DISCUSSION

This map is the first of a series of maps showing the distribution, composition, and age of upper Cenozoic volcanoes and volcanic rocks of the United States. Designed primarily as a guide for exploration and evaluation of igneous-related geothermal resources, this map series also should be useful as a base for evaluation of volcanic hazards, for studies of volcanology and volcanotectonics, and for studies of the general geology of volcanic rocks. Because little or no reliable data are available for many areas, these maps are, to a considerable degree, our interpretation of the general age and composition of the volcanic rocks. Thus, current gaps in the data may be located by the combined use of the reliability and data source diagrams. (figs 1 and 2).

For the purposes of this map the late Cenozoic extends from 16±1 million years (m.y.) ago to the present. This cutoff was chosen because it has meaning in a volcanological and tectonic sense; there was a widespread change in the style of volcanism at about this time over much of western United States (Christiansen and Lipman, 1972; McKee, Noble, and Silberman, 1970; Stewart, Moore, and Zietz, 1977). This change coincides, in a general way, with the onset of the tectonic extension and breakup that characterizes the Basin and Range Province but that is also reflected in bordering areas. This change may have occurred earlier or later than 16±1 m.y. ago in some areas, but this time seems an acceptable compromise for the general purposes of the maps.

The significance of this time cutoff for geothermal purposes is problematical. High-grade geothermal resources of the world are located in regions of late Cenozoic volcanic activity. The high-grade geothermal potential of an area declines rapidly with increasing age of volcanism; all high-grade geothermal resources from which energy has been extracted for power are associated with igneous systems active within the last 1 m.y. Lower grade (that is, lower temperature) geothermal resources may be related to the declining thermal stages of igneous systems or to other sources of thermal energy. However, the low-grade geothermal resource is not well defined, and at this time it is a largely unknown quantity. Hot or warm springs are known to be associated with volcanic areas older than 16±1 m.y. It is doubtful that these areas have significant geothermal resources although the utility of low-grade geothermal is currently uncertain. In any case, we suspect that the major thermal source for low-grade resources is very deep in the crust and that the hot-spring activity is related to very deep circulation of ground water. This same statement may apply to most large igneous systems older than a few m.y. and to many small systems older than a few tens of thousands of years.

Within this late Cenozoic time frame, the ages of the volcanic rocks are arbitrarily divided into three categories: present–5 m.y., 5–10 m.y., and 10–16±1 m.y. The time increment from the present to 1 m.y. is further subdivided by use of colored vent symbols; all vents older than 1 m.y. are shown in black.

The volcanic rocks, including some hypabyssal rocks, have been classified into five major types based primarily upon their known or assumed silica content:

1. Feldspathoidal basalts including basanite, limburgite, tephrite, and other rare alkalic rocks	Less than 46 percent SiO_2
2. Basalt including trachybasalt, hawaiite, etc.	46 – 54 percent SiO_2
3. Andesite including trachyandesite, etc.	54 – 62 percent SiO_2
4. Dacite including rhyodacite, quartz latite, trachyte, etc.	62 – 70 percent SiO_2
5. Rhyolite including pantellerite, etc.	Greater than 70 percent SiO_2

This rock classification is a compromise between the simple silicic-basic distinction that is considered to be significant for geothermal purposes (Smith and Shaw, 1975), and a more detailed classification that would be desirable for purely volcanological purposes. In most areas the existing published data are inadequate for a systematic application of a more detailed classification. This classification also emphasizes dominant rock types. Unique and otherwise rare alkalic rocks are lumped together with the infrequently occurring feldspathoidal basalts unless, like trachyte, they represent the salic end of a rock series and may be interpreted, like dacite and rhyolite, as suggesting a high-level thermal source.

Considerable effort was made to accurately locate and represent the volcanic vents. The distribution, age, and morphology of vents must be known to interpret structure, type and geothermal significance of volcanological systems. The type of vent is also a general indicator of rock chemistry and thus allows an interpretation of composition in the absence of other data.

Volcanic eruptions have occurred within the last 1 m.y. in approximately 15 different volcanic loci in Arizona and New Mexico. At least one eruption has occurred less than 250,000 years ago in 14 loci and less than 30,000 years ago in eight loci. The most recent eruption was that at Sunset Crater, Arizona, about 900 years ago (1064–1066 A.D.).

Seven of these 15 loci have had a history of recurrent eruptions for 3 m.y. or more. There seems little doubt that all 15 loci reflect viable thermal anomalies at mantle depth today and have potential for future volcanic eruptions and perhaps potential for heat storage at high crustal level. However, only two of these loci, the Jemez and San Francisco Mountains fields, show surface evidence, in the form of very young silicic rocks, of high-level heat storage with potential geothermal significance.

Twelve of the 15 loci are located on three major volcano-tectonic lineaments: 1) Jemez volcanic lineament from the Raton area in northeastern New Mexico through the Jemez Mountains into Arizona, and possibly extending to include the Pinacate field in southwestern Arizona and northern Mexico; 2) Mogollon volcanic lineament (southwestern border of the Colorado Plateau in Arizona) from the White Mountains through the San Francisco Mountains to the Unikaret field in northwestern Arizona; and 3) Rio Grande Rift.

More than 25 volcanic loci have been active within the last 5 m.y., and all but three or four of these are located on the three above-mentioned lineaments. In addition to the 15 loci referred to earlier, several of these additional 10 loci may be potentially viable volcanic fields in the future.

Of particular interest is the general north and northeasterly migration of volcanic activity along the southwest border of the Colorado Plateau during the last 10 m.y. or more. Much of southwestern Arizona represents a data gap which must be filled before this general drift in volcanic activity can be fully interpreted.

REFERENCES CITED

Christiansen, R. L., and Lipman, P. W., 1972, Cenozoic volcanism and plate-tectonic evolution of the western United States; II, Late Cenozoic: Royal Soc. [London] Philos. Trans., ser. A, v. 271, no. 1213, p. 249–284.

McKee, E. H., Noble, D. C., and Silberman, M. L., 1970, Middle Miocene hiatus in volcanic activity in the Great Basin area of the western United States: Earth and Planetary Sci. Letters, v. 8, no. 2, p. 93–96.

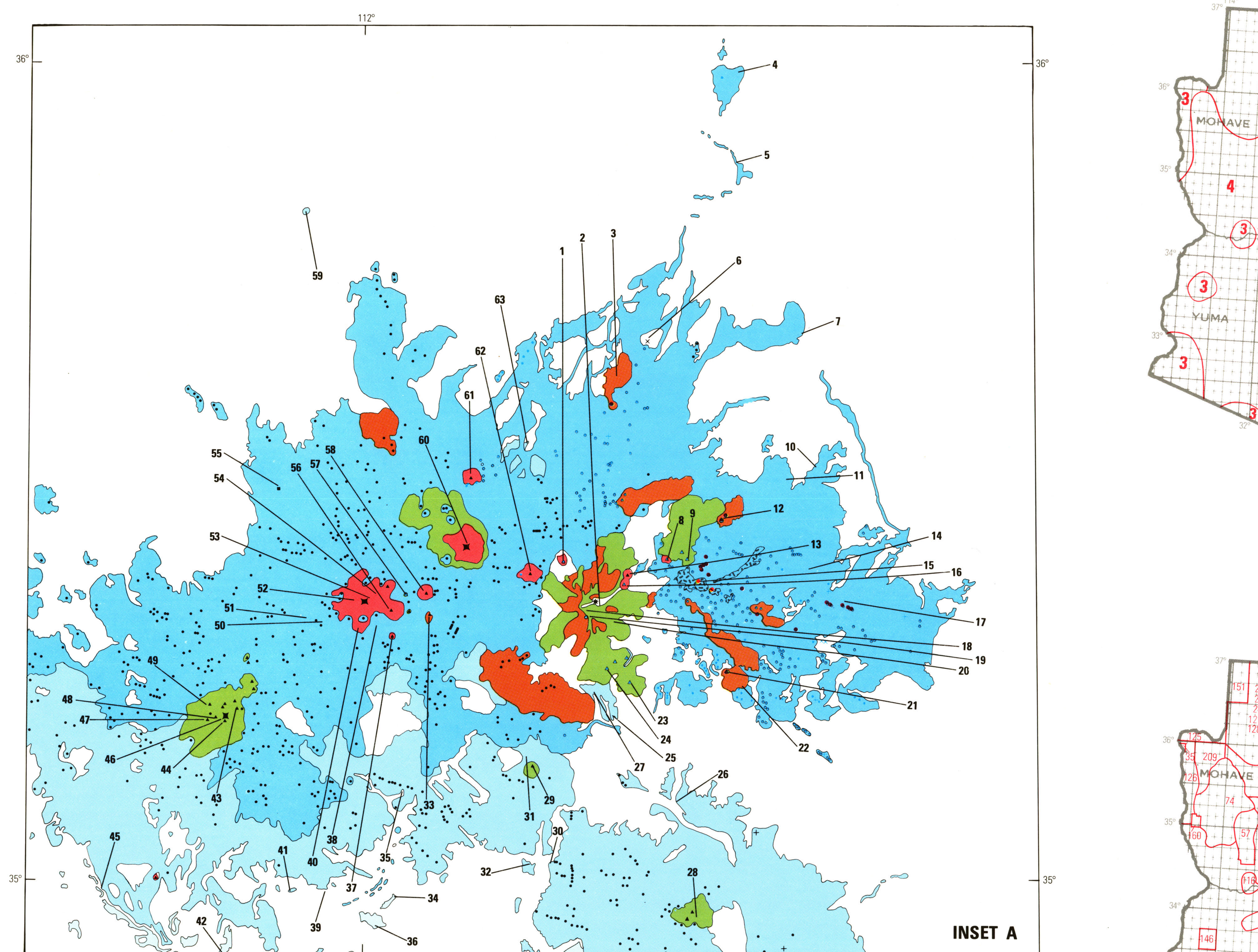
Smith, R. L., and Shaw, H. R., 1975, Igneous-related geothermal systems, *in* White, D. E., and Williams, D. L., eds., Assessment of geothermal resources of the United States—1975: U.S. Geol. Survey Circ. 726, p. 58–83.

Stewart, J. H., Moore, W. J., and Zietz, Isidore, 1977, East-west belts of Cenozoic igneous rocks, aeromagnetic anomalies, and mineral deposits, Nevada and Utah: Geol. Soc. America Bull., v. 88, no. 1, p. 67–77.

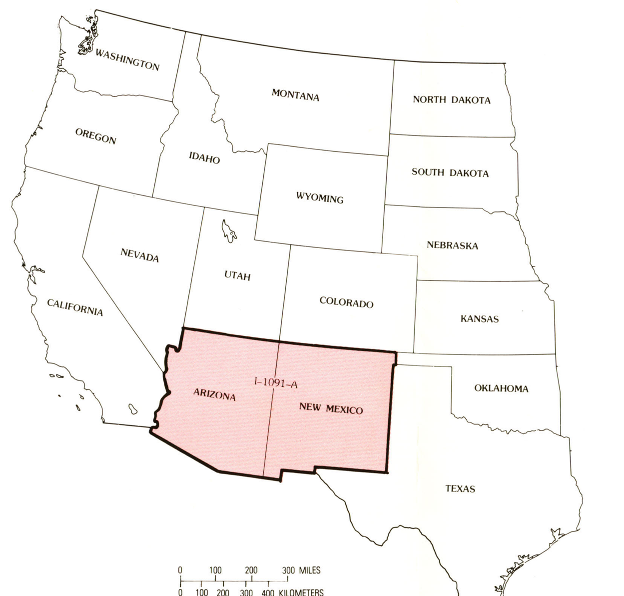
SOURCE REFERENCES

[Keyed to fig. 2]

1. Akers, J. P., 1964, Geology and ground water in the central part of Apache County, Arizona: U.S. Geol. Survey Water-Supply Paper 1771, 107 p.
2. Akers, J. P., Shorty, J. C., and Stevens, P. R., 1971, Hydrogeology of the Cenozoic igneous rocks, Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: U.S. Geol. Prof. Paper 521–D, 18 p.
3. Akers, J. P., Irwin, J. H., Stevens, P. R., McClymonds, N. E., and Chenoweth, W. L., 1962, Geology of the Cameron quadrangle, Arizona: U.S. Geol. Survey Geol. Quad. Map GQ–162.



INSET A



Index map showing location of study area (shaded)

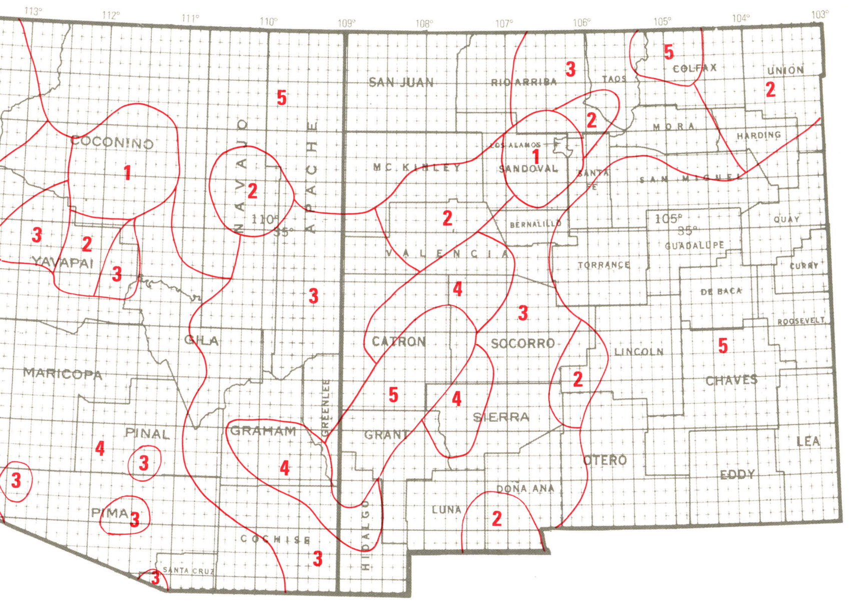


Figure 1.—*Data reliability map for volcanic fields within the map area. Area rank is based on the availability of (a) detailed geologic maps, (b) detailed chemical and (or) petrographic data, and (c) adequate geochronologic data. RANK 1—Must satisfy all above criteria. RANK 2—Must satisfy 2 of above criteria. RANK 3—Must satisfy 1 of above criteria. RANK 4—Little or no adequate data. RANK 5—Not applicable. This classification is in part subjective; greatest weight is placed upon geologic maps; rock chemistry and (or) geochronologic data without detailed geologic relations and locations have minimal value. It cannot be overemphasized that a prime purpose for this reliability diagram is to point out those areas where geologic information is needed. Regardless of area rank, data gaps exist in all areas.*

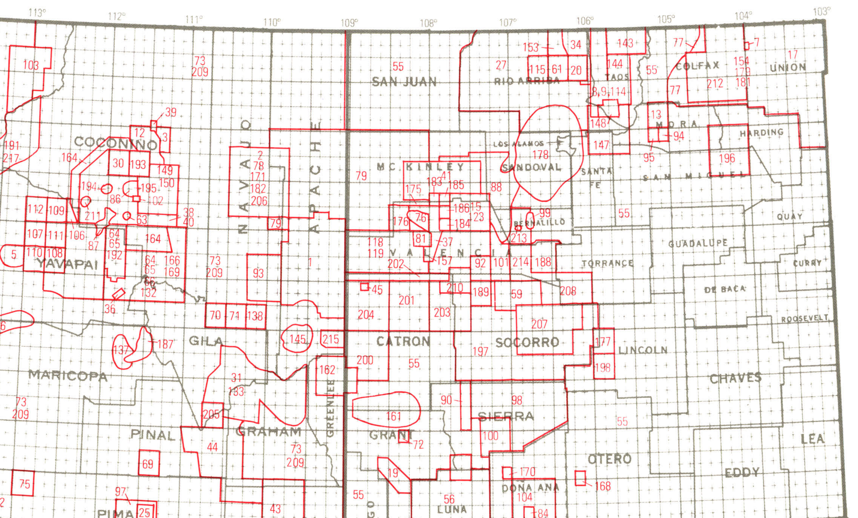
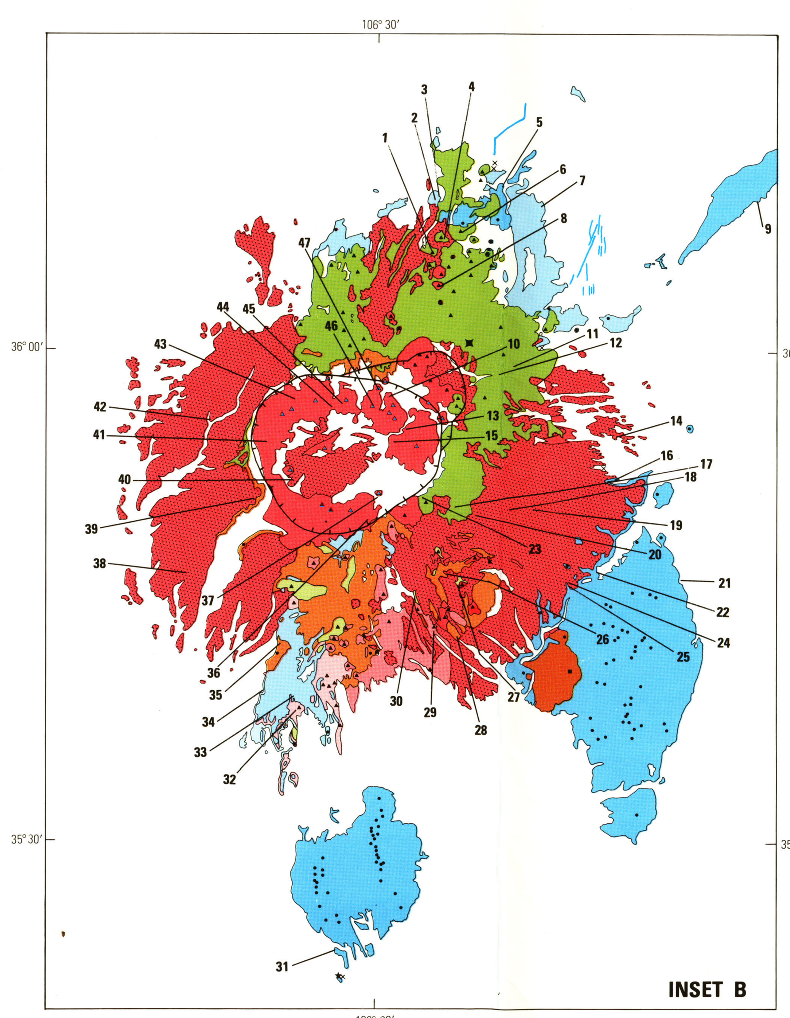


Figure 2.—*Map showing principal sources of geologic, petrologic, and geochronologic data. The geology and vent information in some localities have been modified or supplemented through study and interpretation of topographic maps and aerial photographs. Where applicable, an original source is used and indicated although it might have been in part superseded or incorporated in a more recent source.*



INSET B

EXPLANATION

ROCK TYPE (silica range content) / AGE (m.y.)	Feldspathoidal basalt and related rocks (<46 percent)	Basalt (46–54 percent)	Andesite (54–62 percent)	Dacite and related rocks (62–70 percent)	Rhyolite (>70 percent)
<0.01	■	■			
<5	■	■	■	■	■
5–10	■	■	■	■	■
10–16+		■	■	■	■

Ash-flow tuffs—Rock type and age indicated by color

Caldera

Dike—Rock type indicated by color

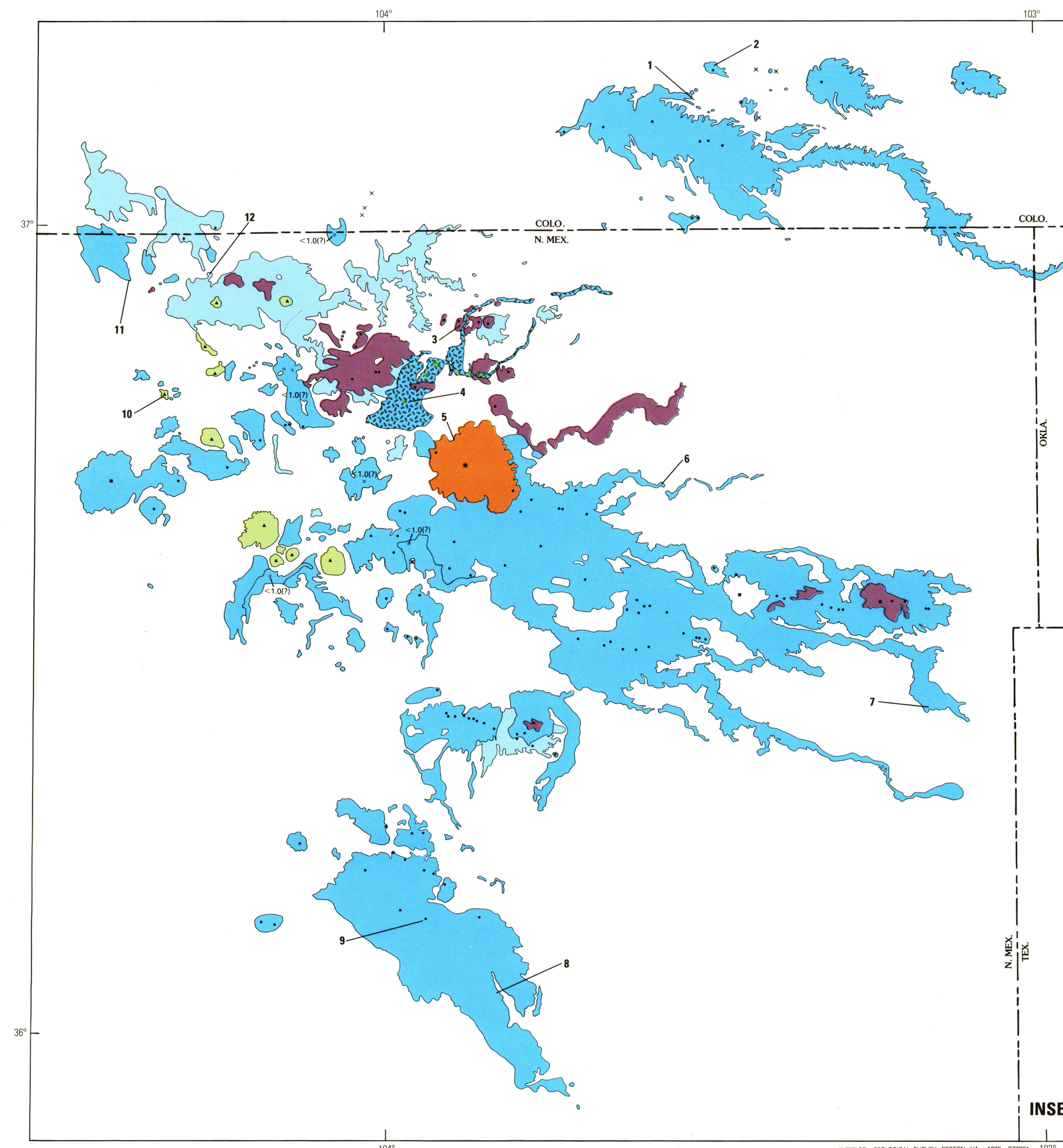
Buried lava flow

Direction of migration of volcanic loci

1.38±0.29(118) Radiometric age date in m.y.—Number in parentheses indicates data source. All data are radiometric (K-Ar) determinations unless otherwise noted

VENT TYPE / AGE (m.y.)	>1.0	1.0–0.1	0.1–0.01	0.01–0.001	0.001–0.0001
Cone, cinder, etc.	•	•	•	•	•
Dome	▲	▲	▲		
Shield	■				
Stratovolcano	✱				
Maar	+	+			
Diatreme	★				
Dome cluster	✱				
Volcanic neck	×	×			
Dome plug	▼				

Note—Potassium-argon ages shown are from original sources and are not recalculated using decay constants and isotopic abundance adopted by the International Union of Geological Sciences Commission on Geochronology August 24, 1976



INSET C

U.S. GEOLOGICAL SURVEY RESTON, VA. FEB 23 1979 LIBRARY

MAP SHOWING DISTRIBUTION, COMPOSITION, AND AGE OF LATE CENOZOIC VOLCANIC CENTERS IN ARIZONA AND NEW MEXICO

By
Robert G. Luedke and Robert L. Smith

1978