DISTORTION OF CONTINENTAL ASIA

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ABSTRACT

Asiatic arcs are capable of being divided into several classes according to type and distribution. Those which run along and parallel to the Pacific border form several peripacific chains, including the festoon islands, with the convex front of each individual arc facing south-east. It is found that these arcs have resulted from modified waves of anticlinoria of Neocathaysian or generally N.N.E. trend due to the interception and repression at regular intervals by powerful E.-W. zones of compression. The second class comprises trans-continental chains of the ϵ type of arcs arranged on the whole east-west with their main convex front facing south. They are traced right across the Asiatic continent from the Pacific border to the eastern Mediterranean except in the Himalayan and Kangtien-Burma geosynclines and in the unruly mass of Tibet.

These fold-arcs arising from various parts of the abandoned site of the Tethys stand in strong contrast to the shield-like mass of India, where fractures of definite orientation predominate at least since the latter part of the pre-Cambrian era.

From the evidence furnished by distorted clay it can be shown by analogy that both the peripacific and trans-continental arcs are due to southward movements of parts of the continental mass. Such movements are in agreement with the requisite cause for setting up horizontal pressure to produce lineaments in Gondwanaland.

PREAMBLE

IN the fall of 1945 when the writer, like many others, was lying in Chungking seriously ill and exhausted under the strain of the recent war, a letter from Professor Birbal Sahni came in one morning through the thin line of communications of those days. That letter not only conveyed the warmth of friendly sympathy, but also contained illuminating hints on certain promising scientific undertakings which imparted, in no small measure, revitalizing interest to a life in distress. Fresh hope shone in the almost failing eyes of the afflicted.

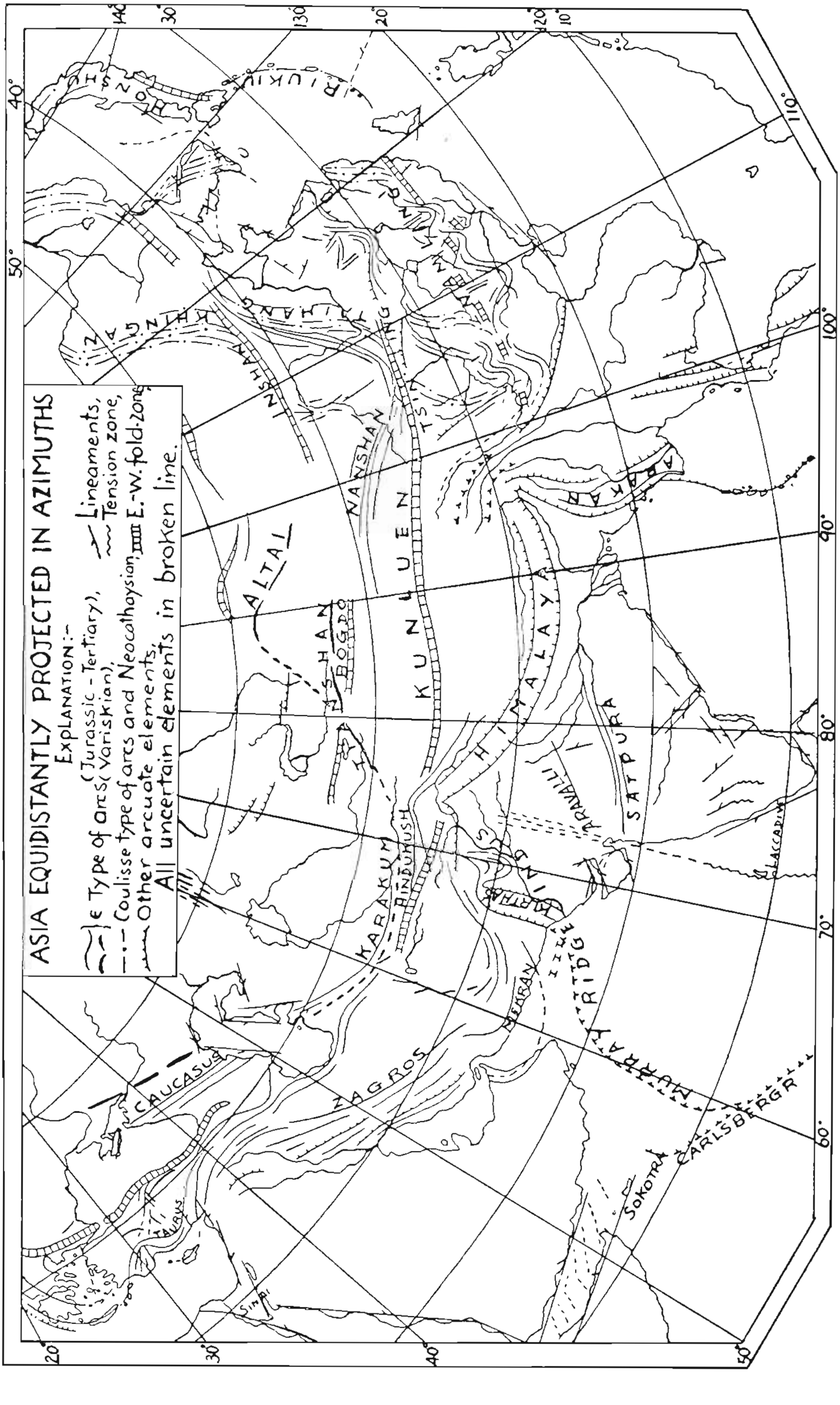
Professor Sahni alluded to, among other things, subjects so remote from orthodox geology as fossil magnetism, in the hope of securing possible evidence for the successive stages of diastrophic development leading to such extraordinary distortion of the crust of the earth as the hair-pin bend in north-eastern India. This is just one example of how his searching and restless intelligence was probing the dark corners of vast, and as yet unexplored, fields. His inspiring remarks led my own thought wandering over India as a landmass which has stoutly withstood through the ages the onslaught of raging tectonic storms from the abandoned sites of ancient waters. As one groping on the Tethyan side, I quickly responded with the promise to make an attempt to summarize, the relevant facts and deductions in a paper to be presented on a suitable occasion to our learned Indian colleague.

Nearly five years passed. Throughout these years it could not be imagined that an unkind fate could deprive science of a man who did so much in the past to open up new paths and had so much more to contribute in the future; and that the present writer who happened to make a promise under circumstances when the future seemed utterly uncertain shall now have the opportunity to fulfil it, although as a sad duty. Professor Sahni's contribution to palaeobotany is well known. May it not be out of place here to give expression, though in an inadequate way, of our appreciation of the wide range of his interests by making known how the writing of the following pages came about.

ORIENTATION OF ARC-CHAINS AND LINEAMENTS

Students of Asiatic tectonics now seem generally agreed that the well-known Suessian arcs are by no means of the same type and the same origin. This may also be said of certain classes of Argand's virgations. There are, however, two distinct classes of arcs apparently originated from related movements of parts of the continent. They occur in chains, each being characterized by arcs of a specific type, which are distributed and oriented in a definite way.

The first of these classes, namely the peripacific chains, comprises several trinomial series of simple arcs, i.e. arcs formed by a simple bending of fold-zones. They gather


ASIA EQUIDISTANTLY PROJECTED IN AZIMUTHS
Explanation:-
ε Type of arcs (Jurassic - Tertiary),
(Variskian),
Coulisse type of arcs and Neocathaysian,
Other arcuate elements,
All uncertain elements in broken line.
Lineaments,
Tension zone,
E.-W. fold-zone,
ALTAI
NANSHAN
KUNLUEN
HIMALAYA
KARAKUM
HINDUKUSH
ARAVALLI
SATPURA
ZAGROS
CAUCASUS
TAURUS
SINAI
SOKOTRA
CARLSBERG R.
MURRAY
RIDGE
ARAKAN
BOGDO
TSIN
LACCADIVE
RIUKIU
KHINGAN
SHAN
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
10°

Map

round the Pacific border with their coulisse-like fronts all facing south-east. The second class, namely the trans-continental chains, embraces a polynomial series of arcs of the ϵ type formed by syntaxis of sinusoidal fold-zones. As a whole they run east-west; but occasionally they are arranged tandem from north to south. To these two classes may be added a third comprising those mononomial arcs which generally trend north-west to south-east, convex to the north-east, and typically represented by the Nanshan and Tapashan ranges.

No arc belonging to these three classes bears any relation to the unique Himalayan arc, or has any characteristics in common with that mountain arc which sweeps round the west border highlands of China, Burma, and the Andaman, Nicobar and east Indian islands. This grandiose, complex arc with its prolonged geosynclinal history, essentially meridional trend and convex front to the west or south-west in its southern part, only finds a parallel, on a still grander scale, in the Cordilleras of the North and Central Americas, and another, less certain, in the Murray and Carlsberg Ridges found by Wiseman and Sewell to inflect in between the longitudes of about 58°-68° E. under the Arabian Sea and the western Indian Ocean. It is not improbable that the Dinaride-Hellenian arc also presents a diminutive example of this type of arcuate structure in a partial sense.

No attempt will be made in the present paper to deal with these various special arcs. And for economy of space only some of the salient features of those belonging to the first and second classes will be enumerated in a tabular form.

The Coulisse Type of Arcs and Cathaysian Lineaments — The coulisse type of arcs consists of crescentic zones of anticlinorial folds involving rocks up to Upper Cretaceous in age. They are arranged in three linear series running parallel to one another, and more or less to the Pacific border of the Asiatic continent. The area embraced by them is largely the site of the old landmass Cathaysia and the Cathaysian geosyncline of Palaeozoic and early Mesozoic times. The steeper limb of the anticlinoria is generally on the south-eastern side as is the convex front of the individual arc, though over-thrusting is not always directed south-east. There is a general tendency for the landmass behind the raised front of the arc to broaden out to form a plateau, only to be compensated further inlandward by a basin or a belt of subsidence. Oro-igneous activity has migrated from the inner to the outer zones since the latter part of the Jurassic; but its intensity depends more closely on the nature, rather than the geographical position, of the terrain affected.

There is hardly any question that these coulisse-like arcs as well as the island festoons have resulted from folds of N.N.E. trend inflecting to the W.S.W. against the robust E.-W. fold-zones; for in numerous cases the individual fold or plane of over-thrust forming the arc can be traced on the one hand to a typical Meso- or Neocathaysian fold running N.N.E., and on the other to the W.S.W., merging ultimately into an E.-W. zone. A remarkable regularity in the tectonic plan of eastern Asia is largely attributable to this similarity of relation between these arcs and the E.-W. zones (*see* TABLE I).

Structurally, however, the arcs are not all equally well developed. Nor are the depressions all of the same type. The Honshu arc is broken right across its middle with unmatched development of rocks in its north-eastern and south-western parts. The Korean and Tientai-Taiyun-Minnan arcs are partially foundered into the sea. If Ph. H. Kuenen's terminology may be applied to the depressions, we may consider the Dolonor, Shensi and Szechuan basins as of the nuclear type, the north and south Manchurian plains, Pohai, north China plain and central Yangtze basins as intramotane troughs, the Yellow Sea as a discordant basin and the Okhotsk Sea, the Sea of Japan and the East China Sea as partially discordant basins. From the point of view of tectonic evolution of the Cathaysian region it does not seem disproportionate to regard the intermediary and marginal series of depressions as sequent geosynclines in the sense of Ch. Schuchert; for they are obviously progenies of the more ancient Cathaysian geosyncline. They are, therefore, sometimes called Neocathaysian geosynclines.

The breaking down of parts of the arcs and the development of the discordant aspects of the basins are mainly due to faulting which has resulted either concomitantly with, or subsequently to, the rupture along powerful lines, in a lineaments pattern with one set of fractures running N. 10°-20° W. and the other N. 65°-80° E. Among

TABLE I – COULISSE TYPE OF ARCS AND THEIR RELATED FEATURES

I. INLAND ZONE			II. INTERMEDIARY ZONE			III. MARGINAL ZONE		
DEPRESSION	ELEVATED LAND	FOLD-RANGE & ARC	DEPRESSION	ELEVATED LAND	FOLD-RANGE & ARC	DEPRESSION	ELEVATED LAND	FOLD-RANGE & ARC
Dolonor Basin	Mongolian Plateau	Great Khingan, Yenyuanshan arc	North Manchurian Plain	South-eastern Manchurian Highland	Sikhota-Alin, Tungus arc	Okhotsk Sea		Kuril arc
				INSHAN E.-W. ZONE				
Shensi Basin	Shansi Plateau	Taihang Range, Hiungerh arc	South Manchurian Plain, Pohai, N. China Plain	S. Manchuria, Shantung, N.-W. Korea	Taipaksan, Korean arc	Sea of Japan		Honshu arc
				TSINLING E.-W. ZONE				
Szechuan Basin	Osi-Kweichow Plateau	Shuehfengshan Range, Miaoshan arc	Central Yangtze Basin	Coastal highland of Chekiang & Fukien	Tientai, Kuatsang, Taiyun Ranges, Minnan arc	East China Sea		Riukiu arc
				NANLING E.-W. ZONE				

the outstanding examples of the former set may be named the Hsiaokiang fault in north-eastern Yunnan, the transcurrent fracture across the mid-western part of the Kuangsi platform, the Tayishan zone with a narrow band of injected porphyritic granite in southern Hunan, and many others in Chinese coastal provinces. It is probably these fractures that have primarily determined the western and eastern coastlines of the Luichow Peninsula in southern Kwangtung, many of the inlets near Hong Kong, the south-western coast of Formosa, the coast of northern Kiangsu, western and north-eastern coasts of Korea, the Bungo Strait between Kyushu and Shikoku and the Itoi-Shizuoka-Bonin Islands line of rupture. The characteristics and extensive distribution of this set of tectonic features in China are fully considered in a paper by L. P. Wu who rightly names the Tayishan as a classical example. Hence the term Tayishanian is proposed to denote their general trend. A distinction must, however, be made between these fractures and the north-westerly curvilinear fold-zones of the Tapashan type which differs in origin.

The other set is exemplified by a large transcurrent fault in north-eastern Yunnan associated with, and to the east of, the Hsiaokiang fault, a number of important thrusts on the north-western border of Kuangsi and numerous transcurrent faults often accompanied by local folding and thrusting of the same trend in Chinese coastal provinces, more especially in Fukien, Chekiang and Shantung. In Chekiang they are known in certain cases to have determined the distribution of the red rhyolite and some dacite of the Cretaceous age, and the latter are also in some cases known to be sliced by them. In Shantung they occur as large transcurrent faults of which the one running along the southern foot of the Taishan range is perhaps the most typical. Hence the term Taishanian is proposed to denote their general trend. That this group of fractures is no less important than the Tayishanian is further shown by their wide prevalence in southern Manchuria and northern Korea, where many imposing ranges of the block type are determined by faults belonging to this set of the Cathaysian lineaments. The southern coast of the Korean Peninsula and the northern and southern shores of the Seto inland sea of

Japan are likewise controlled by congeneric features.

Numerous instances can be given to show the intimate association, in the geographical as well as geological sense, of these two sets of fractures with each other and with the Meso- and Neocathaysian folds. It seems natural to regard them all as products of a single tectonic process.

The ε Type of Arcs — Tectonic systems of the ε type have been described on several occasions in connection with discussions on the structure of various parts of China (LEE, 1933, 1941). We may now claim a fuller understanding of the characteristics and distribution of this common structural type than when it was first recognized some twenty years ago (LEE, 1929). A generalized description of its salient features in the light of accumulated field experience since that time may, therefore, prove to be desirable.

Each individual system of the ε type of arcs consists of two zones of strong tectonic disturbance due to horizontal compression usually directed north-south. One, comprising folds and their related thrusts and cross faults, stretches on the whole east-west but with its axis describing a sinusoidal curve convex to the south in its central part, termed the main or the frontal arc, and to the north in its flanks, called the reflex arcs, the latter being generally more broadly curved. The other, composed either of crowded folds with related thrusts and faults in an anticlinorium, or of a broad arch rent into lineaments, runs rectilinearly north-south with its axis closely following the axis of bilateral symmetry of the whole system and is always confined to the concave side of the main arc. It usually narrows down towards the south and finally dies out before the apex or vertex of the main arc is reached. This sagittal zone is named the backbone.

Between those two zones usually spreads a horseshoe-shaped and often more or less depressed area, called the betwixtland, in which orogenic stress is least active.

The fold-zones may be partially, but hardly ever completely, replaced either by radiating faults in fan-shaped arrangement (only applicable to frontal arc) or by lineaments, the bisectrices of the angles that they contain being perpendicular and parallel to the folds which should, but fail to, arise. Notable departure from the simple, normal form is generally attributable to one of two reasons: preoccupation and contemporaneous or subsequent disruption. In many cases the ε system is developed in a region which had been already occupied by another tectonic system. As a consequence parts of the old system may be suppressed by, or incorporated in, the new. In other cases new or contemporaneous tectonic elements may break in and disrupt the simple ε form either through the compounding of two systems of the same type or by the invasion of another. These complications are tectonically expressed in four different types of relation between the elements of the different systems involved: superimposition, juxtaposition, transposition and interposition. Examples of these relations will be found in the accompanying tables (TABLES II & III).

Field experience has again and again led us to the conviction that the possession of a knowledge of certain vital parts of this tectonic system does not only prove to be of help for the correlation of other component parts which are known to exist but unknown in their tectonic relation because of lack of continuous exposure or of stratigraphical data, but also offers a guiding principle in mapping out hypothetically certain major structural lines in a complex tectonic region to be explored. The backbone and reflex arcs are particularly of predictive value. It is on this basis that many a component part of the ε system has been identified; and it is also largely on this basis that we are able to determine the age of those systems which have been recognized and confirmed in recent years (*see* TABLES II & III). Those occurring in southern China commenced to develop towards the latter part of the Jurassic culminating in the Upper Cretaceous, except the Kuangsiide which is shown to have dated back to Variskian times (CHAO, 1947; CHANG, 1942). The Tauro-Anatolide apparently came into existence at the end of the Cretaceous, but probably did not attain its full growth until the Middle Eocene. The Iran-Afghan arc only arose in post-Oligocene times if we disregard its history during the geosynclinal stage of development. The great Eurasian system with the Urals as its backbone and a frontal arc sweeping round the southern border of the " Russian Platform " and reflexing into the heart of Mongolia, is obviously of Variskian age and, therefore, falls out of our present scope of discussion.

TABLE II — DISTRIBUTION OF THE ε TYPES OF ARCS IN SOUTH CHINA

	Kangtienide	Kunmingide	Chiensiide	Kuangsiide	Yuenpeiide	Hsiangnanide	Kangnanide	Minsiide
Eastern reflex arc	Mainly in Weining & Shuicheng districts (about lat. 26°40′-53′ N., long. 104°10′-40′ E.); partly in Hsuanwei	Probably in Loping district, eastern Yunnan, & Hsinyi & Hsinjen districts, S.-W. Kweichow, only partially identified	Thrusts in Palaeozoic limestones on the northern & north-eastern sides of Kweiyang Basin	Overthrusts in Devonian limestones in the neighbourhood of Yungankuan, N.-E. Kuangsi & western Hunan	Probably north of Lienping district, N.-E. Kuangtung	The Wukungshan & hills of Chaling, Yuhsien, eastern Hunan, Lienhua Ningkang, Western Kiangsi, involving Devonian & metamorphics	From Shihcheng in S.-E. Kiangsi to between Ninghua & Kienning in Fukien, Cretaceous red beds involved, granite intrusions frequent	Neighbourhood of Sichin, near Nanping
Eastern wing of the main arc	South-eastern Huicheh Carbon. Perm. Trias. overthrust to N.W.	Mileh, Luliang, Lusih districts, folds involving Triassic & older strata	North-easterly fold ranges from Anshun to Chingcheng, central Kweichow	Yaoshan & Lungshan Ranges with a core of pre-Devonian metamorphic eastern Kuangsi	A zone of north-easterly folds between Yinteh-Wongyuan & Fukang-Hsinfeng districts with intrusive granite	Compressed folds of Palaeozoic & Jurassic rocks in Anjen, Yunghsin, Tzebsin districts, S.-E. Hunnan	Folds & overthrusts in Palaeozoic rocks from Shihcheng to Huichang juxtaposed with Neocathaysians	High ranges on the south eastern side of the Shachih river metamorphics & Jurassic rocks involved
Vertex	Middle of Kiulung thrust, neighbourhood of the Taheishan east of Chaotzeshan	Between Tunghai & Chuchih, south of the lake districts of E. Yunnan	Vertex of innermost fold-arc at Shachiamachang (about lat. 26°40′ N., long. 105°36′ E.)	Between Kulah & Kuntang villages, S.-E. of Pingyang (about lat. 22°50′ N., long. 109°5′ E.)	Lutipo, S. of Yueyuan, N.-W. of Yinteh (about lat. 24°30′ N., long. 113° E.	Vertex of inner arc probably S.-E. of Hsintien (about lat. 25°48′ N., long. 112°20′ E.) outer arc at Hotientuh, S.-E. of Lanshan	Vertex of innermost arc at Tachiao village S.-E. of Sinfeng (about lat. 25°22′ N., long. 115° 5′ E.)	S. of Huangli about 10 km. S. of Yungan city; (about lat. 25°55′ N. long. 117°20′ E.)
Western wing of the main arc	Probably in Hueilih, S.-E. Sikang	East of the upper reaches of the Red river; apparently block-overthrusts in Sinian & older strata	North-westerly fold ranges between Chibkin & Langtai	Tamingshan & Tuyangshan Ranges, largely folded & overthrust Devonian rocks	North-westerly folds extending from Yinteh to Yangshan, thence interrupted	Inner arc from Hsintien to Chiyang, outer arc from Lanshan to Taohsien, S.-W. Hunnan	Folds & overthrusts involving Middle Carboniferous transposed across metamorphics of N.-S. trend in S.-W. Kiangsi	Metamorphics & folded Permian strata with strong N.-W. cleavage transposed across north-easterly folds in Mingchih Chinliu districts
Western reflex arc	Still unexplored	Undetermined	Around the Shuicheng & Weining districts, common with eastern reflex arc of Kangtienide	In Chenfeng, Hsinjen, Hsinyi districts, S.-W. Kweichow. Jurassic thrust upon Trias, common with Kunmingide	Undetermined	Partly in common with Kuangsiide & partly cutting into the latter by thrusts along the Tayungkiang	In common with the eastern reflex arc of the Hsiangnanide in Lienhua & Ningkang districts	In common with the eastern reflex arc of Kangnanide
Backbone	Meridional anticline involving Sinian & Palaeozoic strata, eastern side of the Hsiaokiang (about lat. 26°25′-56′ N., long. 102°53′ E.)	N. of the Kunming Lake & along the course of the Putuho, overfolds & overthrusts of meridional trend involving Triassic & older rocks	Meridional ranges between Picheh & Tating (about lat. 26°40′-27° 30′ N., long. 105°15′-38′ E.	Pre-Devonian metamorphics west of the Linkiang with highly compressed meridional folds juxtaposed with Neocathaysians	Yaoshan anticline in northern Kuangtung, between Lochang & Pingshih, subsiding at Yueyuau	Meridional anticlinorium from between Tanshih & Yungfeng, central Hunnan, to the N. of Shangning (about lat. 26°28′-27°35′ N., long. 112°20′ E.)	From Tachiao to the Hsiashan hill-range west of Yutuh & again powerful overthrusts from E. to W. in Patuh district, West of Yungfeng, trending generally a few degrees east of north	From the Nanchinshan, N. of Yungan, to the meridional thrusts & dykes in Jurassic sandstones, W. of Tsianglo
Other particulars	Cut by transcurrent faults along Hsiaokiang (Tayishan trend) & passing through Huicheh city (Taishanian trend)	Often juxtaposed with Neocathaysian elements & sometimes interposed between E.-W. zones in the eastern part. Faults predominating towards west; possibly two systems in tandem relation	The Sanchaho roughly follows the general strike of the main arc	Interposed between elements of the frontal arc occur E.-W. zones; large transcurrent faults of Tayishanian trend cut across the eastern wing & betwixtland	Disruption due to Neocathaysian elements frequent	Often disrupted by Neocathaysian & E.-W. elements. Western reflex arc more or less squashed by the Shuehfengshan range & the Miaoshan arc	Frequently disrupted by E.-W. zones Neocathaysian folds & granite intrusions; partly covered by red beds	The backbone is in several sections shattered by E.-W. faults. Considerable disturbance in the main & reflex arcs is caused by the Minnan arc

TABLE III — EASTERN MEDITERRANEAN AND WESTERN ASIATIC ARCS

	Hellenian Arc	Tauro-Anatolide	Iran-Afghan Arc
Eastern reflex arc	Folded marine Cretaceo-Jurassic, Flysch & some Trias in Arkot, Bulancik, Ala & southern Ilgaz Dag forming crescentic zones in northern Anatolia being cut off by northern Ilgaz massif & Pontid zone towards east	Two crescentic fold-zones separated by relatively undisturbed young formations: northern zone of Cretaceo-Tertiary strata almost wedged out to the south-east of Ercincan, southern zone characterized by white marble around Kurdistan	Arcuate range running from south of Pamir along the course of the Panjah river, and then to join the Karakoram to the south-east
Eastern wing of the main arc	Partly forming the " faisceau de plis d'Ankara ", partly subsided or suppressed under the Konya Plain, reappearing to the south-west of Afyonkarahisar, & continuing to beyond Rhodes	Cilician Taurus	North-eastern part of the Hindu-kush, the Chitral Hills, the Paghman and fold-ranges extending from east of Ghazni, past Quetta to southern Baluchistan
Vertex	Island of Crete	From south of Karaman to the northern part of Cyprus	Mekran (in the neighbourhood of long. 60° E.)
Western wing of the main arc	Ionian-Adriatic, Olonos-Pindos & Tripolis zones of C. Renz, possibly including parts of Albanian coast	Sultan Dag	South-western Iranian ranges
Western reflex arc	Uncertain, may be represented in south-western Yugoslavian coastal ranges & the islands of the Lagosta group	Sharp fold-arc to the south of Afyonkarahısar & N. of the latitude of Isparta with strong meridional folds to S. of Isparta & W. of Antalya forming reflex backbone	Following on the eastern reflex arcs of the Tauro-Anatolide, essentially in superimposed relation
Backbone	Meridional folding in the island of Chios & elsewhere along the western Anatolian coast & lineaments in the Cyclades Archipelago given by R. A. Sonder suggestive of compression between Pelagonian, Attic-Cycladian & Lydian massifs in E. by S.-W. by N. direction	Folded & uplifted lobe of land-mass protruding southward from northern Central Anatolia into the " intermediary zone " with meridional thrusting to the north of Keskin (" 10 km. fault "), along a line running from west of Cankiri to the Middle Kizilirmak & in the Jurassic, south-west of Ankara	Yet unconfirmed. Probably to be found in the en echelon ranges near the eastern border of Iran, east of the longitude of Birjand
Other particulars	Western wing for the most part superimposed on the Dinarides; backbone, largely sunk into the Aegean Sea, probably represented by an elongated arch with axis running N. by E.	In the northern part of the backbone the meridional elements being partly juxtaposed with, & partly transposed across, the "faisceau de plis d'Ankara", in the southern part replaced by lineaments of the Tuz Golu region	In the event of confirmation of the presence of a backbone by establishing meridional features — most likely block-overthrust or lineaments in the eastern border ranges — the name Iranafghanide is to be preferred

SOME RELEVANT TECTONIC PROBLEMS OF PENINSULAR INDIA

Few hill or mountain ranges in Peninsular India can claim to be of orogenic origin and of post-Vindhyan age except perhaps the Satpura. This zone of rather highly denuded and partly buried Mesozoic and older rocks forms a series of sharp scarps running between the Narbada and Tapti valleys (Blanford, 1869) and stretching in a north-easterly direction past Mahadeva to the neighbourhood of Rewah. If it may be assumed that the whole of this hill-range is in some way tectonically connected with the curved escarpment of the Vindhyan mountains with which it runs parallel, it would seem not unlikely that its tectonic axis extends further north-east to the southern side of the Kaimur hills where it appears to turn to the east around the Amarkantak plateau. Folding along this range cannot be seriously in doubt, and may have taken place more than once before the outpour of the Deccan Traps; for such movements are not only shown by the stratigraphical relation of the latter with what it overlies, as revealed in parts of the range, but also implied in the invasion of Cenomanian waters into a narrow inlet confined to the present Narbada valley.

Towards the west and north-west the same tectonic zone possibly extends across Kathiawar and Cutch as suggested by the presence of broadly folded Jurassic of east-west or north-westerly trend (WYNNE, 1872). No such reflex effect of an arc is, however, suggested further north-west as is in the Kaimur hills in the north-east, nor can it be expected in an area where everything is so deeply buried in the plain of the lower Indus and so powerfully crushed in the Kirthar range.

These circumstances, together with the fact that the presumed zone of disturbance is largely buried under horizontal beds of the Deccan Traps, make it difficult to assert whether or not we are here to deal with an arc in the usual sense of the term. On the assumption that we have not greatly erred in our estimate of the axial trend of the range as outlined above, the apex of the arc would seem to lie in the neighbourhood of Broach, east of the Gulf of Cambay. This, in turn, gives rise to the suspicion of an ϵ structure with an unusually broad frontal arc sweeping round central and north-western India provided that evidence can be found of strong east-west compression some distance to the north, and in the longitude of Broach, e.g. a zone of closely folded rocks impressed with dominant north-south strike broadening towards the north, or a broad anticlinorium with a meridional axis. Further, such a zone would run obliquely across the south-western part of the ancient Aravalli folds which are distinguished by their dominant north-easterly trend, and the Thar Desert below the Ecoene deposits. Thence northward, it may dive, as it broadens out, into the plain of the Punjab. A subterranean meridional zone of endurated rocks lying in such a position would precisely serve as the " tongue-like projection " postulated by Wadia in explaining the origin of the hair-pin bend of the north-western Himalayas (WADIA, 1949, p. 314).

Whatever may be the true tectonic interpretation of this part of Peninsular India, the fundamental fact remains that the structure of that sub-continent is on the whole dominated by two sets of fractures: one trending north-east which for convenience may be tentatively termed the Chambalian, from the fact that the upper Vindhyan strata are brought into contact with the Aravalli schists by a mighty fault running north-east roughly parallel to the course of the Chambal river (WADIA, 1944, p. 98); and the other trending south-east, the Godavarian, from those faults which determine the distribution of Gondwana rocks in " a series of more or less connected troughs forming an elongated band along the Godavari river from near Nagpur to the head of its delta " (WADIA, 1944, p. 128). To these we should perhaps add a subordinate third set running north-south typically represented by the Coromandel coast. The famous Cambay-Laccadive-Maldive line may partly be a feature of the same kind.

There is hardly any question that faults of these, and especially the first two, types have contributed much to the deposition and preservation of many isolated bands and patches of the Gondwana rocks in Peninsular India implying that fractures of Chambalian and Godavarian trends have been kept either intermittently or incessantly active since the beginning of Gondwana time throughout that vast region. Fractures that run along the western coast of the peninsula, that cut off Cutch and Kathiawar from the mainland and from each other and that stretch from the head of the Godavari delta to the north-east of Cuttack along the Eastern Ghats front, all bear witness of the operation of such cratogenic or rhegmagenic activities in relatively recent geological times.

It must not, however, be supposed that they are everywhere and at all times developed exactly in the same direction. For instance, those which mark the natural boundaries of Cutch and Kathiawar seem to differ noticeably in orientation from those occurring further south in the peninsula, i.e. along the front of the Western Ghats and the Malabar coast. This is only natural; for in no circumstances can we assume that the operating stress from which these lineaments result have remained identical permanently and throughout the expanse of the whole sub-continent.

STRUCTURAL PATTERNS IN DEFORMED CLAY

Flexural and fractural patterns analogous to those natural structural types described in the foregoing section can be induced in clay by various methods under suitable conditions. The pattern to be obtained by a given method of deformation is found to depend largely on the solidity or fluidity of the clay and to vary only in minor details according to the kind of clay used.

Experiment on Lineaments — For producing fractural patterns the clay used should be fairly solid so that it can be cast into any desired shape and dimension. The free surfaces should be rendered as glossy as possible; for a surface of that nature not only facilitates the determination of the earliest traces of fracture but tends to increase surface energy distribution, which is of advantage for experiments on such material as clay.

Various mechanical devices may be used to apply axial load or essentially plane stress to the clay to be tested (LEE *et al.*, 1948, pp. 25-32). In some cases, notably in continued compression, a stage is found at which the clay suddenly hardens and its mechanical behaviour alters to some extent. This important property, though usually regarded as a case of " work hardening ", is in fact still ill understood (WILLIAMSON, 1947, p. 658).

The few experiments recorded below seem to be of interest for our present purpose.

By applying simple compression to the ends of cylinders (PL. 1, FIG. 4) and rectangular blocks (PL. 1, FIG. 2) of clay, both solid and layered, simple tension to clay bars through bending (PL. 1, FIG. 1), shear, or combined tension and compression, to clay cakes (PL. 1, FIG. 6) and so forth, it can be shown that shear fractures generally develop at two stages while the load is being continually added.

At an earlier stage the glossy surface of the loaded clay suddenly becomes, in all cases, covered with abundant Lüders' lines which presumably represent traces of two sets of minute shear fractures penetrating vertically into the clay for uncertain depths. In the case of simple compression and shear the two sets of Lüders' lines run across each other nearly at right angles. The bisectrix of the pair of slightly smaller angles between them, as far as can be ascertained, generally agrees in direction with the compression. But in the case of simple tension it is always the bisectrix of the obtuse angles contained between them that runs parallel with the direction of the stress applied. And the obtuse angles in this case are considerably larger than the acute ones.

If we accept the planes of no distortion or of uniform distortion which coincide with the circular sections of the strains ellipsoid, as far as it holds, as agreeing with the two sets of shear fractures, it simply means that the shear plane always lies at a smaller angular distance to the least than to the greatest axis of the ellipsoid, but in the last case the difference between these angular distances is still greater than in the first two cases. In all cases the medium axis is always perpendicular to the free surface.

As compression advances, these earlier shear fractures are generally being " flattened " against the compression, with the dihedral angle between the pair of them which faces compression correspondingly increased up to 130°, but rarely more. When the clay becomes notably hardened through further compression, an altogether different system of shear fractures now appears for the second time. Compared with the earlier ones they are far more conspicuous, clean-cut and penetrating but much fewer in number. The acute angles between a pair of them are considerably reduced, varying as a rule from 50° to 65°, occasionally more but seldom less.

At the advanced stage of compression or shear, tensile fractures characterized by more or less uneven surface begin to develop. They are roughly plane in surface but are locally somewhat wavy, rude or even hackly in appearance. They generally run parallel with the direction of primary compression. Sometimes, however, they follow a zigzag course, taking advantage of pre-existing planes of weakness, notably those created by shear (PL. 1, FIG. 3). This fact serves to explain the origin of a class of faults ascribed to the appositional type often met with in south-eastern China where shear faults are well developed. The phenomenon of " trailing ", first recognized by C. H. Dinham and rightly emphasized by E. M. Anderson (ANDERSON, 1942, pp. 28, 32), appears to be traceable to the same cause.

The phrase " primary compression " needs some explanation. The issue involved does not only affect our proper appreciation of tectonic experiments in terms of the relation between strain and stress but also of the mechanical meaning of a given tectonic element as we see it among others in the field. Take the example of our clay cake. On the first application of shear in its plane compression is set up in a certain direction. Because of that compression two sets of shear fractures usually result with the bisectrix of the acute angle contained between the two pointing to the direction of compression.

These may be conveniently referred to as shear fractures of the *first order*. As shearing goes on, the compressive stress set up by it inevitably rises in intensity until a time when the cake starts to buckle, determined by its " slender ratio ". As soon as buckling or bending takes place, the upper layer of the buckled tract, namely the layer above the neutral plane, becomes now subjected to tension instead of compression. This reversion of stress condition may give rise to new sets of shear fractures. Such fractures of the *second order*, if they actually appear, can be contrasted with those of the first order by the fact that the bisectrix of the acute angle between the two sets now runs parallel to the direction of tension which was originally the direction of compression. But the shear fractures of the first order still remain. They naturally serve as ready-made fractures to relieve the new shear strain. Under such circumstances those of the second order often fail to develop. Sometimes, however, the reverse is the case. We are thus enabled to see why the bisectrices of the acute and obtuse angles between two sets of related shear fractures appear to be vacillatory in their relation to the axis of an anticlinal fold. What is said of shear fractures is equally applicable to other tectonic elements.

It may be worth while to point out another case in connection with our experiments. When a shear is applied to a cake of clay resting on a divided plate by sliding one half of the latter against the other, it always happens that the shear fractures which first appear in the clay do not follow the line of contact between the two halves of the plate but run oblique to it. One set makes an angle of 12° to 18° and the other 78° to 83° with the direction opposite to that of the sliding movement of the side on which they occur (PL. 1, FIG. 6). These fractures are obviously determined by the principal stresses, namely tension and compression, aroused by the slide. They may be regarded as being of the first order. As the sliding movement continues, the angular position of the first set remains essentially the same, but the second set gradually alters to 96° or even more depending on the amount of distortion that they undergo as a result of the slide (PL. 1, FIG. 6). At the same time each fracture belonging to the first set tends to widen and to become tortuous; but those belonging to the second set all become distinctly appressed, some being turned into thrusts accompanied by miniature folds of the same trend as the appressed fractures. These local thrusts and folds, largely confined to the tract where maximum distortion occurs, are then fractures of the second order. Occasionally the crests of the second order folds are cracked in their axial direction. Such minute cracks due to tension acting parallel to the axis of the folds are then fractures to be assigned to the third order, and so forth. In this sequence of development we see as matter of experimental fact how shear is transformed into compression and compression into tension, and so on, at successive stages represented by characteristic structural features, while the nature of the primary stress or of regional movement remains unaltered.

Experiments on the ε Structure — The clay used for the present purpose should be made highly plastic by adding to it a considerable proportion of water, and also slightly " rigid " by mixing with it an ample amount of well-digested paper pulp. The mixture is thoroughly well stirred and adjusted to the state in which it can effect a tardy flow on an inclined surface. This or any other sheet-like material of suitably elasto-plastic nature is spread on a polished, plane board hinged on a horizontal base. The surface is roughened, say, by driving some short studs into it, in two circular areas, some 5 cm. in diameter, 25 cm. apart from centre to centre, and a little less than half the height of the whole surface as measured from the hinge. The rest of the surface should be lubricated by paraffin wax.

The clay is then spread over the surface in a laminated form by inserting uniform tissued paper of friable nature at regular intervals to resist thixotropic recovery of the disturbed clay and to preserve its state of distortion more or less permanently. A thickness of about 1 cm. usually proves to be suitable. By gradually increasing the inclination of the surface, faint ripples will begin to appear on the paper-covered clay. In that fixed position the process of deformation of the clay will go on for some time until the ε pattern of folds, sometimes accompanied by fractures running across, is fully developed.

The patterns obtained, though essentially similar in all cases, are to some extent dependent on the fluidity of the clay, the distance between the two roughened areas and the dimensions of the clay sheet. When the material is extremely plastic or the two parts of the clay around the resisting areas can freely effect bodily rotation against the surface on which it rests, then the resulting pattern consists of numerous similarly arranged fold-arcs resembling parabola of some high order. No backbone is developed. In general the stiffer the clay used, the more prominent is the backbone and the broader is the unfolded space behind the frontal arc.

Instead of gravity centrifugal force may be used as the distorting agent by placing a fan-shaped clay sheet on a rotating disc. Under those conditions the ϵ pattern produced only differs from that obtained in the gravity field in being slightly asymmetrical; for when rotation starts, there is not only a strong tendency for the clay to creep outward in the radial direction, but also some tendency to creep backward against the direction of rotation before it attains the speed of the disc and to creep forward when the speed decreases. The result is that the whole ϵ pattern becomes somewhat twisted around one of the resistant areas (PL. 1, FIG. 5).

A chain of ϵ patterns is obtained when a number of resistant areas are present on the surface on which the clay is spread.

ANALYSIS OF EVIDENCE

Aside from theoretical implication, a comparison of the type of Asiatic arcs with similar structural patterns in distorted clay almost inevitably leads to the inference that parts of Asia have been creeping southward since those arcs began to develop. Such movements perfectly agree in direction with what is known of the Himalayan orogeny. Extensive nappes have been long recognized thrusting forward against the Gangetic foreland. Apparently innocent succession of strata in the Salt Range have been made to yield, in the hands of Professor Sahni, evidence for vast-scaled inversion (SAHNI, 1944). Practically in all cases the overriding rock-mass comes from the north. This fact has been accepted *a priori* as the tectonic basis on which geodynamical deductions rest.

Demands from the geomechanical side cannot, however, be satisfied by this simple truism; for if it is legitimate to regard the overthrust mass as moving forward to the extent to which it covers the down-trodden rocks, to that extent it would be equally legitimate to consider the underthrust mass as to have moved forward in the opposite direction. It may be argued that we are not concerned with absolute movements. But if once this view is admitted, we must be prepared to envisage such possible consequences in the field of geotectonics as India, as a part of Gondwana, wedging into the Himalayas as a result of its northerly drift, and as the western Pacific floor being undertowed into the eastern border of the Asiatic continent (AMPFERER, 1906; HILLS, 1947). We shall see that these hypotheses, attractive as they are from a certain angle, find no support from the evidence offered by the several structural types under consideration.

It is self-evident that the evidence furnished by the Himalayan zone, whatever its nature, cannot be valid beyond the extent of that zone and the regions to the immediate north and south of it. Similarly the geodynamical evidence presented by each of our ϵ structures also cannot be extended to beyond the area which it covers. And the southward creep that it indicates is only relative to those parts of the land where the reflex arcs occur. If besides such a relative movement the continent as a whole, or a large part of it, undergoes a uniform displacement, the effect would not be disclosed in the distortional picture of the ϵ type but might appear in the same field as incongruent elements obstructing or disrupting the latter. The para-equatorial and meridional or submeridional zones of folds often encountered by those belonging to the ϵ systems are apparently due to movements of that nature.

Analysis based on plane stress distribution in a horizontal sheet of stratal membrane of elasto-plastic nature shows that north-south compression attains a maximum in the vertex part of the frontal arc (LEE, 1945, p. 645). Large tensile fractures of north-south trend are often thus opened up, and igneous injection may result. In China the injected material is almost always a granite. If north-western and central India prove to be involved in an ϵ structure as is suggested, we should expect to find an additional amount of meridional pressure being applied to the peninsula, which is already heavily loaded from the north by the Himalayan and Hazara zones, somewhere in the longitude, and to the south of Broach. Here, then, we have a specific reason to believe that the fissures, through which the Deccan Traps poured out, probably occur in a zone running north-south close to the western coast, and may reach as far south as the Laccadives and Maldives.

Strictly speaking, some of the Chinese ϵ structures and the Tauro-Anatolide are not bilaterally symmetrical with respect to a meridional axis, but are slightly twisted to the west. Comparing these with the type obtained in the clay sheet on a rotating disc it appears suggestive that another component, a westerly one, has played a part in the relative displacement of the distorted region. Indeed this tendency for parts of the continent to creep towards the west seems to be no less important than that to the south. Large longitudinal sectors of subaerial probably as well as submerged. sialic crust are involved in such movements. Take any two adjacent longitudinal sectors which for some reason, e.g. difference in firmness in their attachment to the subcrust, are not capable of creeping with equal facility towards the west. The contact zone would be subject to compression when the sector which creeps more readily lies on its eastern side. The Kangtien-Burma-Malayan orogenic zone, the Suleman and Kirthar ranges, the Murray and Carlsberg Ridges appear to be the more impressive examples of such a longitudinal zone of compression. To a lesser extent the same cause seems to be contributory to the uplift of the south-western Iranian ranges, the Dinarides, and may even have affected — acting in unison with the compression along the backbone of the Eurasian ϵ structure — the Ural-Novaya Zemlya and Timan zones during the Variskian epoch. A longitudinal zone of tension would be set up when the more readily creeping sector lies on its western side. The Cambay-Laccadive-Maldive line is believed to be partially due to this cause. The rifts of Africa including those between Africa and the Scychelles Bank and indeed the fragmentation of Gondwanaland and graben-faulting in western Europe are all probably to be traced partly to the failure of the eastern mass to keep pace with the western in effecting the westward creep.

Since according to this interpretation Australia must have crept relatively but little, if at all, towards the west because of the presence of a compression zone on its eastern side, and is, therefore, diametrically opposed in matter of relative displacement to south-eastern Asia, the region lying in between, i.e. that between the equator and latitude 10° S., would afford a crucial test of our hypothesis. It will be noticed that New Ireland (REED, 1949, p. 683) and the Solomon Islands (GLASSNER, 1915; REED, 1949, p. 688) are aligned from north-west to south-east. The same is the general trend of New Guinea and Sumba. These appear to represent lines of compression which had already commenced to operate in Eocene times. On the other hand, it seems fairly certain that tensile fractures running north-east and south-west play an important part in determining the shape and orientation of many other islands scattered in the area or parts of their coast. The south-eastern coast of New Britain, the transverse coast-lines of New Guinea, the Aru, Great Kei and Tenimber Islands, the north-western coast of Wetter and Timor and the south-eastern coast of the latter as well as the Lomblem and Solor Islands are significant examples. Thus the array of these islands bears witness to the effect of a powerful shear caused by south-eastern Asia creeping westward against Australia. The actual condition is of course rendered much more complex by an uneven southward creep of the Asian mass resulting in linear as well as rotational movements, as shown by the presence of various curvilinear axes.

The pressure or tension called forth by these two components of mass-creep is faithfully reflected by lineaments in Gondwana. The potent effect of the north-south and east-west principal stresses aroused thereby is revealed everywhere in the visible parts of the old landmass by their north-easterly and north-westerly trend in general, and by their local modification in response to local pressure or tension in particular. In the southern part of Peninsular India, viz. to the south of the Satpura range, the bisectrices of the two pairs of angles between the lineaments appear to run due north-south and east-west. These are evidently of general importance. But in the northern part of the peninsula, especially in the area between the Aravalli and Vindhyan ranges, the lineaments, at least parts of them, are so oriented that the bisectrices of their containing angles are found to run approximately parallel and perpendicular to the Himalayan axis. In the Cutch and Kathiawar area their orientation seems to be influenced somewhat by the south-eastern front of the Iran-Afghan arc. Such modifications are precisely what may be expected under these circumstances.

In East Africa the rift valleys are obviously in appositional relation with lineaments which, for the reason of having the bisectrix of the acute angles contained between them oriented north-south, disclose the operation of meridional compression or east-west tension or both; though probably not in conjunction with each other — for in that case the resultant would be a shear — but in succession. The latter inference throws some light on the vexing problem of the origin of the rift valleys. It seems perfectly legitimate to assume that the parts of the earth's crust which had been rent asunder first by shear and then by tensile fractures through the application of meridional compression, became more susceptible to differential creep towards the west, each according to its own disposition. In this way phenomena associated with compression, such as "ramping", certain types of mass distribution inferable from gravity anomalies, etc., may be found side by side with those associated with tension.

An example is presented by the southern Red Sea and the Gulf of Aden. There, the orientation of the lineaments appears to be influenced by the Iranian arc which supplied compression from the north-east. The northern part of the Red Sea coast, including the western Sinai Peninsula, falls, however, in line with the Erythraean component of the African lineaments, and is probably determined to some extent by the Tauro-Anatolide. So far we are only concerned with the north-south and a locally modified north-east to south-west component of earth pressure. Now, submerged features of great interest are given by T. Stocks (STOCKS, 1942, p. 355) in the Gulf of Aden. They represent in all probability a series of folds trending north-east. They cannot be formed by simple sinking, but must be features of the second order due to Somali highland sliding westward along a line extending from Sokotra to Harar against the Arabian coast. If Somaliland and the south-eastern part of Abyssinia can creep westward independent of other blocks from which it was rent apart not by a westward tension but by a shear arising from compression, it can be easily surmised what might happen between other blocks.

Thus the tectonic picture presented today by Tetho-Gondwana is in no way suggestive of a forcible union, after a collision, of two inherently incompatible parts of the earth's crust, each undergoing folding or fragmentation of its own accord and having no relation to each other, but rather of a harmonious whole, unfolded stage by stage since at least the latter part of the Mesozoic era if not earlier. There still remain the peripacific arcs and the leading lineaments of the Cathaysian region to be accounted for.

It is sometimes held that the arcs, which are no more than wrinkles in the continental mantle, may have been caused by the undertow of the subcrustal current from or towards the Pacific (HILLS, 1947). But the idea of raising a central Asian dome to accommodate the fluid basalt seems hardly more tenable than the old conception of Asia growing and spreading around a nuclear mass in Siberia; for a central dome with reference to the two types of arcs is simply non-existent, and the old land Cathaysia existed long before the Caledonian movement. Nor do we find sufficient tectonic evidence to show the presence of any extensive shear plane (VENING MEINESZ, 1947, p. 25, FIG. 10) or rift between the island arcs and the mainland as is claimed by some authors. An ingenious explanation believed to be applicable to nearly all the Asiatic arcs, more particularly to the island festoons, is offered by P. Lake (LAKE, 1931) by making use of the simple geometrical fact that an arc of a given curvature is obtained when a thrust plane crops out at a suitable angle of inclination on the surface of the globe. No further assumption is made in formulating this hypothesis. Yet, it happens to have received support over a wide range in its implications, especially in the field of deep focussed seismic disturbances.

As is well remarked by Umbgrove (UMBGROVE, 1947, p. 150), such a wide-ranging agreement between a hypothesis and facts cannot be light-heartedly discarded as mere fortuity. Nevertheless, fortuity does sometimes unwittingly go a long way to foster freaks of human imagination on a subject of this nature. As an example, it will be found on a globe that the coastline of China from Taku, a port near Tientsin, to Moncay, a small border town on the Tonkin Gulf, almost completely agrees with a semicircle if we disregard the Shantung and Luichow peninsulas. The pole of this semicircular arc, which is characterized by a similar oro-igneous history throughout, falls somewhere on the northern side of the Yangtze gorges. Within permissible limits of interpretation, the position of this point will be found to lie on the same great circle passing the poles of the Iranian and Himalayan arcs. Obviously nothing can be more arbitrary than to assume that there exists some tectonic relation between these points.

In all these hypotheses in which an extensive overthrusting of the continent is involved, no matter whether the thrust comes from the Pacific or the continental side, one can hardly expect the movement to be uniform. And any non-uniform tangential movement affecting a mantle of continental material would inevitably produce, as suggested by our clay experiments, a structure with a backbone pointing at one end to the direction of the overthrust and at the other to the source whence the large-scale movement virtually or actually originated. None, however, of the peripacific arcs is of the ϵ type. More recently R. A. Sonder approached the problem of the origin of the island arcs from an altogether different angle (Sonder, 1939, p. 39). He attaches more importance to the spacing of the submerged basins on the border of the eastern Asiatic continent than to the alignment of the island festoons bordering on them, and pre-supposes a possible control over the development of the latter by an old-established lineament pattern inherent to the contracting earth with an elastically anisotropic crust. It will be noticed that the span of each marginal basin from north to south precisely agrees with the width of each segment of the continent divided by the east-west fold-zones. It seems to be an open question whether we are here merely dealing with two different ways of presentation of the same phenomenon, or with two fundamentally different tectonic phenomena which here happen to coincide in space. A further exploration along these lines would seem well worth while.

In the meantime, attention may be called to the persistence of lineaments of the Taishanian and Tayishanian trends over the Cathaysian region. These shear fractures, or glides, are everywhere, and also in point of time, closely associated with the Meso- and Neocathaysian folds which are shown to have given rise to the peripacific arcs by a gradual but unmistakable inflection on encountering the east-west zones. It can hardly be doubted that these lineaments have resulted from the same process of compression as that determining the Meso- and Neocathaysian folds. The latter cannot be the result of uniform, simple compression between the continental border and the Pacific floor; for they do not run parallel with the real border of the continent but somewhat oblique to it. Close examination of the lineaments often discloses steeply inclined slickensides in association with powerful horizontal ones in the zone of fracture. These, together with large amounts of " heave ", local sharp folds and even local imbrication of strata, show that the horizontal *décrochement* of the first order is accompanied by folds and thrusts of the second order. Distortion subsequent to the development of the shear fracture is thereby suggested. Such a type of distortion is far more frequent in connection with fractures of the Taishanian trend. On the other hand, those of the Tayishanian trend are at least in some cases of the nature of more or less open fissures which facilitated the injection of magma as in the Tayishan itself, or of volcanic outburst as in the Fossa Magna-Bonin line.

Comparing these with the shear fractures obtained in the laterally sheared clay cake, it is found that those which are transverse to the direction of primary shear resemble, with all their distorted characteristics, the Taishanian component of the Cathaysian lineaments; while those making a sharp angle with the direction of the primary shear tend to open out in those tracts where there exists a major discontinuity in the direction of the primary shear applied to the clay cake. Such a discontinuity does not necessarily reach the surface of the clay subjected to the test. They are related to the invisible or visible discontinuity, the primary shear fracture, in the same way as the feather joints are to the master joint and the splay faults to the main fault if the latter is of a " sinistral " kind instead of " dextral " as in the case given by E. M. Anderson (Anderson, 1942, pp. 77-84). They appear to be comparable with the Tayishanian component of the Cathaysian lineaments. These lineaments, together with their associated Meso- and Neocathaysian folds and occasional primary shear planes of north-south trend, make up a structural pattern which indicates in the highest degree of probability a southward differential creep of the eastern Asiatic continent against the Pacific floor. Towards the western part of the same continent the Tayishanian trend is matched in a symmetrical sense by fractures typically represented by the Tekir Graben of Frech or the Ecemis Corridor of Blumenthal (BLUMENTHAL, 1941). Indeed, these lineaments of the "Asiatic" type play an important part in the fault pattern of the Rhine Graben, as illuminatingly pointed out by Sonder (SONDER, 1938, p. 206, FIG. 4). The evidence in the west as in the east agrees, therefore, to show that the central parts of the Asian mass have even crept farther south as compared with the Pacific and western European region since at least mid-Tertiary times.

Finally, a few words must be said of two important aspects of theoretical implication throughout the reasoning we have followed so far. Firstly, are we justified in considering horizontal stress operation alone, as we have done, in dealing with the types of crustal deformation of the earth? We are not discouraged to provide a positive answer when we realize, by balancing the three principal components of stress due to three principal components of strain in a thin spherical shell, that the horizontal components always turn out to be incomparably more important than the vertical if the thickness of the shell is small compared with its diameter, whatever is the nature of the strain. This theoretical consideration is greatly substantiated by such field experiences as those leading to the understanding of *décollement* and "exotic blocks" (KRAFFT, 1902; HEIM, 1937) in connection with what were once regarded as inconceivably fantastic horizontal movements and of vast numbers of vertical or nearly vertical shear planes occurring in regions dominated by lineaments. Gravity is of course a potent force. But it can only act, and will not fail to act, where there is an unbalanced component or uncompensated mass distribution. Its possible influence in determining the plasticity of rocks at various depths leads us to the second important question: Are we justified in comparing the deformation of rock, a material known to possess definite rigidity within our laboratory experience so far, with clay cakes? The situation we are in today is one of flat contradiction. Against the hard and fast elastic qualities exhibited by rock specimens under the usual laboratory method of treatment, we have before us naturally recorded facts pointing to plastic flow of rocks not only in the deep interior of the earth but even under surface conditions. Long continued stress is usually supposed to perform the mystic function of enabling the elastic mass to effect the plastic flow. No real escape can, however, be afforded by the time factor unless the mechanism of rock creep is brought to light.

Such a creep, if it has actually occurred, must be either intragranular or intergranular. In the latter case the effect must be visible, at least at times, in the outer layer of small enclaves or small entombed bodies of roundish contour structurally distinct from, and more rigid than, their surrounding material. This rare combination of conditions is often fulfilled by minute petrified tests of fusulines embedded in an ordinary limestone. In numerous instances the crumbled but healed outer whorls are drawn out into "flow layers" around the inner ones with all the original minute structure of the latter perfectly well preserved. And in some cases the evidence is clear that the process of fossilization and transformation of various parts of the original test into a mosaic of minute grains of calcite, and consequently of the consolidation of the rock, took place long before the introduction of the "flow" effect. That effect obviously arose from the more rigid, petrified test rolling, as it were, in the surrounding limestone which, because of its homogeneous character, subsequent recrystallization and so on, yields no evidence of the same kind.

Enclaves with internal "S-surface" merging into the external in S-shaped curves, repeated movements along several "*ab*" planes and rotation around the "*b*" axis of mineral grains, as seen in their lattice orientation, are related phenomena well known in the fabrics of certain types of rocks which disclose no palpable signs of deformation under severe pressure or raised temperature. Facts of this kind together with the possible effect of relaxation of stress give us an insight as to how terrestrial stress may slowly become relieved and the results of progressive elastic deformation fossilized and accumulated in the course of time. This, indeed, seems to be the only way to account for the paradoxical flow of rocks within their elastic limit usually accepted as such.

The final answer to our second question must, however, be deferred until the rate of creep and relaxation of stress is determined in the laboratory from loaded rocks of various kinds. And further, as a means to test rock creep on a continental scale, a systematic survey of fossil magnetism in certain selected areas, as advocated by Professor Sahni, may yet prove to be most helpful.

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EXPLANATION OF PLATE 1

1. A partial view of the anticlastic surface of a bent clay bar with two sets of intersecting shear fractures. Note that the bisectrix of the obtuse angles contained between the two sets of fractures agrees with the direction of tension.

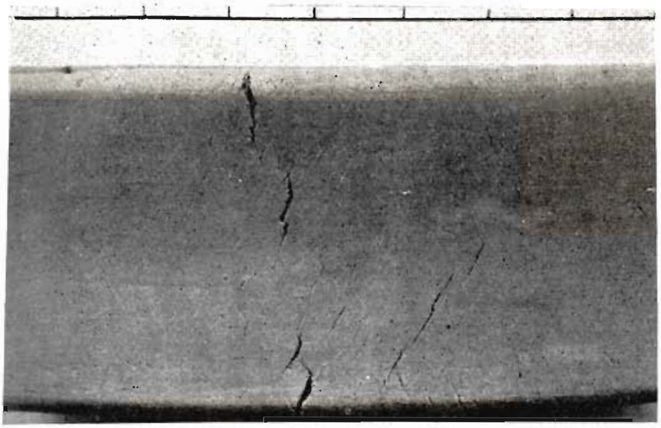
2. Shear fractures produced in a clay block after being pressed from top to beyond the "hardening" stage.

3. Appositional tensile fractures due to compression from top of the clay block. Note the zigzag course of the fractures.

4. Twin helical fractures in a clay cylinder compressed from both ends.

5. A sheet of clay distorted to form an ϵ pattern on a rotating disc with its centre at C. The parts in which the clay sheet is relatively firmly held are located in front of the slightly raised crescentic areas; rotation counter-clockwise and at a speed of 250 r.p.m. Note the ϵ pattern not strictly symmetrical but somewhat twisted to the left.

6. A rectangular clay cake being distorted to a rhomboidal form by the application of a shear in the ss′ direction; aa′ direction of fractures parallel to the primary shear; bb′ and cc′, fractures due to uniform distortion; dd′, fractures due to local distortion at a later stage; AB, direction of flexures with a tendency to overthrust to the right. Note the highly compressed condition of the fractures parallel to cc′ which have undergone a considerable amount of rotation.



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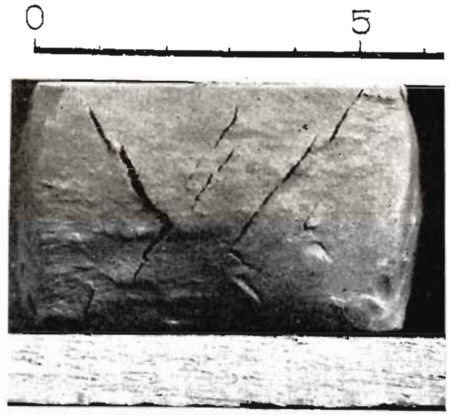

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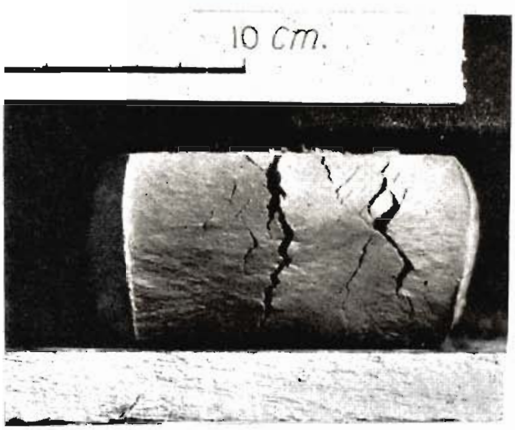

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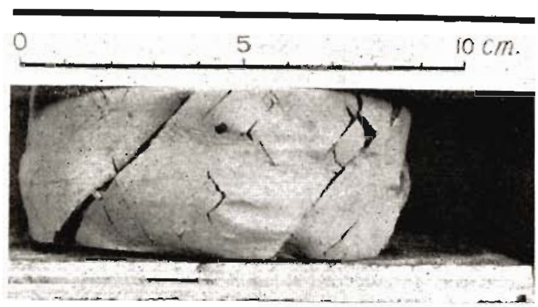

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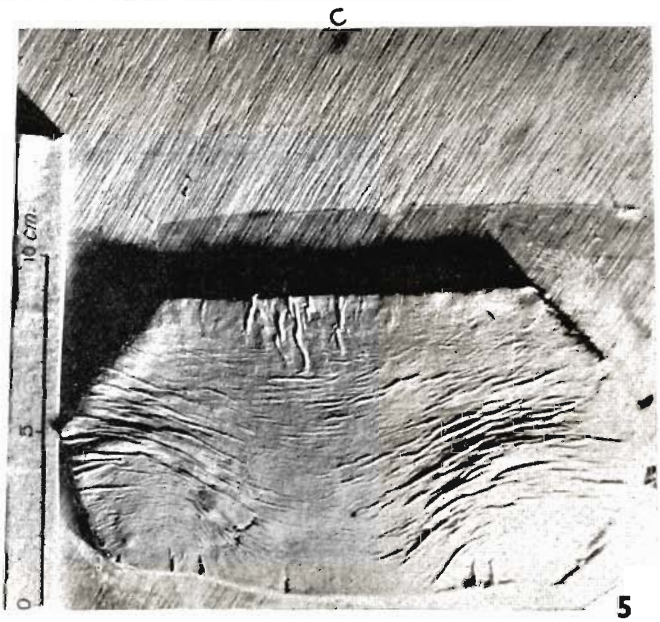

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