition beneath the moving ice.

Fig. 20 shows clearly the nature of the lower 6.1 m. of the section. The material includes pebbles of rocks of many kinds, among them rocks resembling the Castro volcanics, numerous quartzites, granites, and others. Some of the pebbles are distinctly striated, and many of them are faceted like glacial stones. Faceting alone, of course, is not a sure indication of glacial origin because rocks broken along joints and moderately eroded often closely resemble glacially faceted erratics. Many of the stones are sharply angular and some are rounded. This condition is well shown on Fig. 20, taken near the bottom of the till section, and on Fig. 22 taken near the top. In the latter picture all of the stones lying loose in the foreground, as well as those in place in the till, are erratics from the till. Angular and faceted forms are very common.

The question has been raised whether the material which I am calling till may not actually be colluvium (material accumulated on a slope by weathering and creep) or the deposit of an alluvial fan. Explanation as colluvium seems to me to be ruled out by the great variety of materials; by the thickness (15.8 m.); and by the essentially horizontal vaguely stratified structure of the deposit.

Interpretation of the material as that of an alluvial fan is opposed by its total lack of bedding of the kind produced by deposition in or by water, and its total lack of sorting.

Every feature of composition and structure corresponds with glacial till of the type formed beneath moving ice, and I see no escape from the conclusion that the material actually is till of pre-Furnas (?) age. Anneliese Caster, Kenneth E. Caster, and Reinhard Maack who visited this area in the middle 1940's believed it to be till.

Fig. 22 — Contact of till with overlying Furnas (?) sandstone in area of Fig. 23.

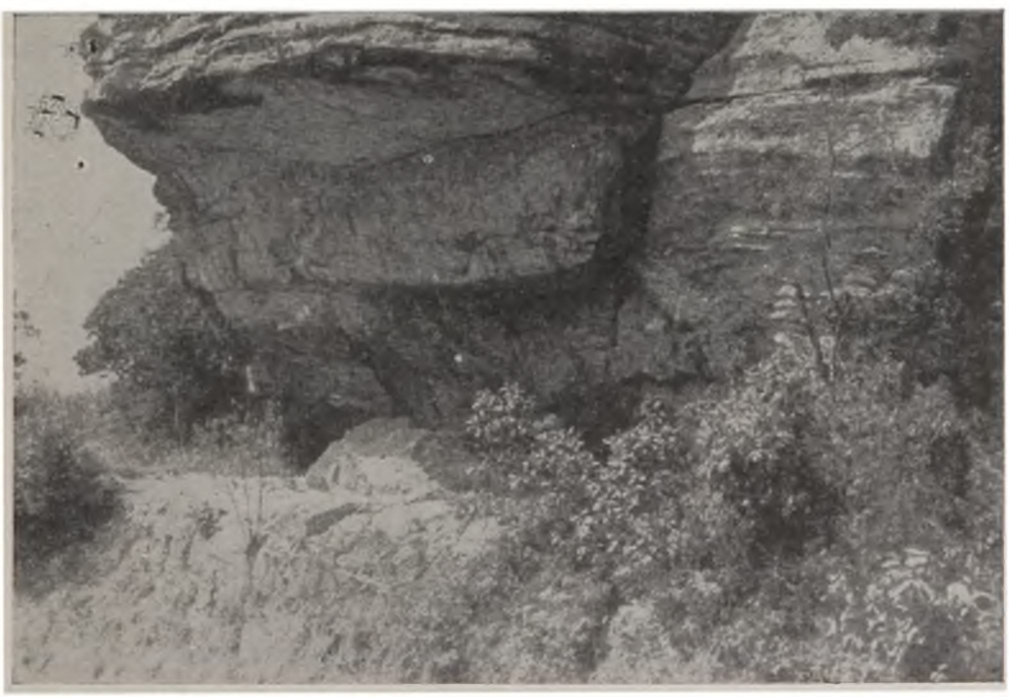

Fig. 23 — Furnas (?) sandstone overlying till (white) a few meters to the left of the site of Fig. 22. The bedding of the sandstone is well displayed, and is typical of that of the Furnas sandstone of the region.

The question has been raised whether the sandstone overlying the till is actually Furnas or may possibly be a sandstone of the glacial Itararé series. In view of the nature of the sandstone and of its geological distribution, it seems to me certain that it is actually Furnas. As shown by Figs. 19, 22, 23, and 24, the sandstone immediately overlying the till has the even, wave-worked type of bedding typical of the Furnas. Fig. 24 showing in detail the area encircled in white on Fig. 19 reveals cross-bedding inclined toward the west or northwest which, according to Maack, is the characteristic direction for the cross-bedding in the Furnas sandstone. Such evidence alone might not be convincing, but the geomorphic evidence seems to me to be inescapable. The massive sandstone overlying the glacial deposit in question is part of a continuous great cuesta escarpment extending almost all the way across the State of Paraná from close to its southern border north and thence east to the State of São Paulo. This cuesta everywhere else is recognized as being caused and capped by the Furnas sandstone. A great, thick, marine basal sandstone is not likely to be discontinuous and its place as a scarp-maker suddenly taken by another sandstone of notably younger age without interruption in the continuity of the scarp!

After leaving the site in question, the road to Tibagí climbs to the top of the thick sandstone under discussion, then, apparenthy, follows its dip slope down to Tibagí. The typical landscape along this road is illustrated by Fig. 25, showing one of the tributary canyons to the Rio Iapo which cuts a water-gap through the cuesta a few miles to the north. My recollection is that the road follows on this sandstone all the way to the bridge across Rio Tibagí just southeast of the town of that name, where the new road cut at the west end of the bridge shows Devonian Ponta Grossa shale resting on undoubted Furnas sandstone.

A sure way to check the identity of the sandstone at the till locality would be to follow it along the canyon of Rio Iapo to determine whether or not it is continuous with the undoubted Furnas sandstone at the bridge east of Tibagí.

Another method of checking would be by study of aerial photographs or by aerial reconnaissance of the Furnas scarp from the point where it is crossed by the Curitiba-Ponta Grossa road, past the point where we crossed it east of Ponta Grossa on the way to the talc deposits, thence to the point where it crosses the road from Ponta Grossa to Castro, thence

Fig. 24 — Close-up of bedding of the Furnas (?) sandstone in area circled in white of Fig. 19, a few meters above the contact with the till.

to the point in question where it is underlain by the till, and finally following the canyon of Rio Iapo to Tibagí.

The possibility of a pre-Furnas till is important enough so that the true age of the sandstone overlying the deposit in question should not long be left open to doubt.

b) Possible Glacial Erratics in the Furnas Sandstone at and East of Tibagí.

On the Castro-Tibagí road, somewhere between one-half mile and a mile or more east of the new bridge across Tibagí river southeast or east of that town, is a deep new roadcut through cross-bedded white sandstone (Fig. 26) which contains numerous pebbles of quartz and quartzite, some of them up to six inches in diameter, scattered irregularly through the sandstone without sorting. Some of these pebbles show faceting similar to that of glacial erratics. They seem too large to have been carried along the bottom by the ordinary current which deposited the sandstone, and the suggestion has been made by Dr. Maack that they may have been dropped from icebergs floating in the sea in which the sandstone was being deposited.

Similar pebbles, though smaller and not more than two or three inches in diameter, are common in the upper few feet of the undoubted Furnas a few feet above river level at the base of the steep hill southeast of the church at Tibagí. Here there can be no question but that the material is Furnas sandstone rather than a sandstone of the glacial series, nor can there be question that it contains quartzite pebbles of considerable size. Finding these pebbles here tends to make it more probable that the sandstone just described with pebbles up to six inches in diameter is Furnas than it would be if no pebbles of any kind were found in the undoubted Furnas sandstone at the village of Tibagí.

c) The Barreiro Sandstone; Is It Devonian or Permo-Carboniferous?

Twenty-five kilometers, more or less, north or northwest of Tibagí we were taken by Dr. Maack to see the section of the Ponta Grossa shales and the Barreiro sandstone which he considers to overlie them and to be of Devonian age. I was interested to see that the Ponta Grossa shales there contains

Fig. 25 — Typical landscape on the sandstone which overlies the till of preceding pictures. Taken from near Castro-Tibagí road where a tributary of Rio Iapo cuts headward into the backslope of the Furnas (?) cuesta. The bedding has the typical appearance of Furnas sandstone rather than of the sandstones of the Itararé series (Compare Figs. 29, 30, and 31.)

Fig. 26 — Road cut in cross-bedded sandstone on Castro-Tibagí road a few kilometers southeast of the new bridge at Tibagí. The sandstone contains scattered large pebbles (up to 150 mm.) of quartzite. Note a layer of lag-gravels between the sandstone and the surface soil. Knife measures 87 mm.

Fig. 27 — Panorama of cliff of Barreiro sandstone near divide northwest (?) of Tibagí. Note that type of bedding suggests deposition in open water. Near right border, note interesting structural feature extending up and to the left across the cliff. For a closer view of this feature, see Fig. 28.

Fig. 28 — Looking S. 15° W. at structure shown near lower right margin of Fig. 27. The cross-bedding suggests a large-scale ripple-like feature which persisted and migrated to the left as successive strata were deposited. Since the cliff face extends approximately east-west, the structure thus interpreted suggests open water on the right (west) and a gradual migration eastward as deposition continued. It is suggested that the feature may have been a small sub-aqueous bar.

two or more zones of what appears to be bituminous shale of the type which would make them offer important possibilities for the genration of petroleum deeper in the Paraná Basin to the west and north, especially should the bituminous element in the shale section increase in those directions along with a probable increase in thickness.

Near the divide on the road which we followed, we were shown what was said to be a typical outcrop of the Barreiro sandstone at an easily identifiable point where the road passes an almost vertical cliff of that sandstone more than 20 meters high (Figs. 27 and 28). The bedding of the sandstone suggests deposition in an open body of water, either marine or lacustrine, under conditions of strong wave action.

The sandstone is locally conglomeratic and contains many large pebbles and small boulders dropped indiscriminately through it as if from floating icebergs. Many of the pebbles and boulders are faceted as if by glacial action, but I do not remember whether or not we found distinct glacial strie on any of them.

The panorama (Fig. 27) shows an interesting structural feature extending up across the cliff diagonally from right to left. A closer view of the lower part of this disturbed zone is shown in Fig. 28, taken looking S. 15º W., aproximately at right angles to the trend of the cliff, which probably trends approximately east-west. The structure in question appears to be a sedimentary one and my nearest approach to an interpretation of it is that it represents a small sub-aqueous bar behaving on a large scale very much like the ripple marks in the varvites at Itú which migrated diagonally upward in the section as deposition continued. It is my suggestion that this may represent a small bar formed offshore at the greatest depth at which storm waves broke during the most severe storms, and that the bar migrated slowly shoreward as deposition continued and sealevel gradually rose (or the land gradually sank). If this interpretation is correct, we have the suggestion that open water lay to the west; that the bar was built by a transgressing sea (or other water body); and that the deeper water lay to the west.

The occurrence near Tibagí (Fig. 26) of faceted boulders similar to those which are abundant in the Barreiro sandstone in what appears to be Furnas sandstone tends to make more probable Maack's idea that the Barreiro sandstone is Devonian rather than belonging to the Itararé series, because if glacial condition existed previous to the deposition of the Furnas sandstone and also somewhere within reach during the latter part of the deposition of that sandstone, so that ice-rafted boulders could be floated to the Tibagí region at that time, it would not seem necessary to assign an Itararé age to the Barreiro sandstone on the basis of its faceted pebbles. I recognize that Setembrino Petri (1948) has found material which he interprets as varvites beneath the Barreiro sandstone in the Lambedor region. The question arises as to the composition of the material constituting the "sedimento varvico" which Petri illustrates in photo 2 opposite page 30. To judge from the photograph, this laminated material is siltstone. If so, it may be similar to the varvites already discussed from the quarry at Itú; but in any case lamination such as this does not necessarily indicate glaciation; rather it indicates, I think, the deposit made at the base of a clinoform or on the adjacent fondoform where showers of silt stirred up during storms have accumulated in thin layers. Material like the varvites of Itú, even containing standing ripples migrating diagonally upward across the section, such as do those at Itú illustrated in Fig. 3, have been found by the writer in the Chester section of the Upper Mississippian in central Indiana, in a region where there can be no possibility of glaciation anywhere within reach of that sedimentary basin at the time of deposition. The presence of pebbles of granite and quartzite in the "sedimento varvico" of Petri does not seem to me to prove that the Barreiro formation belongs to the Itararé series, because pebbles of possible iceberg origin occur in the upper part of the Furnas sandstone at Tibagí as well as in the Barreiro sandstone.

It is interesting that Petri's profile near Lambedor (pages 83-84) seems to show gradual transition from the Ponta Grossa shales into the Barreiro sandstone. At least he finds thin layers of conglomeratic sandstone separated from the main mass of the Barreiro by fossiliferous siltite. This observation seems to me to add to the possibility that the Barreiro sandstone may belong to the Devonian and not to the Itararé.

In connection with the suggestion that has here been made that the upper part of the Furnas sandstone near Tibagí contains ice-rafted pebbles and that the Barreiro sandstone also contains them, it is interesting to note that on our return from Ponta Grossa to Curitiba, Dr. Maack and I examined the Furnas sandstone at several places south of Palmeira without finding any such pebbles in it there, and Dr. Maack told me that he had never seen any in that vicinity. If, however, the ice came into this region from the north, as is indicated by Dr. Maack (1946, p. 206) it may not be so surprising to find the pebbles decreasing in abundance from north to south.

d) Origin the Sandstone at Vila Velha.

The Vila Velha sandstone, 48 m. (157 ft.) thick (Maack 1946), is a remarkable deposit of character and composition so different from most other sandstones that the problem of its origin becomes one of special interest. The sandstone is massive, with no clean-cut stratification; it is broken into polygonal blocks by a system of jointing (Fig. 29) similar to the contraction or shrinkage jointing of basalt. The sandstone seems to be entirely without stratification except in a very broad general way, but even this vague broad stratification does not seem to persist for any considerable distance. The typical material is unsorted sand. The grains are very well rounded and some of them frosted. The grains of the Vila Velha sand are noticeably more rounded than those of the Furnas sandstone in nearby outcrops. In the lower part of the formation Maack has described, and the writer saw, scattered erratic pebbles placed irregularly in the rock with no semblance of stratification.

Maack has classified this sandstone as of glacio-fluviatile origin. That the material belongs to the glacial series cannot be doubted because it is underlain by red varved clays containing ice-rafted pebbles, but the main mass of the Vila Velha sandstone itself, it seems to me, cannot possibly be of fluvial origin, glacial or otherwise. Lack of stratification and of sorting seems to rule out both water and wind as agents of deposition.

Except for the varved clays beneath it, the Vila Velha sandstone is the lowest representative of the glacial series of the region. To me it seems that the most likely explanation of this peculiar sandstone is that it is a very sandy till, representing the first invasion of the actual ice over the region. Its very sandy composition may represent a reworking of residual sand that had accumulated on the erosion surface of the Furnas sandstone in preglacial times and, in view of the fact that the sand grains are noticeably more rounded than those of the Furnas sandstone in place, and that many of them are frosted, it even seems likely that this residual material may have been reworked by wind before being picked up and incorporated in the basal till of the glacial series.

The vague stratification of the Vila Velha sandstone is such as is not uncommonly seen in till, but not that characte-

Fig. 29 — Polygonal jointing of shrinkage type in Vila Velha sandstone at Vila Velha.

ristic of water-laid or wind-laid deposits. The blocky, contraction-type jointing of the material also is similar to that sometimes observed in till. In other areas seen on our excursion, a sandstone more or less closely the equivalent of the Vila Velha is evidently water-worked, at least in part, as for example in the outcrop visited by our excursion at Campos Gerais, west of the road between Restinga Seca and São Luiz (Figs. 30, 31) It seemed to the writer, however, that the material at this outcrop, while water-worked, should hardly be called fluvio-glacial, at least not in the sense of having been deposited by glacial streams or by streams from the glacier, because the bedding exhibited by it, and well shown in Fig. 31, seems to be of the wave type rather than such as would be formed on land by braided glacial streams. More likely this material has been reworked by the waves of a considerable body of water. Whether deposited directly in such a water body or deposited on land and later reworked by waves is a problem for future solution.

e) High Silt Content of Late Glacial and Post-Glacial Rocks of Central Paraná.

In driving along the road from Ponta Grossa to Guarapuava, I was impressed by the large proportion of silty material making up the rocks of the section from the top of the continental glacial tillites to the base of the Botucatú sandstone. The fossilliferous marine glacial beds of the Tubarão series have the texture and appearance of water-laid loess. The same is true of a considerable part of the Passa Dois series. A conspicuous exception to this series of silty rocks is the Iratí formation and a part of the overlying Estrada Nova. Both of these appear to be fondo shales, the Iratí being bituminous and the Estrada Nova not so. All of the rocks from the base of the Iratí formation to the base of the Esperanza member of the Passa Dois series apear to have been deposited in open water. The Seriña-Terezina formation is water-bedded silt from base to top, and has a texture suggesting that it may be reworked or water-deposited loess. The clays and sands of the Esperanza formation suggest by their stratification that they are swamp deposits. They contain abundant plant remains.

Fig. 30 — Conglomeratic sandstone of the Itararé (glacial) series west of Curitiba-Ponta Grossa highway on Campos Gerais. This has been interpreted as fluvio-glacial. The bedding suggests deposition in open water rather than by a stream on an outwash plain or valley train.

Fig. 31 — Another exposure of «fluvio-glacial» conglomeratic sandstone on Campos Gerais. Decidedly wave-worked type of cross-bedding suggests deposition in or re-working by open water subject to strong wave action.

f) Possible Open-water Nature of the Lower Part of the Botucatú Sandstone on the Road to Guarapuava.

In climbing the escarpment of the Serra Geral on the road from Ponta Grossa to Guarapuava, I noted that the Botucatú sandstone in the lower part of its exposure, below the spring, seems to have a bedding of open-water wave-worked type in contrast to the obviously aeolian bedding of that sandstone in the upper part of the same section where it is interbedded with the lava flows. This problem merits further investigation.

g) Underground Drainage on Furnas Sandstone near Ponta Grossa and on Lavas of the Guarapuava Region.

It was surprising to discover that commonly over the upland in the divide regions on the Furnas sandstone, the surface is marked by numerous small depressions with no surface outlet. Some of them have been plugged so that small lakes are formed, whose drainage must be directly downward.

The apparent explanation of this common occurrence of "sinkholes" in sandstone instead of in calcareous rocks is that the sandstone, possibly slightly calcareous, is rather strongly jointed and that the joints become enlarged sufficiently so that the water takes an underground course along them. The numerous springs coming to the surface in the lower part of the outcrop of the Furnas sandstone are in harmony with such an explanation.

On the lava plateau in the Guarapuava region it is surprising to find abundant undrained depressions on the upland surface. It is obvious here that the water finds it way down into porous lavas, which it follows in true underground drainage. It is believed that jointing in the lavas plays an important part in this process, because it was noted that in many of the shallow valleys on the upland the sinks occur in a row along the valley bottoms.

Our textbooks should be revised to provide for underground drainage and the development of sinkholes in sandstone and in lavas as well as in calcareous rocks. In the Rocky Moutain region I have found sinks and evidences of underground drainage,

Fig. 32 — Rounding of hilltop profile by processes of sheetwash and creep irrespective of pinnacled upper surface of underlying limestone of the Açunguí series east of Ponta Grossa.

Fig. 33 — Panorama of south wall of new railroad cut some 5 or 6 km. east of Ponta Grossa. A beautiful illustration of the smooth rounding of hilltops by processes of creep and sheetwash. The dark material with irregular lower contact totally unrelated to the structure of the underlying Ponta Grossa shales is aluvium with fine gravel at the base. This is an excellent example of the inversion of topography so often encountered where the alluvium or gravel proves more resistant to erosional processes than does the underlying rock. Compare Fig. 18.

even in granites where an old-age surface in granite has been deeply dissected by youthful streams. Apparently faults and other fissures in the granite become water courses and lead the drainage downward, then surface erosion develops sink-like forms leading to the places where the water sinks underground.

I have also seen well developed sinkholes on sandstone mesas in the State of New Mexico similar to those on the Furnas sandstone.

h) Inversions of Topography; Possible Climatic Change.

In the Ponta Grossa region I was fortunate enough to secure several photographs which beautifully illustrate certain geomorphic processes that are perhaps too little appreciated. One of these is the smoothing and rounding of hilltops by processes of creep and sheetwash, or of creep alone where the vegetation cover inhibits sheetwash. The results of these processes are well illustrated in Fig. 32 showing a limestone quarry in the Açungui Series about 25 kilometers east of Ponta Grossa. The limestone has an exceedingly irregular, jaggedly pinnacled top beneath the residual soil, yet the hilltop has a smooth profile developed with complete disregard of the irregularities of the upper surface of the limestone below. A group of people in the quarry gives the scale.

The second illustration of a similar process of smoothing and rounding of a hilltop irrespective of the contour and structure of the underlying rock, and one which also shows clearly the inversion of topography, was found in a new railroad cut some five or six kilometers east of Ponta Grossa. The panorama, Figure 33, presents a smooth, gently convex hilltop with a grass and soil-covered surface developed on Ponta Grossa shales with no regard to their structure, which includes a small fault and considerable dip in one part of the exposure, nor to a shallow, alluvium-filled former valley marked by the dark material having a sharp, irregular line of contact at the base.

In explanation: Following an important principle of geomorphology that alluvial materials tend to be comparatively resistant to erosion because they are generally porous, permitting the rain to sink in rather than to form erosive streams, and are commonly composed of gravels resistant to erosion because they represent concentrations of fragments of rock constituting a residue left behind because of their resistance, (Rich, 1911; Bryan, 1940). the topography has been reversed, and what was laid down as alluvium in a valley bottom now holds up the hilltop. Other illustrations of this principle seen in many places on our trip to Iguape were mentioned in our discussion of the results of that trip.

Another indication of either reversal of topography or of relatively recent climatic change was found in an outcrop on the road from Castro to Tibagí a kilometer or two east of the new bridge over Rio Tibagí near the town of that name. This is illustrated by Fig. 26. In that picture, just below the knife (8.7 centimeters long) is a dark layer of pebbles consisting mainly of quartzite and residual limonite lying immediately above Paleozoic sandstone and beneath about 17 to 26 centimeters of loamy soil which supports the present grassy vegetation of the region. The layer of pebbles is evidently a lag concentrate of the pebbles derived from the underlying sandstone and from secondary incrustations of limonite which are common on the weathered surface of the sandstone. Their concentration immediately above the sandstone and beneath the soil suggests that while they were being deposited, the vegetation cover was so ineffective that sheetwash removed all of the finer materials, leaving only this residue of the coarser more resistant quartz, quartzite and limonite. Later, conditions appear to have changed, permitting the deposition of the fine, loamy, loess-like material which makes up the overlying soil. A similar condition was noted west of São Roque in the State of São Paulo. In both instances I can think of two possible explanations. One is climatic change as just described. Another is inversion of the topography, with the immediate site of the deposit under discussion being once the bottom of a small hillside gully where the gravels were accumulated and later, when, as a result of inversion of topography as described in preceding paragraphs, that valley bottom came to be on a spur between gullies, ordinary sheetwash deposited the finer material over the gravels. The distribution of the gravels which in both instances is sheet-like as shown in Fig. 26 favors the interpretation first mentioned.

F) EXCURSION FROM SÃO PAULO TO ITATIAIA, PETROPOLIS, NOVA FRIBURGO, AND RIO DE JANEIRO.

This excursion was taken under the guidance of Professors Ruy Ozorio de Freitas and João Dias da Silveira. Features of special interest studied on the excursion were: evidences of glaciation at the higher altitudes on Mount Itatiaia; the São Paulo and Paraíba basins and the materials filling them; dome forms in the ranges around Petropolis, Therezopolis, and Rio de Janeiro: and the problem of the nature of the Serra do Mar escarpment.

a) Evidences of Former Glaciation at the Higher Elevations on Mount Itatiaia.

The establishment of a national park and the construction of an automobile road have made accessible the high upland of Mount Itatiaia west and northwest of the highest peak, Agulhas Negras.

The entire summit region is composed of a coarse alkaline intrusive rock (pulaskite) having a granitic texture and behaving like granite with respect to the agencies of erosion. The summit region of the mountain, where we visited it, has comparatively small relief and consists of hills of old-age aspect separating a series of flat basin-like stretches.

Such basins are separated along the drainage courses by narrows formed by low rocky barriers or by accumulations of boulders of possibly morainic origin. In all this upland region the rock is very fresh and reveals little evidence of chemical weathering. No considerable residual soils of decomposed rock were seen. In the bottoms of the basins the streams are flowing on accumulations of peaty matreial. Many of the smaller rock basins contain small lakes, as shown in Fig. 34.

The whole aspect of the region strikingly resembles that of strongly glaciated regions of similar relief and rock character. No small-scale striae were found in the brief time at our disposal, but what is interpreted as large-scale glacial fluting is conspicuous in many places. This is especially well shown in Fig. 35, a short distance above and to the left of the center, where the fluting is essentially horizontal and the smooth surfaces have been stained by water running down over them, but are not deeply grooved into "canelluras" such as are so conspicuous on the Agulhas Negras and in other places where the rock has been long exposed to the weathering.

Fig. 34 — Stereo pair on upland of Mt. Itatiaia. Small lakes and swampy ponds lying in rock basins are common in the valley bottoms and on the lower slopes These have every appearance of having been produced by glacial erosion and plucking.

Fig. 35 — Stereo-pair showing nearly horizontal large-scale fluting on valley side. This is typical of glacial erosion, but is difficult to explain by non-glacial agencies. Pitted boulders at lower right are believed to be pot holes made by a glacial torrent. For a closer view of these boulders, see Fig. 36.

Fig. 36 — Stereo-pair showing enlargement of area shown in lower right corner of Fig. 35. Seeming limitation to a small area suggests the pits are potholes made by a glacial torrent rather than products of differential weathering.

An interesting feature which may be noted in the right foreground of Fig. 35 is that most of the boulders in the bottom of the valley there show potholes (Fig. 36) which, it is suggested, may have been formed by a glacial stream at that point, which is at a constriction of the valley at the lower end of a broad, flat basin. De Martonne (1940, Plate VI, B, p. 124) photographed these or similar potholes and interpreted them as products of chemical weathering, but I doubt his explanation because, in my observation, such features were restricted to places near valley bottoms where the rock may have been exposed to the action of glacial torrents.

What seems to me to be the most convincing evidence of glacial action may be seen on the panorama Fig. 37 showing the western side of Agulhas Negras and the valley west of its northern extension (seen at the left of the panorama) The valley at the left, which descends toward the right, has the typical U-shape of a glaciated valley. Its floor is essentially bare rock, at least in the foreground where the writer examined it closely, and, significantly, talus accumulations such as would ordinarily be expected at the base of a high and steep cliff such as that along the right side of the valley are not to be seen. The valley appears to have been swept almost clean of debris. But at the right of the panorama, in the lee of the Agulhas Negras peak, where the valley widens out, a great accumulation of boulders lies in the very position where it would be expected if we assume it to be a bouldery lateral moraine, but where accumulations of talus would be less expectable than they would be along the base of the cliff farther to the left.

Another conspicuous feature favoring the idea of glacial erosion is that the rocks of the valleyside are notably smoothed except on the higher parts of the Agulhas Negras peak which, presumably, would not have been covered by moving ice.

All the features described above seem to the writer to point to strong glacial action and to the conclusion that the high upland of Mount Itatiaia was strongly glaciated in one of the more recent glacial epochs. The failure, on our brief examination, to find small-scale glacial striae does not seem to negative this conclusion, because the rock is of a nature that does not readily take such striae, or at least does not preserve them on surfaces exposed to the weather since glacial time. Excavation in the bottoms of some of the peat-covered basins where the rock has been protected from the weather might reveal the small-scale striations.

If Itatiaia was glaciated, it is to be presumed that the high mountain mass of Pico Agudo west of the pass followed by the highway from the Paraíba valley near Queluz to Caxambú should also have been similarly glaciated.

The amount of glacial erosion that is indicated on the Itatiaia upland seems to require the presence, somewhere below, of relatively large terminal moraines. Such moraines were not seen in the part of the upland which we visited, but they may possibly exist on the upland lower down in the valleys near its margins. Or the glaciers may have descended from the upland for a short distance into the valleys heading against the southeast face of the escarpment and there deposited their moraines.

It is suggested that search for such moraines would be a next logical step in the solution of the problem of glaciation on Itatiaia. In the area south and southwest of Agulhas Negras such moraines would probably lie in the heads of rather inaccessible, forested valleys, and might be difficult to recognize. South of the pass, in the upper end of the valley followed by the highway as it crosses the pass between the mountain masses of Itatiaia and Pico Agudo, is an irregular topography suggestive of moraines which might actually be moraine and outwash derived at least in part from the mountain mass west of the highway.

It is evident that a decided topographic unconformity exists between the relatively old-age upland in the summit region of Mount Itatiaia and the steep south-facing escarpment by which the upland drops off toward the Paraíba valley. The suggestion has been made that the relatively old-age upland may be a remnant of a former peneplain or old-age surface which has not yet been dissected. Such an explanation may well account for the topographic unconformity and for the general old-age aspect of the upland, but it cannot account for the various features such as lack of deeply weathered rock and residual soil, the smoothing and fluting of the hillsides, and the existence of undrained lake basins described and illustrated above. It may well be, however, that the upland is a remnant of an ancient old-age erosion surface, but if so, in the writer's opinion the surface must have antedated the glacial period and must have been greatly modified by glacial ice in order to produce the features described above.

Fig. 37 — Panorama of the west base of Agulhas Negras. Note U-shaped valley of glacial type at the left; sparsity of talus along the base of the cliff forming the right side of the valley; the fact that the valley bottom is practically bare rock; and the great accumulation of coarse boulders at the right end of the panorama. The latter seems best explained as a lateral boulder moraine accumulated in the lee of the Agulhas Negras peak. The peak rises over 200 m. above the valley bottom in the foreground.

De Martonne (1940, pp. 124-128) described most of the features mentioned above and suggested a glacial origin. What I saw on Itatiaia makes me even more confident than de Martonne seems to have been that a considerable ice field existed on the old-age upland mass of that mountain.

b) Sediments and Geologic History of the São Paulo and Paraíba Troughs.

From my readings previous to and during the 1951 visit to Brazil, and from conversations with various geologists during that visit, I had gained the idea that the São Paulo basin and the Paraíba trough were down-dropped fault blocks which had been partly filled with Late Tertiary (or perhaps Early Quaternary) sediments derived mainly from the higher land bordering the down-dropped areas, and that these Tertiary sediments were now in process of being dissected and removed from the basins by Rio Tieté and Rio Paraíba.

After seeing these basins and their fillings in the course of short excursions around São Paulo and an auto trip to Rio de Janeiro and return, I was led to question my former ideas and to develop a working hypothesis that the Tertiary deposits were made *previous* to the principal faulting at a time when the land surrounding the sites of the present basins was relatively low, and that, later, these sediments were down-dropped by faulting into troughs where they were preserved and are now in process of being removed wherever they lie above the grade of the present drainage.

The evidence leading to the above suggestion is presented below: During an afternoon s excursion with Dr. Freitas and his class to the southeastern suburbs of São Paulo, we visited a large clay pit showing a considerable section of the Tertiary or Early Quaternary beds of the São Paulo basin. They consist of thick beds of unstratified clay and sandy clay between beds of soft sandstone roughly 2 to 3 meters thick. The sandstones appear to have been laid down as the channel-bottom deposits of a meandering river as it swung across its floodplain during its meandering. The origin of such channel-bed deposits is suggested by the accompanying sketch. (Fig. 38)

That the beds here interpreted as stream-bed deposits are, for the most part, sandy rather than gravelly suggests that they are the product of a fairly large stream relatively far from any highland. Certainly they are not of the type which should

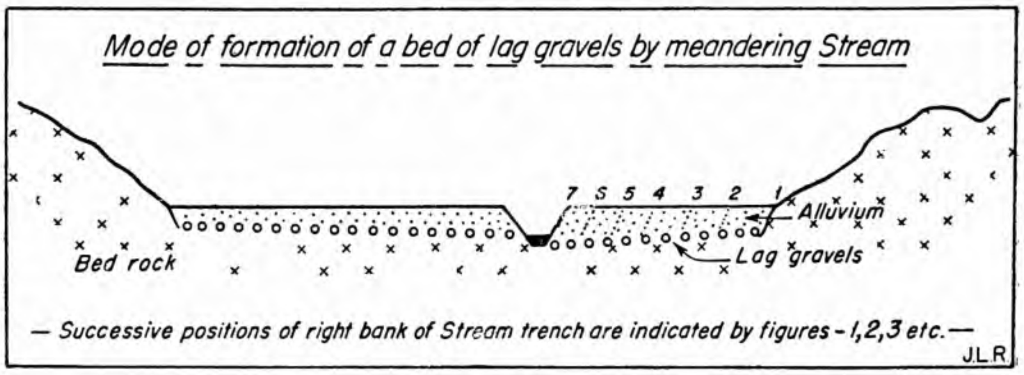

Fig. 38 — Sketch to illustrate the way in which a bed of channel-bottom sands is laid down by a meandering river as it swings across its floodplain. Dotted lines mark successive positions of the channel as the river migrates. The channel gravels remain in place as finer silt and sand are deposited above them after the channel has moved to another position.

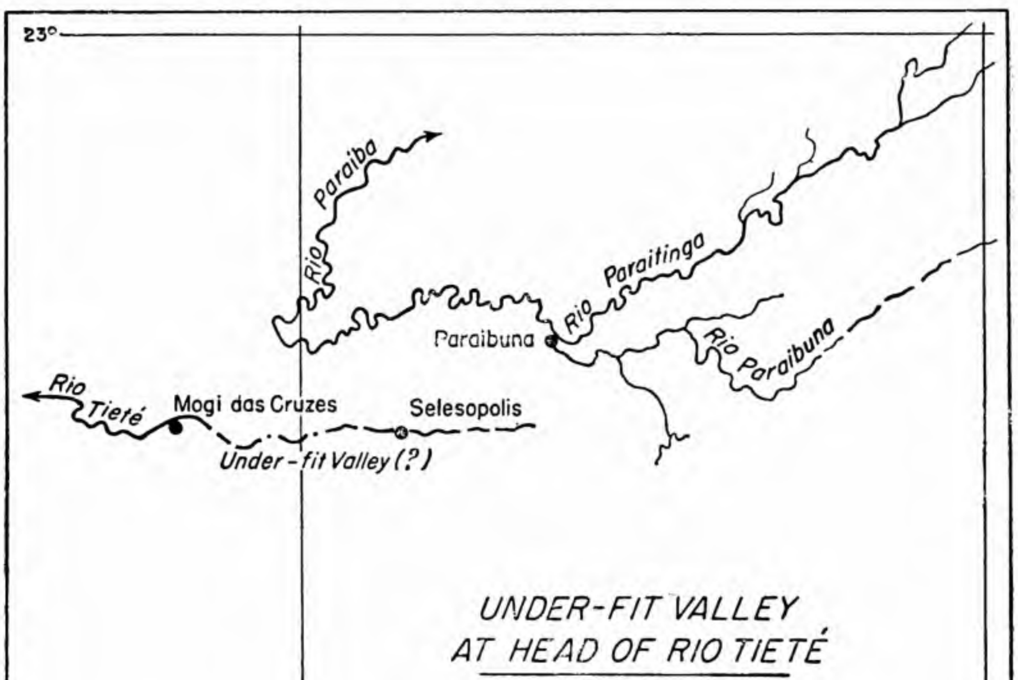

Fig. 39 — Sketch showing drainage pattern east of Mogi das Cruzes, and presumed location of under-fit valley described in text. Drainage was traced from American Geographic Society's 1:1,000,000 Rio de Janeiro sheet.

be expected to have been made by a stream coming from relatively high and nearby mountains such as those which border the present São Paulo basin. The poorly stratified clay between the sandstone beds suggests swamp clays such as might be deposited in the swamps bordering a relatively large slow-flowing and aggrading river. Summarizing: The impression given by the sediments exposed in this clay pit is that of deposits made by a fairly large stream flowing on a broad, swampy plain, rather than in a relatively narrow fault trough bordered by mountains such as border the present São Paulo basin.

This impression is especially strong when one studies the fresh roadcuts along the new São Paulo-Rio de Janeiro highway in that part of its course a few miles west of the point where the road drops down into the Paraíba valley. In that section, the road passes close to the fairly high bed-rock mountains on the north side of the basin, yet the basin sediments there, so far as could be determined by our admittedly rather hasty examination, show no indications of the presence of a nearby mountain mass when they were being deposited. They are such as might be expected to have been laid down in the middle of a large alluvial plain, and to have been carried from a relatively distant source.

These features, though they do not furnish decisive proof, suggest either of two possibilities: (1) That before the Late Tertiary or Early Quaternary faulting, a wide plain of alluvial material lay over the whole region and that the sediments deposited on that plain were later dropped down and preserved in fault troughs; or (2) that moderate structural down-warping preceded the faulting and that the alluvial deposits under discussion were made in these shallow down-warped areas at a time when the bordering land was low and possibly undergoing the final stages of the peneplanation supposed to have been completed in Late Tertiary time. This second hypothesis seems, on the whole, to represent the most likely course of events.

Having been led by the evidence cited to the working hypothesis suggested above, it was interesting to discover that in a report published in 1948 (Ribeiro Filho 1948) Raimundo Ribeiro Filho, quoting and amplifying the ideas of M. Rego, expressed a similar hypothesis with respect to the Paraíba trough and its sedimentary filling.

A considerable dip in the sediments of at least the western end of the Paraíba trough, amounting to 2º, 4º, and even locally 10º, has been mentioned by Ribeiro Filho (loc. cit., p. 16) in the publication cited, and was earlier recorded by Chester W Washburne (Washburne, 1930). Such a dip, while it does not necessarily prove that the troughs were filled previous to the main faulting, does certainly prove that at least part of the faulting occurred after the deposition of the sediments.

With respect to the São Paulo basin, one of the features which has been difficult to explain is the fact that the Tieté River leaves the basin over a bed-rock sill considerably higher than the rock bottom of the basin. Various hypotheses have been suggested for the geological history indicated by this condition, but the principal ones seem to require the following stages: (1) The erosion of the basin; (2) formation of a barrier by faulting or warping which caused obstruction of the drainage; (3) alluviation of the basin; and (4) regional uplift, permitting Rio Tieté to trench the barrier and to cause the dissection and partial removal of the sedimentary filling of the basin.

Using the hypothesis which I have suggested above, a much simpler history offers itself, namely (1) alluviation in Late Tertiary time on a plain or in a sagging area occupying the site of the future basin, this alluviation probably being contemporaneous with the later stages of the peneplanation; (2) faulting, with the lower part of the sedimentary filling dropped below the present baselevel of erosion; (3) Post-Tertiary rejuvenation and erosion to the present condition.

For the reasons given at the beginning of this section, I suggest that special attention be directed to the sedimentation in the São Paulo basin to determine whether, as I suspect, it indicates deposition on a plain before the faulting occurred, and when the surrounding land was low, or, indicates deposition after the faulting, when one or more sides of the basin were relatively high fault scarps.

As to the Paraíba basin, our trip was too rapid for more than cursory examination, but certain features observed in the stretch of the São Paulo-Rio de Janeiro highway between a point which I think was near Queluz, where the eastern of the two highways crosses the Serra da Mantiqueira from the Paraíba valley to Caxambú and the small town of Campo Belo (where the road to Hotel Itatiaia branches off to the north) aroused interest and seemed to have an important bearing on the problem of the history of the Paraíba trough and its sedimentary filling.

The section of highway under discussion utilizes a "through-valley" following close to the base of the Itatiaia escarpment and separated from the main Paraíba trough in which the Paraíba river lies, by a group of rock hills of moderate relief. No single stream now follows this smaller valley. On the contrary, a drainage divide occurs within it, the water of one end flowing to the west, and of the other to the east.

In the new roadcuts in this section of the valley are good exposures of a peculiar material having many of the characteristics of glacial till. It seems to me that careful consideration should be given to the possibility that it is actually Permo-Carboniferous tillite dropped down by faulting and preserved in one of the fault slivers close to the main fault responsible for the Itatiaia escarpment. Other evidence must exist for such an interpretation, because De Martonne (1940, p. 5, Fig. 2) shows several cross-sections in which the Permo-Carboniferous is shown down-faulted in fault slivers in which the rocks dip back toward Mount Itatiaia.

The alternative to explanation as till is that the material in question is actually alluvium of an exceptional composition and showing no stratification. It contains many pebbles and small boulders of quartzite and various other rocks, but, even after considerable search, no fragment of the characteristic coarse-grained pulaskite intrusive rock which constitutes the high mass of Mount Itatiaia immediately to the north could be found, though both large and small boulders of that rock are common in an overlying layer of colluvial or alluvial fan material exposed higher in the same or adjacent roadcuts.

Whether glacial or not, its seeming lack of pebbles from the Itatiaia intrusive, in spite of its nearness and its position at the base of a towering escarpment of that rock, suggests that when the lower material was being deposited, the Itatiaia intrusive had not yet been exposed to erosion. In other words, it suggests that the till-like material containing the quartzite pebbles was deposited previous to the faulting which produced the escarpment either by uplifting the Itatiaia mass or by dropping down the Paraíba trough or by a combination of both.

If this till-like material can be shown to be underlain by typical "Tertiary" sediments like those elsewhere in the Paraíba trough, this suggestion of Permo-Carboniferous age will, of course, be automatically ruled out.

Another problem in connection with this occurrence is the origin of the through valley in which these peculiar materials lie. One possibility is that it may represent a minor down-faulted block separated by a rock barrier from the larger valley to the south which carries the present Paraíba river, and etched out by differential erosion without ever having been occupied by a through stream. Another is that it is in some way related to the meandering of the Paraíba river, but such an explanation does not seem very probable. At any rate, this area is one in which detailed study promises to yield information which may be critical in connection with the broader problem of the origin of the Paraiba trough and its sedimentary content.

c) Underfit stream in Open Valley Possibly Associated With Capture of Headwaters of Rio Tieté.

On the flight from Rio de Janeiro to São Paulo our plane followed for a long distance the general course of a considerable river which, I believe, was the Paraitinga. This stream was flowing on bedrock and actively cutting, but has not yet cut a deep trench. We passed, I think, over or close to the city of Paraibuna and thence flew over Mogi das Cruzes. Before we reached Mogi das Cruzes, in open, unforested country, we noted a wide, shallow, relatively straight valley whose stream, where visible at all, was very small and flowing in intricate meanders whose loops bore no proper relation to the width of the wide, generally flat valley bottom. This valley is totally different in character from the valley of the Paraitinga which we had followed farther east, or any of the other valleys in the region. Its stream is obviously underfit for the valley which it occupies. The valley is, I think, the one shown on the American Geographic Society's map as passing through Sellesopolis and Mogi das Cruzes (See sketch, Fig. 39), and on the map called Rio Paraitinga (not the river of that name which we followed to Paraibuna). We did not see the relations of this old valley to the two branches of Rio Paraíba which join at the town of Paraibuna. The valley in question gives every evidence of being the lower course of a larger stream which has been beheaded by capture. I suggest that it is probably the beheaded upper course of Rio Tieté, which originally was the westward continuation of either Rio Paraitinga or of Rio Paraibuna. It seems likely that a geomorphic investigation in the region around and east of Sellesopolis would solve the problem of the capture of the headwaters of Rio Tieté.

d) Granitic Domes.

The origin of the striking "dome" mountains so conspicuous in the State of Rio de Janeiro has long intrigued geomorphologists. (See De Martonne, 1940, for a relatively recent discussion, with references).

Fig. 40 — Stereo-pair taken from near summit of Stone Mountain, Georgia, U. S. A. A typical «dome» mountain standing as a monadnock above the peneplain of the «Piedmont» province. It is the unjointed — and hence resistant — core of a larger granite intrusive whose outer, jointed portion has been reduced to peneplain level.

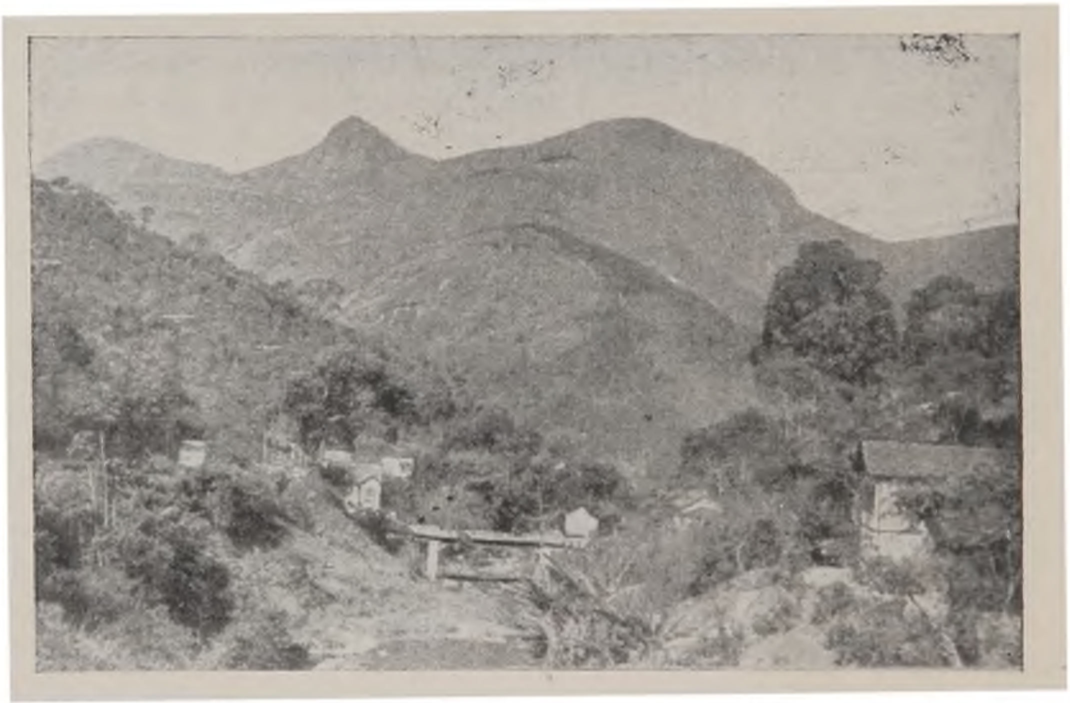

Fig. 41 — Dome mountains on rock of granitic texture a few kilometers north down-valley from Petropolis on road to Itaipava.

It is not my purpose here to enter into a detailed discussion of the Brazilian domes further than to call attention to the fact that the domed forms developed on rocks of granitic type are not, by any means, restricted to Brazil or to the moist tropics. They are common in various parts of the United States, in Africa, and elsewhere. Two splendid examples — Stone Mountain, Georgia, and Mount Airy, northwestern North Carolina, occur in the "Piedmont" province of southeastern United States. Another, equally typical, is found in the "Central mineral region" (Llano uplift) of Texas; numerous examples occur in the Appalachian Mountains of western North Carolina, and several others in New England.

My principal contribution to the problem is this: In every instance which has come to my attention, the feature in common is that the rock is essentially without joints. In several instances, notably Stone Mountain, Georgia, (Fig. 40) and Mount Cadillac, Maine, the "dome" is the central, essentially unjointed part of a granitic intrusive, which is surrounded by a ring of jointed rock, apparently otherwise similar. The jointed ring had yielded to the agencies of weathering and produced a lowland, whereas the unjointed central part remains standing high as a dome.

On my visit to Petropolis, Therezopolis, and Rio de Janeiro, I made no detailed studies of the domed mountains, but, on casual observation every one of them appeared to display a conspicuous lack of jointing (Fig. 41 and 42).

Whether the absence of the jointing is a characteristic of the central part of a typical intrusive stock, while the outer part of the same intrusive body is closely jointed, as seems to have been the case in connection with several of those mentioned, or whether, in some instances, it may be a result of granitization processes may be immaterial if, in either way, masses of rock essentially free from joints are produced.

Examination of the domes of Brazil with these ideas in mind is suggested.

G) SOME OTHER GEOLOGICAL PROBLEMS

a) The problem of the Serra Do Mar.

1 *Generalities*

One of the problems in which I was much interested before the recent return to Brazil was that of the great Serra do Mar escarpment lying between the Brazilian plateau and the Atlantic Ocean or the coastal lowlands which, in some places, lie between the base of that escarpment and the sea.

Some of the observations made during my recent stay in Brazil and some of the thoughts as to their interpretation are presented here in the hope that they may in some measure help in the solution of the baffling problem of the origin of that scarp.

From earlier reading, I had been led to believe that the Serra do Mar is a very recent fault scarp throughout most of its extent, but several observations made during my recent visit cast doubt on that explanation. On automobile excursions in company with Doctors Ruy Ozorio de Freitas, João Dias da Silveira, and Reinhard Maack; on my recent flight from Belem to Rio de Janeiro and from there to São Paulo; on a trip by train to Santos and Itanhaén; through an examination of vertical aerial photographs of the valley of Ribeira da Iguape for that part of its course where it crosses the escarpment, made available by the Power and Light Company of São Paulo; and through a study of the trimetrogon aerial photographs of various parts of the escarpment kindly put at my disposal by the Geographical Institute at Rio de Janeiro, I had considerable opportunity to study the geomorphology of the escarpment for the light which it might throw on the problem of origin.

Specifically, those opportunities were as follows: (1) Coming into Rio de Janeiro and circling for more than two hours over the city before landing gave plenty of time to study the geomorphology of the Rio de Janeiro region. This was supplemented by the flight from Rio de Janeiro on a clear aftrnoon; (2) an auto trip from the Paraiba valley to Rio de Janeiro thence to Petropolis, Therezopolis, and Nova Friburgo and return to Rio de Janeiro by the eastern route, descending the scarp a few kilometers south of Nova Friburgo; (3) trips from São Paulo to Santos and return by auto and from São Paulo to Santos and Itanhaén, and return by train; (4) an automobile excursion from São Paulo to Pariquera-Açu, Iguape, Xiririca, Sete Barras, and São Miguel; (5) Curitiba to Paranaguá by rail and return by auto; (6) study of vertical photographs of the valley of Ribeira de Iguape from a short distance above Xiririca to about ten miles above the highway crossing at Ribeira; (7) study of vertical and oblique trimetrogon aerial photographs of the area from Rio de Janeiro to the mountains west of Paratí on the west side of Bahia da Ilha Grande; and (8) a study of a strip of vertical and oblique trimetrogon air photgraphs exten-

Fig. 42 — One of the dome mountains in Rio de Janeiro. Photo taken from the Corcovado. Note apparent absence of jointing.

Fig. 43 — Panorama, looking north-northwest, north, northeast, and east-northeast from church on hill at Itanhaén. Extremely even skyline at edge of Planalto is well shown in center, and abrupt seaward front of Serra do Mar appears at right.

ding from the mouth of Ribeira de Iguape along the coastal belt past Cananeia to and beyond the São Paulo-Paraná State line.

2. *The Rio de Janeiro Region and Westward to Ubatuba*

Coming into Rio de Janeiro by airplane from Belem on a clear morning, we were compelled by ground fog over the airport to circle the city for about two hours at an altitude of about 5000 feet. This gave an excellent opportunity for study of the geomorphology of the region, and I gave special attention to a search for evidence of relatively recent faulting, but could find none. The topography seems to be controlled mainly by the effects of differences in rock resistance to weathering and erosion, leaving the more resistant rocks standing up as monadnocks in a hilly lowland underlain by the weaker rocks.

The monadnocks, of which the group in and around the city of Rio de Janeiro is typical, are mostly of rocks of granitic texture which, because of sparsity of joints, have proved especially resistant to erosion.

Strong structural lineation such as is clearly visible near the center of Fig. 85 of "The Face of South America" (Rich, 1942) is characteristic of the region. Its trend intersects that of the general coastline at an angle of about 25º, — the structure trending approximately S. 45º W. while the trend of the coastline is about S. 70º W. The aligned rocks are schists, apparently of sedimentary origin, dipping rather steeply to the northwest.

It seems to me that in a region of metamorphic rocks such as this, any Late Tertiary or Post Tertiary faulting should be marked by a fault-scarp, or at least by a fault-line scarp that would be clearly visible in the topography. No such scarp could be seen.

The south base of the mountain mass on which Petropolis is situated has a relatively abrupt contact with the lowland which suggests faulting, but no topographic expression of the faultline could be seen. The area above mentioned and the two straight-fronted mountain masses shown in "The Face of South America", Fig. 86, are the only topographic features in the Rio de Janeiro region which seemed to me to suggest recent faulting, but in each of those instances the possibility remains that they are fault-line scarps or intrusive contacts separating masses of resistant rock from weak rocks.

Large lone mountains on the Rio de Janeiro lowland, such as the Serra da Madureira Fig. 85 of "The Face of South America" which Prof. Freitas tells me is an intrusive of alkaline rock, would seem to me without much question to be monadnocks standing high because of their superior resistance to erosion. This mass, however, and possibly some of the others, may well be bounded by faults on one or more sides, but because only the resistant rock masses now stand topographically high, it is most likely that any such faults, if they exist, are ancient and that the present relief represents fault-line scarps rather than relatively recent fault scarps.

The broad, relatively low, maturely dissected divide region separating the northwest side of the Rio de Janeiro lowland from the Paraíba trough, and well shown at the left margin of Fig. 85 of "The Face of South America" did not reveal any clear evidence of recent faulting as we crossed it by automobile or as I saw it from a distance on the oblique trimetrogon photographs examined in Rio de Janeiro.

In the Petropolis region the dominant mass of granitic rock, very sparsely jointed and characteristically weathering into great rounded domes (Fig. 41) seems to be extremely resistant to erosion. I believe that the possibility must be faced that this superior resistance has been sufficient to cause the present high relief of the Petropolis mountain mass without the necessity of post-Tertiary faulting, and that the relatively sharp break in slope at the present south base of the mountain may represent an exhumed contact between those resistant granites and the weaker schists occupying the lowland. In this connection, the view south from the Belvedere Monument near the top of the climb on the main highway from Rio de Janeiro to Petropolis shows at the left a moutain spur descending gradually toward the lowland in the center and, on the right skyline, another high mountain mass also with its spurs descending toward the same lowland. Certainly no suggestion of faulting is visible in the topography. Rather, it has the appearance which would be expected from the erosion of a belt of weaker rocks lying between the resistant granites on the left and those on the right.

The descent along the highway from Nova Friburgo along the route followed by the railroad shows a similar condition on a smaller scale.

Continuing westward along the coast, we find (Fig. 88 of The Face of South America) a high mountain mass, evidently composed of granitic rock, as indicated by the domed forms in the higher parts of the mass, but showing no evidence of faulting in the topography of its seaward face. In the background we see the maturely dissected plateau draining toward the Paraíba valley. In Fig. 89 of Face of South America we find a similar granitic mass producing an area of exceptionally high relief, but again descending to the coast without any suggestion of a fault scarp or even of a fault-line scarp.

This mountain mass lies immediately east of the relatively low pass through the Serra do Mar occupied by the road and railroad ascending from Angra dos Reis toward Barra Mansa. As we flew directly over the divide where it is crossed by the road and railroad, it was evident that the relatively low pass corresponds with a belt of weaker rocks showing a strong alignment in a southwest-northeast direction. These weak rocks may very likely prove to belong to the same series as that already mentioned as lying west of Rio de Janeiro. It is interesting to note that this belt of weaker rocks is in alignment with and seems to pass directly into the northeastern prolongation of Bahia da Ilha Grande. Also it may be significant that the relatively straight wall of the escarpment shown in the center of Fig. 91 of Face of South America appears from trimetrogon photographs to be composed of granite and may, therefore, possibly represent a contact between relatively resistant granite forming the escarpment and the weaker rocks mentioned above. The area shown, however, is the one of all those which I have seen or photographed along the Serra do Mar which gives the most convincing appearance of being a fault scarp. It is one, therefore, which deserves special study in connection with the alternative possibility just mentioned.

A little farther west, Fig. 93 of Face of South America shows the continuation of the escarpment discussed in the preceding paragraph and the encroachment of the drainage of its face into structurally controlled drainage having the northeast-southwest trend. On that picture no fault-line scarp is evident, and photos (Fig. 92 and 94 of Face of South America) strongly suggest gradual down-bending rather than down-faulting for the Serra do Mar in that region. Farther west however, where the highway descends the escarpment to Ubatuba, the edge of the Planalto drops off abruptly for several hundred feet then descends gradually until submerged beneath the sea. This area is in line with that portion of the scarp north of Caraguatatuba which De Martonne (1940, page 11) figures as a fault scarp. Judging from the photograph and from De Martonne's drawing, it seems highly probable that a fault with displacement of several hundred feet has occurred here at the point of maximum down-bending.

3 *The Region of Santos-Itanhaén.*

It seems probable that the section of the Serra do Mar escarpment crossed by the railroad and highway between São Paulo and Santos has had more influence than any other region in giving rise to the idea that the Serra do Mar escarpment is a great, recent fault scarp. The escarpment here facing the ocean is extremely abrupt and very straight as it borders the Cubatão lowland and certainly has every outward appearance of being a recent fault scarp. In line with it to the southwest is a similar straight wall making the northwest side of the deeply encased valley of Rio Branco which enters the ocean at Itanhaén. These two straight and abrupt sections of the escarpment, being directly in line, would certainly constitute strong suggestive evidence of recent faulting were it not for the fact that between them a bridge of the Planalto extends to full height for several miles out toward the ocean. The question properly arises "How could a fault producing those two prominent escarpments have failed to affect the portion of the Planalto lying between them?"

Recent developments with which I am not personally familiar but which I found described in a report of the Department of Highways written in connection with the construction of the new highway from São Paulo to Santos, as well as information from the Power and Light Company, indicate that detailed studies of the Cubatão area not only fail to reveal evidence of faulting, but show that the Cubatão valley with its steep straight escarpment on the northwest side is actually a slightly overturned, steeply dipping synclinal valley which has infolded slates and limestones presumably of the São Roque formation. Also, in a recent publication (Baixada do Rio Itanhaén, Universidade de São Paulo, Bol. 116, Geografia Nº 5, p. 20-21) Dr. J. R. de Araujo Filho includes a geological map showing that the São Roque series follows the valley of Rio Branco, crosses the bridge between the head of that valley and Rio Cubatão and thence extends northeastward. This situation makes it seem probable that the scarp in that region is a product of differential erosion rather than a fault scarp.

There remains in the Santos region another straight, abrupt mountain front extending northeastward from Mongagua which has every appearance of being a fault scarp or faultline scarp. The lower slopes of the escarpment are composed of fresh rock of granitic type. Here again, however, we are faced with the possibility that we are dealing with a fault-line scarp, or a scarp related to a contact between the granite and weaker rocks rather than an actual fault scarp, and that the lack of significant weathered material on the granite may be an effect of wave action during some relatively recent period of higher stand of the sea. Evidence which might help to solve this problem might be searched for in the small outliers in front of the scarp. If they are composed of rock different from that of the escarpment, that fact would favor the idea of a fault-line scarp or a differential erosion scarp. Otherwise it would seem that, locally at least, we have strong evidence of faulting at this particular locality.

In the Santos region as well as in that west of Rio de Janeiro, the ancient structure is not parallel to the general trend of the Serra do Mar escarpment.

A noteworthy feature of the Santos lowland, which is also similar in that respect to the lowland surrounding Bahia da Ilha Grande and the Rio de Janeiro lowland, is that its topography is much more marked by monadnocks of resistant rock than that on the Planalto. This problem is discussed in a following section.

An excellent idea of the appearance of the Serra do Mar escarpment from the little monadnock on which stands the old church at Itanhaén can be gained from panorama Fig. 43. The skyline of the Serra do Mar in the center of the panorama is striking.

4. *The Iguape-Juquiá Lowland.*

As already described in the account of the excursion to Iguape, we failed to find there any evidence of faulting along the margin of the Serra do Mar, though a problem arose as to whether the trough at Juquiá might be bordered on one or both sides by a fault. The geomorphology of the Iguape-Juquiá region suggests that arching, rather than faulting, combined with differences in rate of erosion between streams taking the long course to the sea via the Rio Paraná and those taking a short course down the face of the arched escarpment would be sufficient to account for the topography observed.

5. *The Serra do Mar between Iguape and Paranaguá.*

To bridge the gap between the portion of the Serra do Mar which we saw on the Iguape trip (which carried us up Ribeira de Iguape as far Xiririca) and Paranaguá, I examined a set of trimetrogon vertical and oblique photographs taken on a flight along the coast from Iguape to a few miles southwest of Cananeia and also took advantage of an opportunity to inspect a set of vertical photographs covering the course of Ribeira de Iguape from a short distance below Iporanga to about ten miles above the crossing of the São Paulo-Curitiba road at Ribeira. These latter photographs covered a space of six or eight miles on each side of the river. The river throughout that portion of its course is flowing in an ingrown meander valley with numerous local patches of swing terraces bordering it. The river is everywhere cutting in rock with rapids every few hundred yards, yet the gradient throughout is surprisingly even. All the tributaries also are essentially graded, but all are cutting on rock. Nowhere could I find any topographic or structural suggestion of a fault that might represent the front of the Serra do Mar. Mature topography seems to arch up essentially at the same gradient as the river, so that there is no escarpment. The spurs, in general, increase in height away from the river. At various places structural alignments represent change in character of the rock and perhaps ancient faulting, with fault-line scarps on a small scale, but we found no recent faults expressed by the topography. Belts of rock with abundant sinkholes (presumably developed in limestone) cross the area at many places, and associated with them are sharp ridges which may be quartzite. Whether these sinkhole-producing rocks and possible quartzites represent the Açungui series is a question. I was puzzled by the numerous sinkholes in the area and wondered if some of them might have been developed in the granite, as are sinkholes which I have seen on the Front Range in Colorado.

On the trimetrogon photographs examined in Rio de Janeiro, covering a flight along the coast westward from Iguape, I noted numerous small residual mountain masses of monadnock type and also, northwest of Cananeia, a remarkable old-age upland of moderate altitude not yet dissected except around the borders by the streams draining it (*). I also noted, a little farther southwest along the coast at a spot whose location I could not determine exactly, an area of a few hundred feet relief which seemed to consist of mesas capped by a nearly horizontal bed of resistant rock. But nowhere along the line of flight could I discover any evidences of a fault of recent date.

In flying into Curitiba in 1939, I took two pictures (Figs. 105 and 106 of "The Face of South America" which record the topography inland from the coast. These pictures show maturely dissected mountain spurs extending seaward, but no suggestion of a fault along the front of the highland, which has every appearance of an erosional escarpment. They show the coastal lowland and monadnock mountain masses rising above it.

The lowland around Paranaguá and Antonina appears to be a weak-rock lowland similar to those near Iguape, Itanhaén, and Santos.

The imposing escarpment between Curitiba and Paranaguá, descended by train and ascended by automobile, is set far back from the coast at the head of a valley draining toward the sea and, I am disposed to believe, is purely a product of differential erosion of a resistant granitic intrusive — resistant enough to rise as a group of prominent monadnocks as seen from the Planalto and as a particularly imposing escarpment when seen from the coastal lowlands. Its situation with respect to the general line of the coastal highland is too far inland for it to be considered a product of any great fault responsible for the Serra do Mar. The monadnock is obviously a massive intrusive. It is relatively poor in joints, and thus its essential reason for being is the same as that for the pronounced monadnocks in and around Rio de Janeiro.

6. *Tentative Conclusions Concerning the Serra do Mar Escarpment.*

The course of reasoning outlined briefly above leads me to think that the Serra do Mar escarpment is not a product of

(*) Could this be a down-faulted or down-arched fragment of the peneplain of the Planalto not yet reached by the dissection now being done by the coastal streams?

a single great fault, but rather, of a combination of epeirogenic uplift on the continental side with downwarping on the oceanic side, accompanied by local faulting in a few places. Strong erosional dissection of the seaward face of the scarp, together with the development of the extensive coastal lowland (much of it now submerged beneath the sea) and the numerous small mountain masses rising as monadnocks above the lowland or as islands above its submerged portion, may well be the product of rapid erosion by the short, steep, seaward-flowing streams, as compared with the relatively slow erosion by streams taking the long course via Rio Paraná to the Atlantic at Buenos Aires. The fact of decided net uplift of the formerly peneplaned Planalto in comparatively recent times is clear from the circumstance that all the rivers, even those having long courses to the sea, are now trenching their valleys and flowing on bedrock for much of their courses, and have numerous rapids. Definite downwarping of the coastal area is indicated by the drowned stream-eroded topography such as that around Bahia da Ilha Grande and from there to Santos, which has been submerged so recently that it has scarcely been modified by the waves, though fully exposed to the Atlantic swells.

Where the axis of down-bending happened to coincide closely with the original drainage divide between the interior and the coast, we find a bold escarpment standing close to the sea, with stream dissection from the seaward side extending only a moderate distance, if at all, inland from the old divide, whereas in areas like that drained by Ribeira de Iguape, where the drainage divide was far back from the coast, we find a rough, maturely dissected region covering a large area extending far back from the coast, and we find Ribeira de Iguape essentially graded throughout and almost everywhere flowing on bedrock, as indicated by numerous rapids. The up-arching which produced the Serra do Mar must have happened long enough ago for the river to have eliminated any nickpoints that may have been produced, and to have developed mature topography over its entire drainage area.

As to the reason for the up-arching of the continent associated with the down-bending of the coastal zone, I suggest that we should look to isostatic transfer of material toward the continent as a result of the long-continued erosion which produced the peneplain on the Planalto and an accompanying downsinking of the margin to supply the material needed to bring about the isostatic balance. For further discussion of this reason for associating up-arching and down-bending, see Rich, 1951 —

"Origin of Compressional Mountains and Associated Phenomena" especially Figs. 1 and 2 and the discussion on pages 1182, 1183, and 1210, 1211.

An important feature which I have not seen mentioned in connection with the problem of the Serra do Mar is the general lack of seismic activity in the region. This, it seems to me, favors a minimum of faulting in connection with the formation of that great escarpment. It seems to be generally considered that the Serra do Mar uplift dates from very late Tertiary into the Quaternary. It would seem that if so great an elevatory movement of so recent date were a product primarily of uplift along a great fault plane, the region should still show considerable seismic activity. Such seismicity, so far as I have been able to learn, has never been reported.

b) Abundance of Monadnocks on the Coastal Lowlands at the foot of the Serra do Mar.

A feature of the geomorphology of the crystalline rock areas of southeastern Brazil which caught my attention and which I have not seen mentioned in any of the Brazilian writings, is that residual mountains, or "monadnocks" produced by the outcrops of the more resistant rocks, are relatively rare on the Planalto, while they are numerous and conspicuous in the area between the foot of the Serra do Mar and the ocean — in fact, also on the shelf extending for a considerable distance out from the coast, as indicated by the islands off-shore, e.g. south of Rio de Janeiro, of Santos and Itanhaén, and elsewhere. Two explanations for the prevalence of monadnocks on the coastal lowland as contrasted with the Planalto have suggested themselves: One is that stocks or other masses of exceptionally resistant rock are more numerous in the belt which is now the coastal lowland than on the Planalto; the other is that on the Planalto the long-continued erosion, ending in peneplanation, finally permitted even the areas of resistant rocks to be eroded down to or near the general peneplain level, so that hard-rock residuals or "monadnocks" are not now conspicuous there, even though hard-rock masses may be as numerous there as in the coastal belt.

If both areas actually have about the same proportion of resistant rock masses, the greater abundance of monadnocks on the coastal lowland may be explained by the more active erosion now in progress there because of the steep gradients of the streams having a short course to the sea. This would permit rapid removal of the weaker rocks, leaving the more resistant masses standing up as monadnocks.

This relation would be the logical result if the Planalto had been brought to its present high level by a monoclinal up-arching at a relatively recent date so as to give the streams on the coastal slope of the arch power to cut rapidly as compared with those taking the longer course to the sea via Paraná river. If, however, instead of the Planalto having been raised as a monoclinal arch, the coastal lowland had been formed by down-dropping of the southeast side of the Planalto along a great fault, the down-dropped block should show the peneplain type of topography like that on the Planalto instead of the lowland-and-monadnock topography actually existing. The same would be true if the coastal lowland had remained stationary while the Planalto was uplifted by a fault. This consideration seems to me to favor the hypothesis that the Serra do Mar is primarily a product of up-arching rather than of faulting.

The problem posed by the observations discussed above is: Are resistant rock masses which might produce monadnocks more abundant in a belt which is now occupied by the coastal lowland than on the Planalto? Or is the observed difference caused entirely by differences in the rate of erosion promoted by differences in distance to the sea along the respective drainage lines of the two regions? The above geomorphic observations bear also on the problem of the origin of the Serra do Mar.

c) On the origin of some of the schists in the Crystalline Complex of Southeastern Brazil.

A petrographical problem which merits more attention than, unless I am mistaken, it has received in Brazil is that of the origin of the various types of schists in the metamorphic complex.

In several areas, I noted the presence of a thick sequence of remarkably uniform biotite schists which appeared to be weak when exposed to the intense chemical weathering characteristic of the region, that did not seem to me to have been of sedimentary origin, but rather, to have been derived from intermediate-to-basic extrusive rocks which, by a relatively high grade of "stress" or "regional" metamorphism, had been converted into biotitic and hornblendic schists. I noted such rocks especially along the road from São Paulo to Santos in the stretch from the southern border of the sedimentary fillings of the São Paulo basin to the edge of the Serra do Mar escarpment, and in the lowland crossed by the road from Registro to Pariquera-Açu.

Two features of schists derived from volcanic rocks distinguish them from schists derived from sedimentary rocks: First their mineralogical composition, which is likely to emphasize biotite and hornblend together with only moderate amounts of quartz, while the schists derived from sedimentary rock, especially from shales and alternations of shale and sandstone, feature muscovite as a prominent mica, and relatively abundant quartz, grading to almost pure quartzite for the layers originally composed of siltstone or sandstone. The second feature is their massiveness and uniformity throughout considerable thicknesses, in contrast to schists derived from shale-and-sand sedimentary sequences, where the original alternations in beds from shaly to sandy are faithfully represented in alternating changes in the composition of the schists.

On the basis of very limited observation, which was sufficient only to induce me to state the problem for the consideration of Brazilian geologists, I make the suggestion that careful study of the schists in the crystalline complex of southeastern Brazil is likely to reveal the presence in the Pre-Cambrian of a thick complex of extrusive volcanic rocks now metamorphosed to biotitic and amphibolitic schists, and perhaps, for some of the more acid extrusives of the complex, to muscovitic and sericitic quartzose schists, all lacking the distinctive alternating changes in mineralogical composition produced by bedding so characteristic of schists derived from sedimentary rocks.

Because of the considerable amount of iron which they contain, schists derived from the intermediate and basic volcanic rocks would ordinarily be weak when exposed to chemical weathering, and would produce lowlands with respect to areas underlain by rocks chemically more resistant.

In this connection, I would like to call attention to the "art" of interpreting the nature of the original crystalline rock from its weathered residue such as is exposed in roadcuts, stream beds, and other artificial and natural excavations. This art is capable of being developed to a point where a geologist can do a surprisingly good job of mapping without seeing fresh rock except sufficiently to enable him, at the beginning, to develop his art of interpretation for the particular types of rock found in the region in which he is working.

H) CONCLUDING NOTE

It may seem unduly presumptuous for a geologist from another hemisphere who has spent only 100 days in Brazil to present a discussion like the preceding of the numerous baffling problems of Brazilian geology which came to his attention; but the aim of this discussion is not to seem to have settled any of those problems, but, rather, to present the thoughts and point of view of an outside geologist who feels that an independent approach based on first-hand observations and not too much influenced by detailed knowledge of what has previously been written, has decided value because of the fresh approach.

Whatever of good may come from the preparation of this summary of impressions and ideas will be due in large measure to Dr. Viktor Leinz who made possible the excursions and suggested the recording of these notes and ideas, and who, in numerous informal discussions of the problems of Brazilian geology, proved a stimulating creator of interest in them. To Anna Maria Vieira de Carvalho thanks are due for a splendid translation into Portuguese of my brief abstract of the report.

In summarizing his impressiones of his Brazilian journeys, the writer, owes more than he can express to his companions on the excursions, Doctors Mendes, de Freitas, da Silveira, and Maack, who provided a background of information on the geology of the areas visited and on the problems discussed, and who in the give-and-take of numerous discussions contributed greatly to the preparation of this paper. With some of the suggestions here made, they probably will not agree, and for none of them should they be held responsible. My hope is that the ideas here presented may prove stimulating and may, in some degree, aid in the final solution of some of the problems here discussed.

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