INTRODUCTION
An elaborate study of the late Cenozoic tectonostratigraphy, climatostratigraphy and morphotectonic features of Iran has furnished useful information regarding the timing, rate and nature of the neotectonic movements and deformations in this active compressional zone.

The relative and absolute chronology has been worked out by analyses of sedimentation rates, climatostratigraphy, soil stratigraphy, archeology and, to some extent, by biostratigraphy, magnetostratigraphy and radiometric dating.

The absolute time-table, preferentially adopted by the author, is essentially based on sedimentation rates derived from varve and sedimentary-cycle analyses (Table 2). This scheme yields a maximum age of about 370 ka for the base of the Brunhes geomagnetic epoch. In this system of dating, the age of the Wurm interstadial and younger horizons remains unchanged, while an age of ca. 90-95 ka is assigned to the base of the oxygen-isotope stage 5 and its inferred land-based correlative horizons. The author is well
aware of the oddity of this scheme. However, those who can not agree with this absolute chronology may simply substitute the conventional system of dating.

In this discussion, the beginning of the late Quaternary is placed at the beginning of the Cromerian (Table 2) and the lower and upper boundaries of the Cromerian are correlated with the base and top of the oxygen-isotope stages 21 and 17, respectively. In the Iranian land-based sections the two datums can be generally located by the combined use of climastratigraphy, tectonostratigraphy, soil stratigraphy and sedimentation-rate studies.

**CROMERIAN MOVEMENTS**

**Timing**: A most severe episode of faulting and folding occurred at the end of the Cromerian and another vigorous, but apparently less intense, tectonic pulse at its commencement. Two more pulsations, evidently of lesser intensity, occurred at intermediate horizons of this stage, subdividing it into three subequal intervals.

Analysis of sedimentation rates, mainly by varve stratigraphy, furnishes an average spacing of about 23 ka between the pulsations, correlating them with precession cycles. The total duration of this period is thus estimated at about 70 ka.

The four main tectonic spasms were coincident with main episodes of volcanism and times of climatic warming, as deduced from the stratigraphic position of volcanic beds in pluvial-interpluvial sequences, examination of the physical nature of weathering horizons and a number of other criteria. The bulk of the Quaternary volcanic bodies of Iran
### TABLE 1: QUATERNARY CHRONOSTRATIGRAPHY OF IRAN

<table>
<thead>
<tr>
<th>Absolute Age</th>
<th>Radiometric (current)</th>
<th>Varve &amp; sedimentary analysis</th>
<th>Magnetostratigraphy</th>
<th>Tecnostratigraphy</th>
<th>Chrono-stratigraphy</th>
<th>European stages</th>
<th>Iranian stages</th>
<th>Lithostratigraphy</th>
<th>Central Iran</th>
<th>Zagros</th>
<th>Makran Area</th>
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<tbody>
<tr>
<td>0.32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Postglacial</td>
<td>Postglacial</td>
<td>Caspian Region</td>
<td>Piedmont areas</td>
<td>Internal basins</td>
<td>Piedmont areas</td>
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<td>0.73</td>
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<td></td>
<td></td>
<td></td>
<td>Ab-e-Ali</td>
<td>N/A</td>
<td>Post Glacial</td>
<td>Piedmont areas</td>
<td>Piedmont areas</td>
<td>Piedmont areas</td>
</tr>
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<td>0.37</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Würm</td>
<td>North Tehran</td>
<td>Postglacial</td>
<td>Piedmont areas</td>
<td>Non-piedmont area</td>
<td>Coastal areas</td>
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<td>0.66</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Eemian</td>
<td>Y/N</td>
<td>Holsteinian beds</td>
<td>Haft Juy Group</td>
<td>Haft Juy Group</td>
<td>Haft Juy Group</td>
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<td>1.67</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Saalian</td>
<td></td>
<td>Turokianian beds</td>
<td>Haft Juy Group</td>
<td>Darya-ye-Namak Group</td>
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<td>Saalian</td>
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<td>Strata</td>
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<td>Saalian</td>
<td>Darya-ye-Namak Group</td>
<td>Haft Juy Group</td>
<td>Haft Juy Group</td>
</tr>
</tbody>
</table>

---Boundary not to time scale.
Partial units referred to as "Upper half, -fourth, -tenth" can be differentiated climatotectonostratigraphically, and hence lithologically, as independent units.
The Seyedekhandan Member is correlative with the Maragheh Bone Bearing Beds, and the Upper Jaj Rud with the Fish Beds of the Tabriz area.
The terminal Cromerian tectonic paroxysm is regarded by the author as the main pulsation or the culmination of the so-called Pasadenaian tectonic event (Table 2). Later pulsations were progressively less intense, presumably as an indication of the fading out of the event. The main tectonic features of the Quaternary were formed essentially by the Cromerian tectonic spasms. The earlier and later pulses were not of great consequence, though one or two pulses, indirectly and roughly correlated with Jaramillo event (possibly its basal horizons), were prominent, judging from their angular unconformities in the sedimentary record and geomorphic levels in the erosional provinces.

**Rate and nature of movements.** In order to study this theme, it is needed to distinguish at least between two different tectonic provinces of central Iran and Zagros fold belt. The Zagros fold belt and a narrow zone of thrusting on the northeast are separated from central Iran by a great linear geostructure, i.e. the main Zagros thrust line. Many folded structures with amplitudes of 1000 m or more were generated in both regions by the late Quaternary tectonic activities. It was commonly the thick molasse cover of bedrock or basement (Hezardarreh and Upper Red Formations of central Iran and Bakhtyari Conglomerate and Fars Group of the Zagros trough)* that was involved in the folding; the bedrock or basement blocks being sheared or displaced at newly formed or pre-existing faults with negligible folding, except locally along the fault zones.

From the amount of folding and simple geometric relations it is estimated that the fold amplitudes are commonly comparable to the amount of displacements along buried faults (wrench or reverse) that created the

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* and older soft sediments
folds. The age of the Cromerian base is estimated at 370 ka by the analysis of sedimentation rates (radiometric age ca. 770 ka). Thus a typical figure of 1000 m for the uplift of crestal areas of late Quaternary folds gives an average rate of fold uplift and fault displacement of ca. 3 mm/year. However, the average rate was increased by a factor of about 5 to 7 during the initial and terminal Cromerian tectonic spasms, judging from the great magnitude of deformations and displacements attributable to these two pulsations alone.

Thickness comparisons of late Quaternary sediments within the synclinal areas and outside them, by geophysical methods and boreholes, has demonstrated that they are either of about the same thickness or somewhat reduced inside the synclinal areas. This is a clear indication that Quaternary folds were produced only by the uplift of anticlines and not by the sinking of synclinal segments.

In central Iran the displacement of basement blocks is predominantly accomplished by wrench-fault tectonics, whereas in the Zagros fold and thrust belt it is accomplished by reverse faulting.

In central Iran the amount of late Quaternary uplift of great mountain segments (e.g. the southern flanks of Elburz mountains in the Tehran region) along major faults amounts to a maximum of 200-250 m. The uplift commonly has produced a group of erosional, marginal rock steps or geomorphic levels, traceable over very long distances along the faults as well as along major valley systems towards the interior of the mountains; the latter being the result of downcutting of rivers in response to the uplift.

Higher older levels or geomorphic surfaces are also generally present. The subhorizontality of these surfaces that are in many cases detectable
up to the highest levels demonstrate that the mountain system underwent a rather symmetrical uplift after an earlier phase of folding.

The normal maximum thickness of the late Quaternary sediments in central Iran is some 300-500 m. Isostatic subsidence of blocks due to this load and the ensuing basification of the crust under the blocks have given rise to a downward vertical displacement of the loaded blocks (comparable to the thickness of sediments) which must be added to the amount of uplift experienced by the positive adjacent blocks (described above) to obtain the total relative vertical displacements.

The Pyrenean orogeny was very vigorous in central Iran. The Elburz mountain system, for instance, underwent a very severe phase of folding and faulting in that time which converted it into what may be referred to as the "younger Elburz". Later movements of the mountain systems were essentially an uplift in masse with negligible folding. A radical shift in the position of the sedimentary basins occurred in central Iran as a consequence of the Pyrenean event. The newly created sedimentary basins were the site of thick (up to 12 km) molasse accumulation (The Lower Red, Qom and Upper Red Formations). There were no appreciable shifts in the position of the basins until the commencement of the Pasadenaian orogeny when, during the short time span of the Cromerian, a new sudden radical migration of the basins occurred. This was accompanied by appreciable faulting and folding within the earlier basins in addition to diastrophism in positive (erosional) provinces.

These observations are taken to indicate that in both the Pyrenean and Pasadenaian events the direction of movement of crustal blocks, and hence the orientation of stress fields; were appreciably altered in central Iran, whereas during the intervening events it was essentially the rate of
movement that underwent a sudden increase. The most obvious evidence of this sharp accelerated rate is the presence of geomorphic levels or rock steps (sudden jumps) in positive (erosional) areas and sharp major lithologic changes in the sedimentary basins (not related to climate, or sea-level changes).

The late Quaternary change in stress orientation, if affecting the Zagros fold and thrust belt at all, must have been practically insignificant. New structures were formed as in central Iran, besides the growth of older structures. The new structures developed as foothills of the fold belt and as south west ward expansion of the belt. The late Quaternary folding of the Aghajari and Lahbari units in the Dezful-Ahwaz region is a good example. This Quaternary phase of folding, involving new southern zones, can be taken as an evidence of the formation of new sets of buried reverse faults in the basement. These deformations and movements transferred the depocenters of basins to more south westerly positions. However, the old NW-SE trend of the faulting and folding remained unchanged, pointing to the fact that the SW-NE compressional field was not practically disturbed.

**POST-CROMERIAN/PRE-HOLOCENE MOVEMENTS**

**Timing.** As in the Cromerian, there is clear evidence that major tectonic spasms were bracketed within warm intervals. The evidence of major tectonic activity in full-glacial intervals is practically lacking, though a minor perturbation seems to be present within the Late Würm glaciation, and it is conceivable that a detailed work would indicate still other examples.
The most clear evidence to this end is provided by the unconformities, sometimes angular, in the sedimentary record. Where present, these are almost invariably formed in deposits of the nonglacial phases. In the late Quaternary marine deposits of the coastal areas of the Persian Gulf they are found in transgressive partial cycles (times of high sea, level) and in the Caspian region they are found in regressive (interlacustral) partial cycles. In alluvial sequences at the foot of lofty mountains these unconformities, together with weathering horizons of nonglacial times, separate the fluvioglacial or glaciogenic depositional units.

In some instances, the tectonically affected features have been uplifted and thus uncovered by later sediments. Such are some marine, fluvioglacial and kame terraces or moraine bodies and bare rock terraces. It is commonly possible, though sometimes difficult, to show that even these features were formed by diastrophism of nonglacial times.

**Rate and nature of movements.** As mentioned above, the greater part of the Quaternary tectonic activity was concentrated in two pulsations at the beginning and end of the Cromerian. Thus the average rate of movements declined considerably following the Cromerian. Nevertheless, diastrophism of this period retained its pulsatory nature, too, and acted rather vigorously during nonglacial times.

The movements and deformations were practically confined to the structures produced or reactivated during the Cromerian pulsations. Very few, and commonly minor, new structures were generated during the subsequent period. Many fold structures almost completed their deformations by the end of the Cromerian. Later movements altered the scence only slightly.
For tight, sometimes slightly overturned, anticlines it is suspected that the buried fault that caused the folding was quite active in post-Cromerian times but was not able to produce further folding owing to mature folding. An example is apparently afforded by the tightly folded Hezardarreh Formation in the Tehran region. The buried sinistral Tehran-Garmdarreh wrench fault system that induced the folding was initiated in early Cromerian times and shows evidence of considerable post-Cromerian activity. Yet the mature complex folds over the buried fault zone show very little sign of further growth after their initial severe folding in Cromerian.

Volcanism of this period was even more diminutive than tectonism. In the few cases where time correlation has been possible, Volcanism occurred in nonglacial intervals.

**HOLOCENE**

**Timing**: There can be found widespread and clear evidence of tectonic activity in deposits belonging to the end of the last glacial phase and earliest Holocene. Subduced activities seem to linger until around 3900 years B.P. when a sudden conspicuous tectonic surge occurred to be followed by a quiet interval. Another tectonic surge, apparently of less intensity, is recorded around 800-1000 years B.P. In short, it is absolutely evident that deglaciation was associated with and followed by conspicuous tectonism.

Several Holocene volcanic bodies are also known from different parts of the country. The most spectacular are the extensive basalt sheets of Mt. Ararat of Turkey that flowed out onto the Maku area of Iran. The sheets are dated approximately to between 3-4 ka B.P. and thus believed to be
related to the tectonic surge of ca. 3.9 ka B.P. Many Holocene travertine bodies, linked to the Holocene tectonic surges are also known.

**Rate and nature of movements.** In many parts of the country morphotectonic features such as fault scarps, monoclines (commonly developed by buried faults), updomed or uplifted tracts, low embryonic anticlines and river or marine terraces have been generated during the Holocene tectonic surges mentioned above. They show a local relief of up to 15-20 m and commonly bear a rather thick Holocene sedimentary cover that generally conceals the pre-Holocene deposits.

The initiation of the uplifted features has been dated mainly by archeology, soil stratigraphy, climatostratigraphy and analysis of sedimentation rates. The oldest in situ archeologic remains on the surface or the youngest in the topmost bed give the date of initiation. Given the rate of sedimentation on adjacent low ground, the thickness of the youngest beds present there, but missing on the upthrown surface, also establishes the date. Some of the features dated along these lines can be correlated with destructive historic earthquakes.

Thus, an average rate of uplift can be estimated. However, it is not much instructive to speak of average rates, since in most instances it can be shown that the feature was developed very rapidly, in a matter of a few hundred years or perhaps far shorter. One line of evidence to this end is the presence of archeologic architectures, disposal plots, flaking floors, etc.; lying on practically stable sloping sides of gullies, carved into the uplifted terrain. The difference in age of this archeologic assemblage and that of the uplifted surface gives the maximum duration of the tectonic perturbations that initiated the feature.
Another evidence is provided by the presence or absence of lower-lying subsidiary levels or terraces fringing the main (highest) surface. Where present, they indicate the development of the feature in several successive jumps, sometimes separated by rather long in tervals of relative quiescence, and thus implying the occurrence of more surges and perturbations than has been described above.

On these lines of evidence a "surge-rate" of uplift of 5 cm/year or more has been estimated for high-perched features. However, it is conceivable that some of these features were developed almost instantaneously, in terms of geologic time, by a few powerful earthquakes.

The apparent presence of rather numerous Holocene incipient tectonic structures may perhaps be taken to imply a somewhat altered stress orientations during this epoch.

SOME CONCLUDING REMARKS
Late Quaternary tectonism and volcanism were concentrated in nonglacial times. They were periodic and bear the same average period as the precession cycles. The author's explanation for this periodicity, presented in 27th IGC, 1984, S.03.2.1., is as follows:

The thick extensive ice masses accumulating over high north-latitude territories during glacial phases impairs the sphericity of the lithosphere and outer layers of the asthenosphere by large-scale (global) isostatic deformations. Since the earth's volume remains constant in the process and since sphericity means minimum surface area with constant volume, it follows that the lithosphere must be extended globally during glacial phases. This superimposes a horizontal tensional field on the initial
lithospheric stress field and hence suppresses compressional tectonics during glacial phases.

During deglaciations and following them, reversed deformations under the field of gravity gradually increase the sphericity of the lithosphere, causing it to contract. This sets up a secondary horizontal lithospheric compression that promotes compressional tectonics during this stage inactive compressional belts. The effects may even be detectable in tectonically inactive areas.

The minimum late Quaternary total amount of crustal shortening over a traverse from the Persian Gulf to the Caspian Sea is estimated very roughly at about 12 km. It can be divided equally between the Zagros region and central Iran including the Elburz mountains. The two zones are separated by the main Zagros thrust. This gives a minimum average rate of crustal shortening of about 3 cm/year. A higher figure, up to about 6 cm/yaer, corresponding to a total crustal shortening of 24 km across the Iranian orogen seems quite possible.